ECONOMIC ASSESSMENT OF SELECTED INVESTMENTS OF THE COOPERATIVE RESEARCH CENTRE FOR FORESTRY

Final Report

To
CRC FORESTRY

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by

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and
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Executive Summary

The Cooperative Research Centre for Forestry (the CRC) required cost-benefit analyses to be undertaken on a number of their current and prospective research investments. Seven analyses were undertaken.

Information from the original project proposals, milestone reports, and other relevant reports were assembled with assistance from the CRC. Discussions were held with Program Managers or Principal Investigators for each research area as well as forestry industry personnel as appropriate.

Each of the seven analyses provides a description of the project background, objectives, activities, costs, outputs, actual and expected outcomes, and potential benefits. The benefits were described in a triple bottom line context. Some of the potential benefits were then valued in monetary terms.

The Present Value of Benefits (PVB) and Present Value of Costs (PVC) were used to estimate investment criteria of Net Present Value (NPV), Benefit-Cost Ratio (B/C Ratio) and Internal Rate of Return (IRR) at discount rates of both 5% and 10%. The PVB and PVC are the sums of the discounted streams of benefits and costs. The discounting is used to allow for the time value of money.

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions.

Sensitivity analyses were undertaken in most cases for those variables where there was greatest uncertainty or for those that were thought to be key drivers of the investment criteria. The sensitivity analyses were conducted for the 5% discount rate.

Some identified benefits were not quantified mainly due to:

- A suspected, weak or uncertain scientific relationship between the research investment and the actual R&D outcomes and associated benefits
- The magnitude of the value of the benefit is thought to be only minor
- There is some uncertainty in the assumptions concerning the counterfactual or the ‘without’ scenario

Table 1 presents the investment criteria for each of the seven investments analysed at a 5% discount rate and expressed in 2007/08 dollar terms.

Table 1: Investment Criteria for Seven CRC Investments
(discount rate = 5%)

Investment	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**B/C Ratio**	**IRR (%)**
Improved forest inventory through high resolution remote sensing	7.8	1.5	6.3	5.2	20
Association genetics for solid-wood properties: *Eucalyptus globulus* and *E. nitens*	6.1	3.3	2.8	1.8	8
Silviculture-processing studies on *Eucalyptus nitens* and *E. globulus*	6.9	0.8	6.1	8.4	85
Optimised log merchandising with mechanical harvesters	6.5	0.3	6.2	19.0	71
Evaluation of electric/diesel hybrid technology on a converted 6X6 truck	3.8	0.3	3.5	13.7	49
Identification and adaptation of leading technology for tracking and management of Australian forest operations	45.2	0.7	44.5	66.0	86
Trees in the landscape	106.6	35.7	70.9	3.0	12

Given the assumptions made for each evaluation, all investments appear to have realised or have prospects of realising potential benefits.

1. Introduction

The Cooperative Research Centre for Forestry (the CRC) required cost-benefit analyses to be undertaken on a number of their current and prospective research investments to assist in identifying the outcomes and benefits that have emerged or are likely to emerge from the investment. Valuation of these benefits, along with identification of investment expenditure, was required in order to demonstrate their contribution to Australia's industrial, commercial and economic growth.

This analysis evaluates the benefits to be delivered from outcomes from seven research areas selected across the CRC's investment areas.

Assessing the impact of investment in research is important as it can demonstrate to stakeholders that the research is making or is likely to make a difference and is providing benefits to industry, commerce and Australia's economic growth.

One method identified for improving the ability to report on the effectiveness of the research investment is to undertake some formalised investment analyses (cost-benefit analyses) in order to estimate the returns to investment. Such analyses take into account the time differences between when the investment occurs and when benefits accrue.

Section 2 of the report provides a brief summary of the methods used in the analyses. Section 3 reports a summary of the benefits and of the investment criteria estimated for the seven investments. A brief conclusion is provided in Section 4. Appendices 1 to 7 provide the full case studies for each of the selected investments.

2. Methods

2.1 Project Selection

It was determined initially that six or seven analyses could be undertaken with the time and resources available for the consultancy. It was understood that there would be at least one analysis undertaken for a project or subproject within each of the four programs. Discussions were held with the Chief Executive Officer of the CRC and each of the four Program Managers to identify projects or subprojects for each program that might be appropriate for analysis. Factors considered in the selection were:

- Some significant progress had been made in the project
- The investment was expected to produce significant outputs and benefits
- The investment's expected benefits were amenable to a cost-benefit analysis

The seven research areas identified for analysis were:

1. Improved forest inventory through high resolution remote sensing (Subproject 1.1.3, Program 1)
2. Association genetics for solid-wood properties: *Eucalyptus globulus* and *E. nitens* (Subproject 2.1.2, Program 2)
3. Silviculture-processing studies on *Eucalyptus nitens* and *E. globulus* (Subproject 2.3.1, Program 2)
4. Optimised log merchandising with mechanical harvesters (Project number not specified, Program 3)
5. Evaluation of electric/diesel hybrid technology on a converted 6X6 truck (Project number not specified, Program 3)
6. Identification and adaptation of leading technology for tracking and management of Australian forest operations (Project number not specified, Program 3)
7. Trees in the landscape (Program 4 (total program))

Together, the investment in these seven analyses represents 46% of the CRC's total investment (in nominal terms). As Table 2.1 shows, a large part of this is contributed by Program 4, where all of the investment was analysed.

Table 2.1: Proportion of CRC Investment Analysed by Program

Program	Value analysed ($)	Total value of program ($)	Value analysed as a percentage of total
Program 1	1,413,756	18,681,000	7.6
Program 2	4,201,964	15,737,000	26.7
Program 3	1,400,399	8,052,000	17.4
Program 4	37,155,129	37,155,129	100.0
Other[1]	0	15,024,000	0.0
Total	44,171,248	95,649,129	46.2

[1] Includes Administration, Commercialisation and Utilisation, and Education and Training

2.2 Individual Analyses

Each investment was evaluated through the following steps:

1. Information from the original project schedules, and any progress reports or other relevant reports and material was assembled with assistance from CRC personnel, Principal Investigators and others.
2. An initial description of the project background, objectives, activities, costs, outputs, and expected outcomes and benefits was drafted. Additional information needs were identified.
3. Telephone contact was made with Program Managers and/or Principal Investigators and the draft sent to that person for perusal and comment, together with specific information requests.
4. Further information was assembled where appropriate from industry and others associated with the industry, and the quantitative analysis undertaken.
5. Some analyses proceeded through several drafts, both internally within the project team as well as externally via Program Managers and others.
6. Final drafts were passed by Program Managers and Principal Investigators for comment.

The potential benefits from each investment were identified and described in a triple bottom line context. Some of these benefits were then valued.

The factors that drive the investment criteria for R&D include:

C The cost of the R&D.

K The magnitude of the net benefit per unit of production affected; this net benefit per unit also takes into account the costs of implementation.

Q The quantity of production affected by the R&D, in turn a function of the size of the target audience or area, and the level of initial and maximum adoption ultimately expected, and level of adoption in the intervening years.

D The discount rate.

T_1 The time elapsed between the R&D investment and commencement of the accrual of benefits.

T_2 The time taken from first adoption to maximum adoption.

A An attribution factor can apply when the specific project or investment being considered is only one of several pieces of research or activity that have contributed to the outcome being valued.

P Probability of an R&D output, commercialisation etc. occurring. Can be applied when the research is not complete or when some further investment is required before the outputs of the research are translated into adoptable outcomes and extended to the industry.

Defining the ‘without R&D’ scenario to assist with defining and quantifying benefits is often one of the more difficult assumptions to make in investment analyses. The ‘without’ scenario (referred to here as counterfactual) usually lies somewhere between the status quo or business as usual case and the more extreme positions that the research would have happened anyway but at a later time; or the benefit would have been delivered anyway through another mechanism. The important issue is that the definition of the counterfactual scenario is made as consistently as possible between analyses.

The Present Value of Benefits (PVB) and Present Value of Costs (PVC) were used to estimate investment criteria of Net Present Value (NPV), Benefit-Cost Ratio (B/C Ratio) and Internal Rate of Return (IRR) at discount rates of both 5% and 10%. The PVB and PVC are the sums of the discounted streams of benefits and costs. The discounting is used to allow for the time value of money. All dollar costs and benefits were expressed in 2007/08 dollar terms and discounted to the year 2007/08. A 30 year time frame was used in all analyses, with the first year being the initial year of investment in the R&D project. Costs for the R&D project included the cash and in-kind contributions of the CRC, as well as any other resources contributed by third parties (e.g. researchers or industry).

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions.

Sensitivity analyses were undertaken in most cases for those variables where there was greatest uncertainty or for those that were thought to be key drivers of the investment criteria. The sensitivity analyses were conducted for the 5% discount rate.

Some identified benefits were not quantified mainly due to:

- A suspected, weak or uncertain scientific relationship between the research investment and the actual R&D outcomes and associated benefits.
- The magnitude of the value of the benefit is thought to be only minor.
- There is some uncertainty in the assumptions concerning the counterfactual or the ‘without’ scenario.

2.3 Comparison of Methods with Framework and Approaches Suggested by the CRC Association

In 2007 the CRC Association commissioned the development of a CRC monitoring and evaluation framework for use by CRCs when undertaking performance reviews. This framework was completed by Deloitte – Insight Economics in June 2007.

The Agtrans method used in this consultancy is consistent with the Deloitte framework. Deloitte refer to an input to impact chain model, which identifies the stages of input, activity, outputs, usage and impact. Agtrans refers to these same stages as costs, project description, outputs, outcomes and benefits.

Deloitte identified three possible benefit channels from CRCs which include

- Benefits for the application of knowledge/intellectual property generated by the research.
- Benefits from access to international knowledge networks.
- Benefits from skills formation.

All three benefit types were evident in the research analysed for Forestry CRC, although most emphasis was on the first benefit type identified above.

Deloitte also identified a number of key challenges when measuring the impact of CRC investment, and a number of these were relevant to the Forestry CRC including time lags, attribution and additionality. Agtrans has considered the attribution and additionality issues through its definition of the 'without' research scenario for each of the research areas.

The Deloitte framework is largely based on retrospective evaluations, and it should be noted that the research areas evaluated here for the Forestry CRC are partially prospective in nature due to the CRC not yet reaching its mid-term point. The framework comments that information on inputs, activities and outputs should be easily found within the research organisation. It should be noted that the internal documentation on these three areas was sometimes lacking in availability and detail. The framework also recognises that obtaining information on usage and impacts will be more difficult, but that appropriate planning for the collection of such data could be implemented. It is recommended that the analysis frameworks developed for the analysis of these seven research areas could form a basis for guiding data collection for any future evaluation of CRC Forestry research investment.

3. Summary of Results

3.1 Qualitative Results

Table 3.1 identifies the benefits from each of the seven case studies. Each benefit is categorised as economic, environmental or social. Not all of the case studies demonstrated benefits from each category.

Table 3.1: Summary of Benefits for Seven Investments

Project	Benefits
Improved forest inventory through high resolution remote sensing	Economic • Reduced costs of assembling inventory data. • Improved inventory data and improved management decision making. • The subproject is centred on achieving a level of detail and understanding that should have consequences for other LiDAR applications with economic consequences (e.g. site selection, forest health management). Environmental • Positive consequences for increased interest and adoption of LiDAR in other applications leading to improved management of streams, watercourses, soils and biodiversity. Social • Contribution to maintaining forest communities through economic viability and environmental sustainability. • Improved harvest planning in stepp areas resulting in greater machine operator safety. Reduced lost work time from injury due to reduced ground distance covered by field inventory.
Association genetics for solid-wood properties: *Eucalyptus globulus* and *E. nitens*	Economic • Potentially increased pulp yield and the consequent economic value of *E. globulus* plantation production. Environmental • Nil. Social • Contribution to maintaining the economic and social viability of forest communities.
Silviculture-processing studies on *Eucalyptus nitens* and *E. globulus*	Economic • Understanding that thinning could be delayed until a commercial product could be obtained from the thinning and the *E. nitens* plantation would realise maximum profitability from the timing and intensity of this activity.

	• Understanding that conventional processing equipment was leading to inaccuracies in cutting that reduced recovery and caused problems in subsequent processing. Environmental • Nil. Social • Contribution to maintaining the economic and social viability of forest communities.
Optimised log merchandising with mechanical harvesters	Economic • Lengths of logs and quality of logs both improved with regard to needs of the market. • Reduced level of downgrading of logs that are outside specifications. Environmental • Nil. Social • Small proportion of benefits likely to be passed along value chain to consumers.
Evaluation of electric/diesel hybrid technology on a converted 6X6 truck	Economic • Reduced cost of in-forest transport of wood chips for pulp hardwood plantations where chipping takes place in the field. Environmental • Contribution to Australian Government targets for lowering greenhouse gas emissions. Social • Nil.
Identification and adaptation of leading technology for tracking and management of Australian forest operations	Economic • Lowered costs of harvesting in both softwood and hardwood plantations. • Lowered costs of harvesting in some native forest logging. Environmental • Reduced carbon dioxide emissions due to fuel cost savings. Social • Increased satisfaction of harvest operators. • Potential for reduced accidents in harvest operations.
Trees in the landscape	Economic • Maintenance of licence to operate for industry, resulting in maintenance of a sustainable industry. • Maintenance of market access due to maintenance of certification and standards. • Saved time and resources expended in conflict resolution. • Improved ability to sustainably manage pests. • Future land use that maximises economic returns subject

	to informed social preferences. Environmental • Improved water quality and/or avoided water quality degradation. • Improved biodiversity and/or avoided biodiversity degradation. • Avoidance of impact on reducing water quantity (groundwater and surface water). Social • Better informed stakeholders of forestry impacts and community aspirations. • Reduced stress to stakeholders involved in the forest industry.

3.2 Quantitative Results

The investment criteria calculated for each research area were the Net Present Value (NPV), the Benefit Cost Ratio (B/C Ratio) and the Internal Rate of Return (IRR). The NPV is the difference between the Present Value of Benefits (PVB) and the Present Value of Costs (PVC). Present values are the sum of discounted streams of benefits and/or costs. The B/C Ratio is the ratio of the PVB to the PVC. The IRR is the discount rate that would equate the PVB and the PVC, thus making the NPV zero and the B/C Ratio 1:1.

Table 3.2 presents the investment criteria for each of the seven investments analysed at a 5% discount rate.

Table 3.2: Investment Criteria for Seven CRC Investments
(discount rate = 5%)

Investment	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**B/C Ratio**	**IRR (%)**
Improved forest inventory through high resolution remote sensing	7.8	1.5	6.3	5.2	20
Association genetics for solid-wood properties: *Eucalyptus globulus* and *E. nitens*	6.1	3.3	2.8	1.8	8
Silviculture-processing studies on *Eucalyptus nitens* and *E. globulus*	6.9	0.8	6.1	8.4	85
Optimised log merchandising with mechanical harvesters	6.5	0.3	6.2	19.0	71
Evaluation of electric/diesel hybrid technology on a converted 6X6 truck	3.8	0.3	3.5	13.7	49
Identification and adaptation of leading technology for tracking and management of Australian forest operations	45.2	0.7	44.5	66.0	86
Trees in the landscape	106.6	35.7	70.9	3.0	12

Table 3.3 presents the investment criteria for each of the seven investments analysed at a 10% discount rate.

Table 3.3: Investment Criteria for Seven CRC Investments
(discount rate = 10%)

Investment	PVB ($m)	PVC ($m)	NPV ($m)	B/C Ratio	IRR (%)
Improved forest inventory through high resolution remote sensing	4.14	1.53	2.61	2.7	20
Association genetics for solid-wood properties: *Eucalyptus globulus* and *E. nitens*	2.08	3.19	-1.11	0.6	8
Silviculture-processing studies on *Eucalyptus nitens* and *E. globulus*	5.79	0.85	4.94	6.8	85
Optimised log merchandising with mechanical harvesters	4.14	0.34	3.80	12.0	71
Evaluation of electric/diesel hybrid technology on a converted 6X6 truck	2.13	0.27	1.86	7.9	49
Identification and adaptation of leading technology for tracking and management of Australian forest operations	23.04	0.60	22.44	38.3	86
Trees in the landscape	46.48	34.27	12.20	1.4	12

Further details on each of these investments and the associated results are provided in the individual analysis reports (Appendices 1 to 7). It is evident from the results there is a wide range in the investment criteria across the seven investment areas.

4. Conclusion

The seven investment analyses all yielded positive results at the 5% discount rate, with B/C Ratios ranging from 1.8:1 to 66:1. Care should be taken in any comparisons across investments or programs due to the different frameworks used for each analysis and the uncertainties involved in each set of assumptions.

The results produced are only as credible as the assumptions made, so that refinement of assumptions and frameworks is where any future focus would be most valuable. In particular, over the remaining period of the projects, efforts could be made to further refine the frameworks and assumptions made in the current analyses and assemble data wherever possible on actual usage and application and potential use and impact.

APPENDIX 1: MONITORING AND MEASURING: IMPROVED FOREST INVENTORY THROUGH HIGH RESOLUTION REMOTE SENSING

Reference Information

Code and Title	Dates and Investigator(s)
Subproject number 1.1.3: Improved Forest Inventory through High Resolution Remote Sensing	Start date: 1 July 2005
	Completion Date: 31 December 2009
	Principal Investigator(s): Jon Osborn (University of Tasmania)

Background

Both native and plantation forest estates need accurate and timely inventory data in order to make informed decisions regarding forest management including harvesting. Central inventory data include areas, tree height and quantity of wood present spatially and the input data required for growth and yield models.

In most Australian estates, sampling a small part of the forest by ground survey is usually carried out to produce such data. The sampling intensity varies considerably depending on the variability across the forest. Plantations of higher value usually require a higher precision (e.g. plantations as opposed to native forests) and therefore are often associated with a higher sampling intensity.

Inventory data is used for the following:
1. Strategic inventory (10 to 200 years); wood flow modelling; sustainable yield estimation; occasionally for some road planning.
2. Tactical (2 to 10 years): Harvest scheduling.
3. Operational (0-12 months): Harvest planning.

Plantation and native forest management requirements and usage of inventory data are very similar, noting the proviso above regarding value.

Airborne laser scanning (ALS) or **LI**ght **D**etection **A**nd **R**anging (LiDAR) is an active system that can directly sense the three dimensional structural properties of a forest and its underlying terrain, compared to remote sensing alternatives which are passive systems. LiDAR methods can measure the height of the canopy and produce digital elevation models (DEMs) by identifying the position of ground hits or non ground hits from return signals of the laser. Also the number of signal returns at each height can provide a measure of the quantity of foliage present. Vertical foliage profiles can then be constructed. Also, knowledge of terrain through DEMs is useful for minimising roading costs and maximising protection of riparian zones.

LiDAR has a major limitation regarding the angle of incidence of the return from the canopy, and the flying height from which it is acquired, as both can affect the accuracy of the estimates. Hence flying height is an important parameter to take into consideration in using canopy metrics as inventory model inputs.

Use of LiDAR technology is relatively new and still mostly in an R&D phase. However, it is expected soon to become used in a routine sense operationally by a range of forest managers. For example:

- Forestry Plantations Queensland has been using LiDAR to produce data of both higher resolution and lower cost than data from conventional surveying (Ken Bubb, CSIRO Media release, 2007).
- In Forests NSW, LiDAR data are initially being aimed at data required by existing inventory models. Most interest to date has been in topographic mapping, catchment management, wood resource assessment, carbon accounting, harvest planning, forest health and fuel assessment (Turner, 2007)
- Forestry Tasmania are directing research at new methods of deriving inventory outputs using LiDAR measured tree and stand level metrics (Musk, 2008)

The central research objective in the CRC project is to derive "pathways" that will allow metrics to be derived from the LiDAR data, and those metrics to be used to generate inventory outputs (Jon Osborn, pers. comm., 2008).

In addition, it is believed that there may be substantial benefits flowing from incorporation of LiDAR data into a number of aspects of forest management other than traditional inventory uses. It is possible that forestry organisations will need to generate multiple benefits from the data in order to justify the expenditure on LiDAR (Musk, 2008). A capacity to derive inventory estimates that achieve the goals above therefore has a multiplier effect if it adds to the "whole" and is a catalyst for wider adoption of LiDAR data for other operations (Jon Osborn, pers. comm., 2008).

Project Objectives

To develop software and guidelines for the collection of LiDAR data to allow the collection of forest inventory measures from remotely sensed data.

Project Costs

A summary of the financial resources invested in Subproject 1.1.3 is shown in Table 1.

Table 1: Investment in Subproject 1.1.3
(nominal $)

Year Ended June	CRC Investment (cash)	CRC Staff (in-kind)	Other (in – kind)	Total Investment
2006	64,375	191,250	70,189	325,814
2007	111,585	191,250	70,189	373,024
2008	93,330	191,250	70,189	354,769
2009	98,710	191,250	70,189	360,149
Total	368,000	765,000	280,756	1,413,756

Source: Forestry CRC

Project Description

The research is investigating methods to improve inventory and is divided into the two theme areas of inventory development and inventory application.

1. The inventory development theme is focused upon identifying appropriate methods to acquire, process and interrogate remotely sensed data, specifically LiDAR and large format aerial photography, for the extraction of forest inventory measures.
2. The inventory application theme is focused upon identifying and developing the commercial opportunities for the integration of LiDAR and large format aerial photography into Australian temperate forest and plantation inventory systems.

The methods of specific focus refer to remotely sensed data and include LiDAR scanner data and aerial photography in order to produce high precision stand level and tree level measures.

Work has been initially focused on deriving allometric models to predict stand metrics using LiDAR data and investigating the impact of data acquisition parameters on derived metrics such as stand height and basal area. Tree level investigations are also planned.

LiDAR approaches to inventory at a plot scale use direct statistical associations between LiDAR metrics and the stand quantity of interest (e.g. basal area). This may be using multiple regression for instance. There is no causal link inferred between the LiDAR predictive parameter and the measure of interest. What subproject 1.1.3 is doing is trying to build links between the LiDAR variable, the structural aspect of the forest and the predicted variable – understanding exactly what it is that the LiDAR is measuring. This is seen as having multiple benefits, including portability of application, increase in the number of questions that can be asked of the data, and more sophistication in modelling. The approach in the subproject will provide much more detail than presently available. Some forest growers desire more detail. For instance, ForestrySA are interested in volume by product class information from their inventory whereas some other growers are only interested in volume x size class data (Mark Hunt, pers.comm., Oct 2008).

The ability to use the single tree approach through fusing LiDAR and aerial photography is seen as beneficial because then questions can be asked about stand density, stocking etc and has application for assessing, for example, drought death, windthrow, hail damage, pest attack. This cannot be done at present.

The methods developed are to be delivered in a way that permits incorporation into a software package to allow future operational applications in forest management without specialised programming knowledge. Close liaison with commercial software developers has already occurred so that the outputs from 1.1.3 can be commercialised at the earliest time. Those beneficiaries of the research who undertake their own programming will be able to incorporate the results without commercial software (Mark Hunt, pers.comm.,Oct 2008).

The intention of the project is to assist forestry operations by developing techniques that allow forest inventory to be derived:

- more accurately, and/or
- less expensively, and/or
- in a manner that allows the inventory to be spatially mapped at higher resolution.

The project is being carried out in close association with forest industry partners.

Outputs

A summary of the principal outputs from the subproject is reported in Table 2.

Table 2: Summary of Principal Outputs

Principal Outputs
Actual (to date)
• Methods developed for extracting stand level metrics such as height percentiles, canopy density, and canopy surface texture from ALS data. Tree level metrics are to be developed next.
• Empirical models developed to remove effects of acquisition specifications.
• Allometric models built for native forest and eucalypt plantations (latter requires further refinement).
• Postgraduate students recruited to work on areas within the subproject.
• May 2007 workshop held in conjunction with Spatial Sciences Institute of Australia regarding LiDAR with attendance by 45 people.
• Papers prepared on calibration of LiDAR data to account for flight

acquisitions specifications; utilising tree height allocation data to estimate timber volume; fusion of LIDAR and image data; management implications of adoption of airborne remote sensing technologies.
Expected (not yet achieved)
• Methods for integrating large format aerial photography with airborne LiDAR scanner data.
• Establishment of capacity to generate orthophotography without reliance on ground control.
• Papers on comparative performance of algorithms for tree level metric extraction; optimal survey sampling design for remote sensing based inventories.
• "Australian Forest LiDAR" under development - a website for forest managers to understand LiDAR, identification of data suppliers and current users of the technology and exploration of sample data sets.
• Streams and water courses are a crucial component of many forests; information is traditionally assembled on location and significance using slow and expensive ground surveys. The utility of ALS data are being investigated in this context.
• Guidelines developed for forest managers specifying minimum LiDAR data acquisition specifications for a variety of forest types.

Outcomes

A summary of the principal outcomes from the subproject is reported in Table 3.

Table 3: Summary of Principal Outcomes

Principal Outcomes
Actual (to date)
• Preliminary results regarding stream courses suggest that it will be possible that LiDAR data may be able to be used for cost effective stream surveys for a range of strategic planning needs in a range of forest types.
Expected (not yet achieved)
• Improved range of forest inventory data possible for both native and plantation forests derived from LiDAR and aerial photography inputs.
• Lower costs in assembling inventory data than currently by ground sampling or by existing LiDAR.
• Inventory data that is more useful for management decision making that current data sets assembled.
• Higher resolution digital elevation models.
• Adoption of improved inventory assessment methods by forest managers for both operational decisions and strategic planning.

Benefits

The likely benefits are identified in a triple bottom line framework as follows:

Economic

- Reduced costs for providing the same level and accuracy of inventory information as currently achieved by ground sampling,
- Reduced costs for acquisition of LiDAR data and for its processing
- More comprehensive and more useful inventory data for the same cost, and
- Improved management and decision making on the basis of more reliable inventory data, and inventory data that is mapped at a higher spatial resolution.

Environmental

While itself focusing on inventory information, the subproject is likely to indirectly contribute to improved environmental management of forests. This is due to the multiple use nature of LiDAR and the subproject's potential contribution to encouraging greater interest and adoption of LiDAR technologies and uses such as generating very high quality digital elevation models. Ensuing environmental benefits would include:

  - Improved stream and water course data for improved management and protection of vulnerable waterway resources;
  - Improved decision about access routing (engineering design of roads);
  - Improved capacity to undertake operations such as cable logging.

Social

As the primary beneficiaries will be those managing forests for production values, social benefits are likely to be limited. However, any improved efficiencies in forest management are likely to contribute to the ongoing viability of forests and the communities they support. There is also the potential for LiDAR to contribute socially through better harvest planning in stepp areas resulting in greater machine operator safety. The reduced ground distance covered by field inventory may result in reduced lost work time from injury (with both economic and social benefits) (Culvenor, pers.comm., Oct 2008).

Adoption

As the improved allometric models are being developed initially for both softwood plantations and hardwood plantations, such forest owners are likely to be the first to adopt the improved LiDAR systems. In addition there is likely to be adoption by native forest managers at a later stage. Adoption is likely to be driven initially by the reduced cost of LiDAR acquisition and data processing as well as the increased precision of inventory data that ensues.

Summary of Benefits

A summary of the benefits emanating from the subproject is provided in Table 4.

Table 4: Summary of Principal Benefits

Economic	Environmental	Social
Reduced costs of assembling inventory data.	Positive consequences for increased interest and adoption of LiDAR in other applications leading to improved management of streams, watercourses, soils and biodiversity.	Contribution to maintaining forest communities through economic viability and environmental sustainability.
Improved inventory data and improved management decision making.		Improved harvest planning in stepp areas resulting in greater machine operator safety. Reduced lost work time from injury due to reduced ground distance covered by field inventory.
The subproject is centred on achieving a level of detail and understanding that should have consequences for other LiDAR applications with economic consequences (e.g. site selection, forest health management).		

Quantitative Analysis of Costs and Benefits

Existing estimates of costs and financial benefit analyses

Musk (2008) reports that published financial analyses of investment in inventory information or in alternative inventory methods are rare. His brief review demonstrates that results vary considerably in terms of both costs of different methods and the added benefit derived from increased precision and end use of the information. Musk also makes the point that high value actively growing parts of the resource such as plantations will benefit from higher levels of information than older less changeable forests.

Scenario without the subproject investment

Existing inventory methods are predominantly ground based and are likely to be ongoing in the absence of this subproject investment. Remote sensing via satellite is not likely to be used extensively for these purposes in the near to middle term due to several factors relating to interplay of coverage, resolution, cost and frequency (Mark Hunt, pers. comm., Sep 2008). Without the CRC project, LiDAR is likely to be used only sparingly in future for inventory purposes due to the difficulty of translating data to useful inventory information for management purposes.

Cost of assembling data from ground surveys

Conventional ground based forest inventories are expensive, time consuming and labour intensive (Turner, 2007). For operational planning usually 1% to 2% of total area is covered by ground plots. For strategic planning usually 0.0001% to 0.02% of total area per rotation is sampled. Tree diameters, dominant height, and sometimes log quality are measured in both cases (Jon Osborn, pers. comm., 2008).

Ground crews of two to three do the assessments for each plot. Teams can typically measure 5 to 15 plots per day. Plots sheets (increasingly digitally recorded) are stored and interrogated via RDBMS (a database engine).

Assuming 10 plots each of 0.2 ha can be sampled in one day by a ground crew of three people, this would provide a total plot area of 2 ha per day. For operational planning, this would mean that a forest area of 133 ha could be covered each day by the crew, based on a ground plot area of 1.5% of total forest area.

Based on a cost per crew member of $280 per day ($40 per hour) and an average of 2.5 crew members, this would total $700 per day. For operational planning, the ground sampling cost per hectare would be $700/133 or $5.26 per forest hectare.

An estimate from Forestry SA is that the costs are $10-20 per ha for pre-harvest on ground plot surveys for Pinus radiata plantations and $45 per ha for site assessment. (Mark Hunt, pers.comm., Oct 2008).

NSW Forests ground surveys for softwoods have a sampling regime of 1 plot of 0.1 ha per 2 ha of plantations for operational inventory purposes. This is about 5% of the total area. So 1,000 ha of forest surveyed would require 50 ha of plots, equivalent to 500 plots. With a sampling crew able to cover 12 plots per day, this is equivalent to about 42 days. At $700 per crew per day this is close to $29 per ha

It is reported that the limits to investment in inventory are reached at an expenditure of somewhere between $20 and $40 per ha applied on at least two occasions during a standard 20-30 year rotation (Jupp et al, 2005). However, overall traditional methods of using ground sampling and aerial photography for inventory purposes is quite variable among forest managers in terms of frequency (Mark Hunt, pers.comm., Oct 2008).

The above shows that the cost estimates for ground surveys vary widely. For purposes of the analysis it is assumed that the ground surveys cost $20 per ha.

The status quo inventory method is usually just ground sampling. Most plantation managers will collect some imagery but the type and costs will vary (Neil Sims, 2008).

Scenario with the subproject investment

Probability of subproject success

It is assumed that there is a reasonable chance of success of the project producing the expected outcomes. This probability is estimated at 80%.

Costs of LIDAR technology

It is assumed the subproject is successful and produces equations and approaches that can be immediately applied by end users in their data interpretation software. It is also assumed that the commercial software developer will continue to work alongside the project team so that a broader 'off-the-shelf' package will be available soon after project completion without future investment required in R&D. Thus interested forest managers can adopt the technology without any further development costs. As LiDAR scanners allow the extrapolation of limited plot data across wider areas (Turner, 2008), they can reduce the ground sampling required in conventional inventory methods. Ground sampling will still be required to validate the models generated from the LiDAR. In this analysis it is assumed that use of LiDAR will still require 40% of the traditional ground sampling effort (and costs).

LiDAR acquisition costs vary considerably and are dependent on a range of variables including the size of the area being flown. Turner (2008) estimates the costs may vary across a range of $0.50 to $12 per hectare. Another estimate is that LiDAR costs some $2-3 per ha plus data processing costs (Mark Hunt, pers.comm., Oct 2008). Data processing costs will vary with the level of automation of the processing, but would probably be about $1-2 per ha for plot scale and $2-3 per ha for tree scale processing. Total costs on average would therefore be about $4 per ha for plot scale LiDAR and about $5 per ha for tree scale LiDAR.

For the purposes of this analysis it is assumed that existing LiDAR costs $4 per ha on average. The total costs of a LiDAR supported inventory including the limited ground sampling is therefore $4 plus 40% of $20 per ha, equivalent to about $12 per ha.

The investment being analysed is expected to reduce acquisition costs of LiDAR by influencing the manner in which the LiDAR equipment is set up on aircraft. The project is also expected to reduce the data processing costs of LiDAR. Based on an assumption that a 10% reduction in both costs will be obtained, equivalent to $0.40 per ha based on the existing average cost of LiDAR. It is assumed that ground sampling will be reduced from 40% to 20% with the improved LiDAR, a saving of another $4 per ha. Total cost reduction compared to existing LiDAR is estimated at $4.40 per ha. Compared to ground sampling the cost reduction would be $(20-12+4.40) or $12.40 per ha.

Frequency of Use

LiDAR technology is being adopted by the forest industry for a range of purposes. Some forest managers fly their estate once in order to obtain terrain data such as DEMs, stream networks and for roading purposes. Other growers fly part of their estate more frequently (e.g. annually) for stand assessment (inventory) purposes. Such information varies among growers in terms of frequency, type of information and detail (Mark Hunt, pers.comm., Oct 2008). Others fly their estate for inventory purposes in an operational sense 2 to 3 years before harvest.

Benefits from improved data assembly from LiDAR
Apart from assembling information at lower cost, there are likely to be additional benefits from the investment in that the improved LiDAR is likely to provide a wider range of higher quality information that enhances decision making compared with the existing information systems (both ground sampling and existing LiDAR) that are currently used.

The specific benefit analysed here refer to a pre-harvest use of LIDAR two to three years before harvest. Such benefits may include:

- Whether to cut a block for pulp or sawlogs
- Increase in processing and marketing efficiency due to higher precision of estimates of wood available, leading to an increase in forest gate wood price
- Whether to cut non-performing block early or fertilise
- Improved preparation for harvesting (logistical requirements) leading to a decrease in harvesting costs

Focus in this analysis is on the first two dot points where it is assumed that the improved LiDAR inventory information leads to an increase in wood price of $25 per ha to the forest manager. This may occur due to selling trees as a higher value product than otherwise, or possibly improved marketing arrangements such as forward selling, or increased confidence by processors in the quantity of wood that will become available.

Adoption of LiDAR technology and the improved LiDAR technology
As the initial allometric relationships being developed in the project are associated with both softwood and hardwood plantations, the harvesting of these estates are the prime target markets considered in the analysis.

A conservative estimate of the area of Australian softwood plantations that is likely to be harvested over the next 30 years is 33,000 ha per annum from a 1 million hectare estate (DAFF, 2007). For hardwood plantations it is conservatively assumed that the current hardwood plantation area of 800,000 ha will be harvested and replanted in future years with an annual harvest of 67,000 ha per annum.

Without the CRC investment it is assumed that the area undergoing pre-harvest LiDAR would grow to 20% of the area harvested in 10 years time and then remain constant.

With the CRC investment, it is assumed that this would grow to 30% in 10 years time due to the lower cost and greater precision of the improved LiDAR systems. This means that an additional 10% of the target market will adopt LiDAR due to the investment. This 10% will capture the highest level of cost reduction ($12.40 per ha). Those that would have adopted LiDAR anyway would gain $4.40 per ha.

All 30% of the area adopting LiDAR would gain from the improved precision of the pre-harvest inventory and the associated increase in returns.

Summary of Assumptions

A summary of the assumptions made in the analysis is provided in Table 5.

Table 5: Summary of Assumptions

Item	Assumption	Source
Without the CRC project		
Cost of ground sampling for inventory 2-3 years before harvest	$20 per ha	From various estimates. See earlier text for references
Cost of use of LiDAR for inventory purposes	$12 per ha	Average of various estimates. See earlier text for references
Future total area of plantation softwoods harvested	33,000 ha per annum	Adapted from DAFF (2007)
Future total area of plantation hardwoods harvested	67,000 ha per annum	Adapted from DAFF (2007)-
Current routine use of LiDAR for inventory purposes	0% area of plantations	Agtrans Research
Maximum adoption of LiDAR in future for inventory purposes	20% of plantation area by 2018/19	Agtrans Research
With the CRC project		
Probability of success of the CRC project	80%	Agtrans Research
Reduction in both acquisition and processing costs of LiDAR for inventory	10%	Agtrans Research
Reduction in traditional ground sampling effort	From 40% to 20%	Agtrans Research
Future total area of plantation softwoods harvested	33,000 ha per annum	Adapted from DAFF (2007)
Future total area of plantation hardwoods harvested	67,000 ha per annum	Adapted from DAFF (2007)
Maximum adoption of LiDAR in future for inventory purposes	30% of plantation area by 2018/19	Agtrans Research

Value of the increase in inventory precision	$25 per ha	Agtrans Research after discussions with Mark Hunt

Results
The period of analysis was for 30 years after the first year of investment. The results are expressed in 2007/08 dollar terms and all benefits and costs are discounted to 2007-08. The results for the cost-benefit analysis are reported in Table 6.

Table 6: Results of Cost-Benefit Analysis for Investment in
(2007/08 $ terms)

Investment criteria	5% Discount Rate	10% Discount Rate
Present Value of Benefits ($m)	7.76	4.14
Present Value of Costs ($m)	1.49	1.53
Net Present Value ($m)	6.27	2.61
Benefit–Cost Ratio	5.2	2.7
Internal Rate of Return (%)	20	

The proportion of the present value of benefits derived from the premium due to the improved precision as opposed to the cost reductions due to LiDAR was 78% with 22% coming from the cost reductions.

Sensitivity Analysis
Sensitivity analyses were carried out on a range of variables and results are reported in Tables 7 to 8. All sensitivity analyses were performed using a 5% discount rate with benefits taken over a thirty year period from the start of the investment. All other parameters were held at their base values.

Table 7 shows the sensitivity of the investment criteria from a change in the assumption regarding the value of the precision gained. If there was no benefit from increased precision, the investment would do a little better than break even based on the cost reduction alone. In this case the net present value was $0.22 million, the benefit cost ratio was 1.2 to 1, and the internal rate of return to the investment was 6% per annum.

Table 7: Sensitivity of Investment Criteria to Value of Harvest from 1% Precision Increase in Inventory
(Discount Rate of 5%)

Investment Criteria	$10 per ha	$25 per ha (Base)	$50 per ha
PV of Benefits ($m)	4.13	7.76	13.8
PV of Costs ($m)	1.49	1.49	1.49
Net Present Value ($m)	2.64	6.27	12.32
Benefit Cost Ratio	2.77	5.2	9,3
Internal Rate of Return (%)	13	20	27

Table 8 shows the sensitivity of the investment criteria from a change in the assumption regarding the maximum adoption of LiDAR in ten years time.

Table 9: Sensitivity of Investment Criteria to Maximum Adoption Level
(Discount Rate of 5%)

Investment Criteria	**20% wood harvested**	**30% wood harvested (Base)**	**50% wood harvested**
PV of Benefits ($m)	4.74	7.76	13.800
PV of Costs ($m)	1.49	1.49	1.49
Net Present Value ($m)	3.25	6.27	12.31
Benefit Cost Ratio	3.18	5.2	9.26
Internal Rate of Return (%)	14	20	27

Conclusion

Given the assumptions made, the evaluation shows that the investment by the CRC in the LiDAR improvements for inventory purposes is quite positive. The relative contribution to the value of total benefits from the cost reduction is very small in relation to the benefits estimated from the improved precision of inventory information. The cost reductions alone would just justify the investment at the discount rate of 5%.

Key drivers of these results are the assumptions about the commercial value of the precision improvement. Information is not readily available in this area. However, the expected investment criteria appear to be quite robust to significantly more adverse assumptions than the base assumptions used in the analysis.

The expected net present value of this investment was $6 million and the benefit cost ratio was 5 to 1 at the discount rate of 5%.

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APPENDIX 2: ASSOCIATION GENETICS FOR SOLID WOOD PROPERTIES: *EUCALYPTUS GLOBULUS* AND *E. NITENS*

Reference Information

Code	Dates and Investigator(s)
Subproject Number: 2.1.2. Association genetics for solid-wood properties: *Eucalyptus globulus* and *E. nitens*	Start date: September 2005
	Completion Date: June 2012
	Principal Investigator(s): Chris Harwood, CSIRO

Background

The discovery and exploitation of natural allelic variation in candidate genes believed to control wood quality would help intensify breeding efforts and result in elevated rates of genetic gain in forestry breeding programs. Modern breeding programs have a multi-trait (at least two traits, e.g. volume and basic density) objective rather than just trying to improve a single trait. The value of individuals for these objective traits can be predicted using genetic evaluation techniques and software such as TreePlan® or ASReml by combining information from each individual and its relatives.

The objective traits at rotation age are linked by genetic and phenotypic correlations with selection traits which are measured at a younger age in the breeding populations. Trees in the breeding programme are ranked for the breeding objective, using a linear combination of predicted breeding values for the different objective traits, appropriately weighted by economic importance in the production system.

The best trees are then chosen for further breeding and deployment systems (seed orchards), and in the case of *E. globulus*, mass controlled pollination of favourable crosses in clone banks or seed orchards. Information from DNA analysis of genes controlling pulp yield would be combined with other selection traits (growth traits, wood density etc.) to select superior individuals. The areas devoted to *E. globulus and E. nitens* plantations and consequent pulpwood production are increasing, therefore efforts to identify genes controlling pulp quality in these species are becoming increasingly attractive in an economic sense. The benefits of research targeting *E. globulus* are examined in this report, along with investment costs.

Project Objectives

This project aims to significantly increase pulpwood product value in *E. globulus and E. nitens* through integration of molecular genetics and quantitative information in CRC members' breeding programs. The effects of allelic variants of at least five candidate major genes on key wood quality traits in *E. globulus* and *E. nitens* for breeding populations of these species will be quantified. An indicative target is that the percentage pulp yield of Australian *E. globulus* plantations could be increased by at least 1%, while maintaining growth rates and wood basic density.

Project Costs

A summary of the financial resources invested by the CRC in this subproject is shown in Table 1.

Table 1: CRC Investment in Subproject (nominal $)

Year Ended June	CRC to University of Melbourne	CRC to University of Tasmania	CRC to CSIRO	Other*	Total
2005/2006	105,000	20,000	4,000	161,250	290,250
2006/2007	171,679	60,000	4,000	294,599	530,278
2007/2008	142,416	80,000	4,000	283,020	509,436
2008/2009	145,000	120,000	8,000	341,250	614,250
2009/2010	145,000	130,000	8,000	353,750	636,750
2010/2011	145,000	50,000	8,000	253,750	456,750
2011/2012	145,000	20,000	8,000	216,250	389,250
Total	999,095	480,000	44,000	1,903,869	3,426,964

Source: Forestry CRC. * CSIRO and Universities.

Project Description

The project involves the discovery and exploitation of natural allelic variation in selected candidate genes believed to control wood quality in the target species. A supplementary line of investigation is using DArT markers to identify those parts of the genome where genetic variation drives variation in wood quality traits. This, linked to information from the forthcoming international sequencing of the eucalypt genome, will refine and confirm the choice of additional candidate genes to meet the core objective of the study. Once variation in key traits is identified, their breeding values will be calculated using software programs such as TreePlan or ASReml. Gunns Ltd has provided access to an *E. globulus* progeny trial that forms the association population for the study and the Southern Tree Breeding Association (STBA) has contributed access to their advanced-generation progeny trials which are being used as validation populations. Molecular genetic research is being conducted by teams at the University of Tasmania and the University of Melbourne

2007-08

Progress points for 2007-08

- Develop a set of molecular markers in candidate genes for association testing in *E. globulus*
- Participate in the development of a high-throughput, high-density (2000+ loci) marker system for eucalypts

Progress points for 2008-09

- Test selected markers within candidate genes for associations with wood property traits (a much larger number of candidate genes than the five specified in the formal project milestone will have been examined by June 2009)
- Establish parameters including rate of decay of linkage disequilibrium, nucleotide diversity and promoter size, specific to *E. globulus*, that will affect application of the forthcoming *Eucalyptus* genome sequence in Project 2.1
- Use the high-throughput marker system to detect QTL for wood properties across multiple pedigrees and find candidate genes in the genomic neighbourhood of significant markers

Some hurdles have hindered progress of the project. These include delays in obtaining lignin phenotyping of individuals in the *E. globulus* base population which could prevent association analysis of candidate genes for lignin. Association data may also need to be verified in a second tree population, as the original anticipated number of individual trees for the studies has more than doubled. McManus (2008) also noted that the less than perfect suitability of trials for association mapping and the high level of nucleotide diversity in Eucalyptus species were slowing the delivery of project outputs.

Outputs

Functional links between natural allelic variation in selected candidate genes and *E. globulus* wood quality will be described, and integrated with other genetic information in CRC members' breeding programs. There are five stages at which molecular information could be gathered and integrated with other information:

1) In the nursery prior to plant-out
2) At the time of first growth assessment (1 year approximately)
3) At the time of wood quality assessment (4 years approximately)
4) "Checking" selected individual about to be inducted into breeding arboreta for control-pollinated breeding
5) "Checking" selected individuals about to be inducted into deployment populations (clonal seed orchards, or mass controlled pollination)

The SNP (Single Nucelotide Polymorphism) data on functional variation in the candidate genes provides additional information on their predicted performance as parents in candidate breeding lines, so improved choices of individuals for breeding can be made. Results of the research will be documented in technical reports, scientific papers, in workshops and provided to partners involved in tree breeding of *E. globulus* and *E. nitens.* Molecular data will be integrated with quantitative genetic information using the TreePlan® software owned by STBA.

Outcomes and Benefits

Identified and validated functional gene variants (usually SNPs) would be analysed in some proportion of the breeding population. The research has already found that the allele 1 of a particular gene lifts kraft pulp yield by 0.3%, relative to allele 2 of the same gene, on average across the entire population. It is hoped that such functional variation combined across several genes will enable accurate prediction of 1% or more of Kraft Pulp Yield. The integration of this information into the breeding population has the potential to increase pulp yield and the consequent economic value of *E. globulus* plantation production.

Quantitative Analysis of Costs and Benefits

Hardwood plantation supply is increasing. Supply by 2010 is forecast to be nearly 14 million cubic metres per year, about four times the volume harvested in 2005–06 (ABARE, 2007). Pulpwood constitutes nearly all of the increase in production from hardwood plantations. The bulk of plantation hardwood pulpwood is sourced from Western Australia, Tasmania and Victoria.

Table 2: Broadleaved Plantation Area by State

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha	'000 ha
Broadleaved							
New South Wales	53.7	51.3	51.0	54.1	55.2	62.6	70.6
Aust. Capital Territory	0.2	0.2	0.1	0.1	0.0	0.0	0.0
Victoria	128.9	142.6	154.7	168.5	164.7	175.3	191.0
Queensland	20.1	26.0	30.5	34.4	37.5	42.8	49.4
South Australia	27.9	32.4	37.1	39.4	42.3	47.9	55.0
Western Australia	234.7	247.5	251.5	259.4	270.8	281.3	294.7
Tasmania	119.9	135.3	146.6	151.3	155.5	174.0	199.1
Northern Territory	2.4	3.2	4.4	8.4	14.1	23.5	23.7
Australia	**587.9**	**638.3**	**676.0**	**715.5**	**740.2**	**807.4**	**883.5**

Source: ABARE (2007)

E. globulus is the dominant plantation hardwood species in Western Australia. Many of these areas were established since 1990 and log volume forecasts made by BRS (2007) were based on the assumption that all these plantations are managed for pulpwood production.

Table 3: Hardwood Pulp Projections by State ('000 m3)

	2005-09	**2010-14**	**2015-19**	**2020-24**	**2025-29**	**2030-34**	**2035-39**	**2040-44**	**2045-49**
Western Australia	2,442	4,531	4,293	4,816	4,319	3,852	4,542	4,537	4,716
Green Triangle	388	4,555	2,923	3,790	3,815	2,623	4,518	2,870	4,381
Tasmania	1,227	2,657	3,577	4,095	4,161	4,195	4,316	4,406	4,273

Source: Bureau of Rural Sciences (2007)

Within the Green Triangle, hardwood pulpwood harvesting will increase with a peak in supply being forecast for 2010–15. Export markets are the key consumers of output from this area, although a proposal to develop a pulp mill at Penola is being considered. In Tasmania, Gunns Limited has proposed a plan to develop a pulp mill that would use a large proportion of the available hardwood pulpwood (BRS, 2007).

It is estimated that the total supply of *E. globulus* and *E. nitens* for pulpwood production is currently around 9 million m^3 per year and this is predicted to peak at 10 million m^3 per year by 2013. This level of production assumes an estate area of 500,000 ha and average productivity of 180 cubic metres per 10-year rotation. Currently, most pulpwood is destined for export, although pulpmill capacity could be increased in key production areas increasing domestic consumption of the product. For the purposes of the analysis it is assumed that 30% of production will be utilised domestically.

An increase in pulp yield would deliver benefits at the farm-gate for domestically consumed pulpwood. Currently a premium of $2 per green m^3 is paid per 1% increase in kraft pulp yield by one company. This premium is factored into the analysis to calculate the plantation-gate economic benefit from improved planting material. The research project is scheduled to finish in 2012. It is assumed that molecular advances and breeding value research would have been completed by this stage and improved planting material would be commercially released and commercial planting commenced in 2012. Follow-on costs are required in the propagation and testing of material. It is estimated that $100,000 per year for three years is required.

Adoption of improved *E. globulus* tree stock is governed by this species harvesting cycles and expansion in the plantation area. Given this species is harvested after 10-12 years; an annual planting of 10% of the plantation area is included in this analysis. Adoption of improved planting material is hampered by 50% of the estate being coppiced (regeneration from the stump), rather than replanted with seedlings. Not all plantations will adopt the improved planting material. It is estimated that around 70% of the plantation area would adopt improved planting material.

Based on a 10 year cycles, 70% adoption and 50% coppice, an annual increase in harvesting of improved planting material of 0.4 million m^3 per year assumed from 2022. This year is forecast to be the first year of economic benefit, as 10-12 years is required for tree stock with improved pulp yield to be harvested. A summary of the assumptions is provided in Table 4.

Table 4: Summary of Assumptions

Item	Assumption	Source
E. globulus and *E. nitens* pulpwood volume	10 million green m^3 in 2008	Volume of green metric tonnes (or m^3 from *E.globulus* and *E.nitens*) from stable estate area of 500,000 hectares.
Year Improved Material First Harvested	2022	Consultant estimate based on crop rotation of 10 years from end of project. Source: C. Harwood (pers.comm)
Incremental Harvesting of Improved Planting Materials	0.4 million m^3 per year	Consultant estimate based on crop rotation of 10 years, 70% of plantation area adopting the improved material and coppice of 50%. Source: C. Harwood (pers.comm.) The total amount of harvested improved planting materials is cumulative.
Percentage of Pulpwood for Domestic Usage	30%	Consultant estimate.
Premium for Improved Planting Material	\$2 per green m^3	Consultant estimate based on premium received at farm-gate for wood with 1% increase in pulp yield from http://www.forestrytas.com.au/forest-management/wood-supply-agreements
Percentage of Improvement Attributable to Molecular Research	75%	Improvement in pulp yield would occur in current breeding programs. 75% of the assumed 1% gain is attributed to molecular techniques.
Cost of propagation	\$100,000 per year for three years	Consultant estimate

Results
The period of analysis was for 30 years after the first year of investment. The results are expressed in 2007-08 dollar terms and all benefits and costs are discounted to 2007-08. The results for the cost-benefit analysis are reported in Table 5. It is evident that the project is positive at a discount rate of 5%, but not at 10%. This is because of the lag of 10 years between planting and harvesting of improved planting materials.

Table 5: Results of Cost-Benefit Analysis for Investment at Selected Discount Rates.

Investment criteria	5% Discount Rate	10% Discount Rate
Present Value of Benefits ($m)	6.08	2.08
Present Value of Costs ($m)	3.31	3.19
Net Present Value ($m)	2.78	-1.11
Benefit–Cost Ratio	1.8	0.6
Internal Rate of Return (%)	7.9	

Sensitivity Analysis

There is a substantial amount of uncertainty surrounding a number of variables used in the baseline evaluation. The impact on investment returns resulting from changes in the attribution of project results to increased pulp yield (Table 6), proportion of hardwood pulp consumed domestically (Table 7) and premium received for wood from improved planting materials (Table 8) are reported in the following tables.

Table 6: Sensitivity of Investment
Criteria to the Attribution of Benefits to Molecular Techniques
(5% discount rate)

Investment Criteria	25%	75% (Base)	100%
PV of Benefits ($m)	1.86	6.08	8.20
PV of Costs ($m)	3.31	3.31	3.31
Net Present Value ($m)	-1.45	2.78	4.89
Benefit Cost Ratio	0.6	1.8	2.5
Internal Rate of Return (%)	2.4	7.9	9.4

It is calculated that the net present value of the investment would increase by over $2 million if the total gain in pulp yield could be attributed to molecular techniques developed in the subproject.

Table 7: Sensitivity of Investment
Criteria to Proportion of Hardwood Pulp Consumed Domestically
(5% discount rate)

Investment Criteria	0%	30% (Base)	100%
PV of Benefits ($m)	-0.26	6.08	20.89
PV of Costs ($m)	3.31	3.31	3.31
Net Present Value ($m)	-3.57	2.78	17.58
Benefit Cost Ratio	-0.1	1.8	6.3
Internal Rate of Return (%)	Na	7.9	14.5

The economic returns calculated for the project are also sensitive to assumptions in relation to the proportion of *E.globulus* and *E.nitens* hardwood pulp consumed in Australia. It is evident that the net present value of the project increases by over $14 million in the event that 100% of production was consumed in Australia.

Table 8: Sensitivity of Investment
Criteria to the Premium Received for Wood from Improved Planting Materials
(5% discount rate)

Investment Criteria	$0.5 per m3	$2 per m3 (Base)	$4 per m3
PV of Benefits ($m)	1.33	6.08	12.43
PV of Costs ($m)	3.31	3.31	3.31
Net Present Value ($m)	-1.98	2.78	9.12
Benefit Cost Ratio	0.4	1.8	3.8
Internal Rate of Return (%)	1.1	7.9	11.6

It is evident that the net present value of the project is sensitive to the premium received for improved pulp yield. A premium of at least $1.1 per green m3 is required for the project to breakeven.

Conclusion

Hardwood plantation areas have significantly increased in Australia, and consequently research that leads to increased profitability have substantial national benefits. The above cost-benefit analysis demonstrates that investment in research to identify and deploy improved planting materials in *E.globulus* hardwood pulp plantations has significant economic merit across a range of assumptions concerning attribution, trade and premiums received for improved planting material. The long lag between planting and harvesting improved materials make the project's economic return very sensitive to the assumed discount rate employed in the analysis. At a discount rate of above 8%, the calculated present value economic benefits do not cover research costs.

Acknowledgments

Chris Harwood, CSIRO

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SILVICULTURE-PROCESSING STUDIES ON *EUCALYPTUS NITENS* AND *E.GLOBULUS*

Reference Information

Code	Dates and Investigator(s)
Subproject Number: 2.3.1. Silviculture-processing studies on *Eucalyptus nitens* and *E. globulus*	Start date: September 2005
	Completion Date: June 2010
	Principal Investigator(s): Russell Washusen, CSIRO

Background

Over 20,000 ha of *Eucalyptus nitens* plantations are being managed in Australia with the aim of producing high quality sawlogs. Within a timber production system, a more intensive approach is being taken which includes the timely application of thinning operations to ensure adequate piece size over 20-25 year rotations (Wood et al 2007).

Minimal management of eucalypt plantations is generally thought to result in reduced timber quality as a result of growth stresses, tension wood and knots (Nolan et al. 2005). To avoid this quality issue, it has been proposed that plantation-grown eucalypts be pruned and thinned for conventional timber supply. Some recent studies, have, however, contradicted these recommendations – as timber quality was found to be satisfactory for some products under minimal management practices.

The range of findings and recommendations found by these various studies was a result of differences in processing methods, particularly differences in product thickness and application of different drying methods. There was need to conduct a study to analyse the effect of the silvicultural treatments on wood quality, product recovery and processing performance using both back-sawing and quarter-sawing strategies for appearance products.

Project Objectives

The overall objective is to describe the impact of silvicultural treatments on wood quality traits that determine log value for defined processing systems producing solid and engineered wood products and residual pulpwood, in three key plantation eucalypt species. The specific objective for Subproject Number 2.3.1 was to better understand the effect of silviculture on processing efficiency and product quality in full rotation stands of *Eucalyptus nitens* yielding large diameter pruned sawlogs.

Project Costs

A summary of the financial resources invested by the CRC is shown in Table 1.

Table 1: CRC Investment in Subproject 2.3.1 (nominal $)

Year Ended June	CRC	Other*	Total
2005/2006	80,000	120,000	200,000
2006/2007	80,000	120,000	200,000
2007/2008	100,000	150,000	250,000
2008/2009	50,000	75,000	125,000
Total	310,000	465,000	775,000

Source: Forestry CRC. * CSIRO, Forestry Tasmania, and University of Tasmania

Project Description

The program of research is to be conducted in three phases:

- **Phase 1:** To be undertaken using the Gould's Country Spacing trial – thinned and pruned at year 6 (trial commenced in May 2006). Research activities include:
  - Processing trials employing conventional quarter-sawing and back-sawing techniques to assess differences between thinning treatments in log quality, wood quality and processing performance.
  - Experimental processing techniques to determine if improvements are possible in comparison to the conventional methods. This will investigate the effect of product thickness on drying performance of back-sawn boards, the effect of log length on quarter and back sawing performance and the effect of microwave pre-treatments and vacuum driers on drying performance of back-sawn boards.
- **Phase 2:** (commenced Oct 2007). Experimental processing techniques to determine if improvements are possible in comparison to the conventional methods. This will investigate the effect of product thickness on drying performance of back-sawn boards, the effect of log length on quarter and back sawing performance and the effect of microwave pre-treatments and vacuum driers on drying performance of back-sawn boards.
- **Phase 3:** Larger scale production runs conducted with logs of known quality from remaining trees in the three trials and adjacent plantations (under similar management). Research during the final phase of the project will validate conclusions and the financial performance of various strategies will be investigated with CSIROMILL (February-March 2008).

The first phase of the project has been conducted in the Gould's Country plantation (northeastern Tasmania). This trial is 21 years old and was set up to test the effect of thinning intensity and pruning on stand productivity and wood quality. As thinned and pruned stands of this age are scarce in Australia this initial project scoped wood quality issues to better target subsequent research. This approach was necessary because recent trials in similarly managed *E. nitens* and *E. globulus* have indicated improved processing performance in stands managed by early thinning and pruning over 'unmanaged' stands. Much of the research experience in Australia has been gained from these unmanaged stands and these trials indicate that a new approach is warranted.

Outputs

The study is adding to the body of knowledge about management practices in hardwood plantations by examining the silvicultural and processing factors that influence recovery of higher-value standard and select grade boards and the causes of board down-grade. To date, the following findings from Phase 1 (differences between thinning treatments at Gould's Country plantation) have been found to be of importance (taken from Washusen et al 2008):

- The results show that there is no processing advantage derived from *E. nitens* logs that have grown following heavy early thinning compared with those that have grown to the same size under stronger levels of stand competition.
- With heavy thinning a greater percentage of the sawlog volume produced on 25-30 year rotations on sites comparable to Gould's Country would be of logs with diameter greater than 43 cm, suitable for quarter-sawing in conventional sawmills.
- Quarter-sawn logs produced recoveries of standard and select-grade boards that were substantially higher than backsawn logs and within the range reported for native forest ash eucalypts.
- The severity and prevalence of surface checking and under-sizing was influenced by the processing methods. Poor sawing accuracy, insufficient weighting of the drying stacks leading to cupping and possibly ineffective steam reconditioning contributed to production of boards close to or below the final target size.

Outcomes and Benefits

The project is currently underway, with silvicultural management strategies already being examined and processing quality the subject of current research efforts. As part of the silvicultural research in Tasmania, it was found that there is no processing advantage following a management regime with early, pre-commercial thinning to reduce levels of competition early in the rotation. As such, thinning could be delayed until a commercial product could be obtained from the thinning and the *E.nitens* plantation would realise maximum profitability from the timing and intensity of this activity.

In a more general sense the trial indicated that conventional processing equipment led to inaccuracies in cutting that reduced recovery and caused problems in subsequent processing. Modification of the sawing system would eliminate the need for many of the face cuts. Saw millers would benefit from improved recovery, however the costs of modifications to mill infrastructure needs to be considered in the overall calculation of profitability.

Quantitative Analysis of Costs and Benefits

The area of *E. nitens* is approximately 143 thousand hectares and is expanding. Around 20,000 ha of the plantation area is assumed to be dedicated to sawn timber production, primarily in Tasmania. Wood et al (2007) modelled the overall financial returns from an early or 'non-commercial' thinning (NCT) compared with a delayed or 'commercial' thinning (CT) using the Farm Forestry Toolbox v.4 software package. The differences in the modelled stem densities and net present value of these strategies are documented in Table 2.

Table 2: Key Characteristics at Thinning and Clearfall for Non Commercial and Commercial Thinning Practices.

Thinning Practice	Characteristics		Medium Site Quality
NCT	Thinning	Age (yrs)	6
(Non commercial)	Clearfall	Age (yrs)	18
		Stems ha^{-1}	298
		NPV ($AUS)	646
CT (commercial)	Thinning	Age (yrs)	9
	Clearfall	Age (yrs)	19
		Stems ha^{-1}	279
		NPV ($AUS)	1479
Difference		**NPV* ($AUS)**	**833**

* NPV = net present value. Source: Wood et al (2007)

The analysis demonstrates that current silvicultural regimes in Tasmania favour later commercial thinning rather than applying an early non commercial thinning. Following the analysis it is estimated that sustaining current thinning, rather than adopting early regimes, generated an increased net present profit of $833 per hectare. This profit difference is calculated as the difference between the commercial thinning net present values of $1,479 per hectare, compared with a profit of $646 per hectare for the non commercial thinning strategy.

Currently there is no readily available data about the costs and benefits relating to the modification of log carriage and improved application of face cuts. The research project has identified that not just this aspect of milling requires attention, as other parts of the infrastructure requires upgrading. These issues are being explored in the latter phases of the project, and therefore the benefits and corresponding costs of processing are not quantified in this analysis. There are potentially positive implications for the cost-benefit study from the inclusion of these data, therefore the current estimates may understate potential project returns.

It is assumed that reduced thinning practices identified during the first phase of the project (ending June 2008) have already been adopted by industry and will increase by 2% per year until a maximum of 10% of *E.nitens* timber plantations are reached. It is assumed that optimal commercial thinning strategies would have been developed by industry in the absence of this project. Consequently it is assumed that similar recommendations that would have been adopted by industry would have occurred by 2014. So a bringing forward of benefits by five years is the benefit. A summary of the assumptions is provided in Table 3.

Table 3: Summary of Assumptions

Item	Assumption	Source
Eucalyptus nitens Timber Plantation Area	20,000 hectares	ABARE (2007) and consultant assumptions
Maximum Adoption of Improved management Practices	10% per year	Consultant estimate. Thinning recommendations focussed on *Eucalyptus nitens* timber plantations
Annual Adoption of Improved management Practices	2%	Consultant estimate
Year Practices First Adopted by Industry	2009	Year Phase 1 of the Project was Completed
Year Lower Cost Management Practices Would Have Been Adopted Without Project	2014	Consultant estimate assumes recommendations supplied 5 years before what would have happened without the research.
Increased Profit From Avoided Early Thinning	$833 per hectare	Derived from Wood et al (2007)

All costs of the subproject are included in the cost-benefit analysis. Given the sub-project is likely to deliver processing benefits, the overall cost-benefit results are likely to be an underestimate as only silviculture outcomes are being included. This approach has been taken to make it consistent with other analyses in this report where some likely benefits are identified, but not valued.

Results

The period of analysis was for 30 years after the first year of investment. The results are expressed in 2007-08 dollar terms and all benefits and costs are discounted to 2007-08. The results for the cost-benefit analysis are reported in Table 4.

Table 4: Results of Cost-Benefit Analysis for Investment at Selected Discount Rates.

Investment criteria	5% Discount Rate	10% Discount Rate
Present Value of Benefits ($m)	6.89	5.79
Present Value of Costs ($m)	0.82	0.85
Net Present Value ($m)	6.06	4.94
Benefit–Cost Ratio	8.4	6.8
Internal Rate of Return (%)	85	

Sensitivity Analysis

There is a substantial amount of uncertainty surrounding a number of variables used in the baseline evaluation. The impact on investment returns resulting from changes in the area of *E.nitens* devoted to timber production (Table 5), maximum adoption of delayed thinning management practices (Table 6) and profitability from avoided early thinning (Table 7) are reported in the following tables.

Table 5: Sensitivity of Investment
Criteria to Area of *E.nitens* for Timber Production
(5% discount rate)

Investment Criteria	10,000 ha	20,000 ha (Base)	40,000 ha
PV of Benefits ($m)	3.44	6.89	13.77
PV of Costs ($m)	0.82	0.82	0.82
Net Present Value ($m)	2.62	6.06	12.95
Benefit Cost Ratio	4.2	8.4	16.7
Internal Rate of Return (%)	50	85	135

It is calculated that the net present value of the project would increase by nearly $7 million if the area of *E. nitens* plantations dedicated to sawn timber production were increased to 40,000 ha. Similarly, if adoption of the management practices increased from 10% to half of the plantation area, the net present value of the project would increase from $6 million to $34 million.

Table 6: Sensitivity of Investment
Criteria to Maximum Adoption of Later Thinning Management Practices in *E. nitens* Timber Plantations (5% discount rate)

Investment Criteria	**2%**	**10% (Base)**	**50%**
PV of Benefits ($m)	1.38	6.89	34.43
PV of Costs ($m)	0.82	0.82	0.82
Net Present Value ($m)	0.55	6.06	33.61
Benefit Cost Ratio	1.7	8.4	41.8
Internal Rate of Return (%)	18	85	234

The economic returns calculated for the project are also sensitive to assumptions in relation to the level of assumed profitability from avoided early thinning (Table 7). A minimum increased profit of $100 is required for benefits to cover costs.

Table 7: Sensitivity of Investment
Criteria to the Profitability from Avoided Early Thinning
(5% discount rate)

Investment Criteria	**$ 100 per ha**	**$833 per ha (Base)**	**$ 1,500 per ha**
PV of Benefits ($m)	0.83	6.89	12.40
PV of Costs ($m)	0.82	0.82	0.82
Net Present Value ($m)	0.00	6.06	11.58
Benefit Cost Ratio	1.0	8.4	15.1
Internal Rate of Return (%)	5	85	126

Conclusion

The economic benefits from the development of cost saving management practices for eucalypt plantations were calculated. These benefits were shown to be substantial. A number of shortcomings were identified in the conventional processing strategies for hardwood timbers. These included poor sawing accuracy with both quarter-sawing and back-sawing. Further benefits may accrue if mills modify log carriages and improve application of face cuts, resulting from the potential future findings of the project.

Acknowledgments
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Matthew Wood, Forestry Tasmania

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APPENDIX 4: OPTIMISED LOG MERCHANDISING WITH MECHANICAL HARVESTERS

Project Reference Information

Project Title	Dates and Investigator(s)
Optimised log merchandising with mechanical harvesters	Start date: 1 October 2005
	Completion Date: 30 June 2012
	Principal Investigator(s): Martin Strandgard, University of Melbourne

Background

The program to which this initiative belongs (CRC Program 3) is focused on field research to lower the cost and improve the efficiency, effectiveness, and safety of forest harvesting and transportation operations. A second focus of Program 3 is to build capacity in forest harvesting and transport operations. The program is carried out in close association with the industry CRC partners involved in both native forest and plantation forest operations.

Partners in the program include:

- WA Plantation Resources Pty Ltd **(**WAPRES**)**
- Forestry Tasmania
- Timbercorp
- Great Southern
- South East Fibre Exports Pty Ltd (SEFE**)**
- Forestry SA
- Forest Enterprises Australia (FEA)
- Hansol Pty Ltd
- Gunns Pty Ltd
- Forest Products Commission (FPC) (WA)
- Forest and Forest Industry Council of Tasmania (FFIC)
- Norskeskog
- Midway Plantations
- Vic Forests
- ITC Limited

Improving harvester measurement accuracy can increase wood volume recovery by allowing operators to cut closer to dimensional limits and improve overall wood value through optimisation of log assortments. The potential revenue gain in Australia is believed to be in the order of tens of millions of dollars per annum. A more reliable estimate will be generated as part of the project.

Most harvester accuracy studies have been carried out by researchers from the Forest Engineering Research Institute of Canada (FERIC) and Skogforsk (Sweden). Hamish Marshall (Interpine) wrote his PhD and an associated paper on the topic. Other recent studies on the topic include those of Andersson and Dyson (2002), Makkonen (2001), Marshall et al (2006) and Sondell et al (2002).

Previous harvester accuracy studies are deficient in two ways:

- They are overseas studies where results may not be applicable to Australia.
- None of the studies considered the impact of manual measurement variability on their results.

The project on optimised log merchandising with computer controlled harvester heads is targeted at developing methods of effective calibration of harvesters under Australian conditions, building value tables and prediction models for Australian trees and being able to deliver optimal lengths and quality of logs to mills and end users.

Most harvesters used in Australia have suitable onboard computer systems so that there is only a very small added investment required in the field to support harvester head computer control. However, very few operators are using the systems for a range of reasons including:

- Poor calibration to Australian conditions,
- Lack of skill, and
- Lack of availability of value tables to optimise log cuts.

Project Objectives

The objectives of the project are:

- Quantify harvester length and diameter measurement accuracy (including estimation of bark thickness)
- Derive bark thickness equation parameters for the equations used by harvesters
- Establish relationship between revenue gain and improved harvester accuracy
- Identify practical methods to improve harvester measurement accuracy

The immediate benefit to CRC members of this specific project is increased wood volume recovery by reducing out-of-size logs. Greater returns will accrue later from a follow-on project through the optimisation of log assortments.

This project forms part of the Program 3 “Harvesting technology and equipment”. The project contributes to the Program 3 objective to increase value recovery by 5% or greater by increasing both the volume and value of wood recovered during harvesting.

Project Costs

A summary of the financial resources invested by the CRC in the Optimised Log Merchandising Project is shown in Table 1.

Table 1: CRC Investment in Optimised Log Merchandising Project (nominal $)

Year Ended June	Total CRC funds (cash and in–kind) ($)
2006	33,333
2007	100,000
2008	83,333
2009	75,000
2010	41.667
Total	333,333

Source: Forestry CRC

Project Description

The objective of the project is to get as close as possible to the specified log diameters and lengths using measuring systems on the harvester that are run through an optimisation algorithm. In Australia log sales are usually based on underbark volumes, so that part of that optimisation is accurately estimating the bark thickness. The other aspect is to ensure the machine is measuring as accurately as possible which requires good calibration. This is being addressed by testing manual measurements and identifying manual measurement needs for good calibrations and then finally doing an operational trial using different log specification tables.

The project is therefore made up of three components. The first component studied errors in manual measurements used in harvester accuracy studies and harvester calibration and recommended techniques for minimising manual measurement variability. The second component is focused on analysing comparisons of manual and harvester controlled log length, diameter and bark thickness data as collected by ForestrySA. The final component will investigate and implement harvester optimisation. Results and data from each component will be used in subsequent projects. The third component, for example, will also use harvester accuracy measurement data, stand-level harvester records, and bark measurements collected by ForestrySA.

Data preparation
Only sawlog data will be analysed as pulp and waste log measurements are generally much more variable and the logs are of considerably lower value. Length and diameter measurement sample sizes need to be sufficient to minimise the impact of manual measurement variability. Appropriate sample sizes will be calculated from the results from the first component contained in the report "Evaluation of log measurement errors as related to harvester log measurement accuracy" (in preparation).

Data analysis
Harvester length and diameter measurement variability will be analysed by comparison with manual measurements as follows:

- Comparing average differences and standard deviations between harvester and manual measurements.
- Comparison between harvesters and with other studies using the Swedish "Best-5" standard for length and % diameter measurements within ±4 mm (Swedish standard) and ±8 mm (FERIC standard) of manual measurements.
- Proportion of logs under or over length specifications. Individual log comparisons of length are complicated by manual and harvester measurements usually being on different log sides leading to length differences due to irregularly shaped logs being misinterpreted as harvester errors. To reduce the impact of these differences, results from butt logs (greater proportion of irregular logs) and with small errors (≤ 1 cm) will be shown separately.
- Proportion of logs under or over diameter specifications. Diameter tape measurements or the average of two caliper measurements at right-angles are acceptable for this comparison. Single caliper measurements are too variable to provide an adequate basis for comparison.

Bias
Calibration aims to minimise bias in harvester measurements. Bias will be examined using paired t-tests ($p \leq 0.05$) of harvester and manual length and diameter measurements.

Bark thickness
Harvesters estimate underbark diameter by estimating bark thickness using inbuilt equations. Equation parameters will be derived from manual bark thickness data and compared with existing harvester equations. The effect of age, site quality and genetics on bark thickness equation parameters will be examined.

Revenue estimation
The relationship between revenue gains through increased volume recovery and harvester accuracy will be established by simulating ForestrySA's harvest data using their copy of Silvia, a merchandising simulation software with error levels ranging from no errors through to the average error levels identified.

Implementation
The project will work with companies and their harvest contractors to determine the best process to disseminate procedures to improve harvester measurement accuracy. Trial procedures will be undertaken with the most receptive contractors to refine procedures before a more general rollout is made.

Consideration will be given to rewarding contractors who participate in the process and who then achieve consistently high measurement accuracy as there is little incentive under existing contractual arrangements.

Updated bark equation parameters need to be installed in each harvester. If multiple sets of bark equation parameters are developed to deal with site or tree differences a process will be required to manage and disseminate parameters as contractors move to new stands. Data transfer between the field and the office is also a key requirement of optimisation so the project will need to consider optimisation data transfer requirements.

Outputs

A summary of the principal outputs (both outputs achieved to date as well as those expected) from the project is reported in Table 2.

Table 2: Summary of Principal Outputs

Principal Outputs to Date
• Definition of harvester head calibration procedure for harvesting operations
• Development of a recommended manual measurement method for harvesters heads used for merchandising in pine harvesting operations
• Development of a preliminary bark model for Australian grown *Pinus radiata* for use in harvester head optimisation formulas and post harvest plantation inventory updates
• Technical report produced on harvester calibration
Expected Outputs Not Yet Achieved
• Technical report of *Pinus radiata* bark model
• Establishment of measurement accuracy of harvester heads in both Pine and Eucalypt operations
• Comparison of manually chosen log lengths and diameters with those from computer controlled harvester heads

• Information on the proportion of logs under or over length and under or over diameter specifications from manual decisions versus computer controlled decisions
• Assessment of bias in harvester measurements
• Improved equations for harvester estimates of bark thickness for *Pinus radiata*
• Relationship between revenue gains through increased volume recovery and harvester accuracy
• A report to participating industry partners detailing harvester accuracy findings, potential revenue gains through improving measurement accuracy and recommended procedures to improve measurement accuracy
• A report to participating industry partners detailing the proposed harvester bark thickness equation parameters compared with existing parameters
• A journal article detailing manual measurement accuracy and its implications to harvester accuracy studies and harvester calibration
• A calibration best practice technical report and accompanying laminated step-by-step guide for use by harvester operators.

Outcomes

A summary of the principal outcomes anticipated from the project is reported in Table 3.

Table 3: Summary of Principal Outcomes

Principal Outcomes
Actual Outcomes to Date
Nil
Expected Outcomes (Not Yet Achieved)
• Higher level of awareness of harvester operators of the inaccuracy associated with manual measurement of log length and diameter
• Improved calibration of data loggers in harvesters from information produced in the project
• Increased awareness by harvest operators and forest owners of the potential revenue gains from improving volume recovery from more accurate matching of log lengths and diameters to specifications
• A higher level of use of computer controlled harvester heads in harvesting of *Pinus radiata* wood resources harvested for sawlogs
• Potential use of the information produced in other projects aimed at optimised log merchandising with computer controlled harvester heads including building value tables and prediction models for Australian trees and being able to deliver optimal lengths and quality of logs to mills and end users

- Potential extension of the methods developed in this project to hardwood harvesting of sawlogs from both plantations and native forests

Benefits

The likely benefits from the success of this project are identified in a triple bottom line framework as shown below.

Economic
It is expected that there would be a decrease in the quantity of logs produced that are outside of required specifications and which are downgraded in value as a result.

Environmental
There are unlikely to be any environmental benefits from this investment.

Social
There would be no direct social impacts of this investment. However, it is likely that a part of the benefits from improved servicing of demand (via meeting users' needs) would be passed along the value chain to consumers, resulting in a lower cost to consumers.

Benefit Distribution
Primary beneficiaries from the investment are likely to be the forest owners as well as log processors. The incentive to adopt this technology may be complex in that there are three parties usually involved in harvesting operations: the forest or plantation owner, the harvest contractor and the processor who receives the logs. In some cases, the mill owner (the processor) may employ the harvest contractor, but in most cases the operation is under control of the forest or plantation owner. Timbercorp is the only plantation owner who has its own equipment for harvest (an integrated operation) and most of its harvesting is from hardwood plantations for pulp and not for timber.

The distribution of benefits from reduced downgrading of logs will depend on the business structure and contractual arrangements between the forest owner, harvest contractor and mill operator. It is possible that all could benefit. The land owner may obtain more value from the fixed resource. The harvest contractor may receive an incentive payment for producing more high value products and the mill owner, while paying a premium for the higher value logs, may obtain improved returns from better recovery and producing higher value products.

Adoption
Once awareness is raised and calibration is successfully effected, adoption is likely to be quite rapid as there is only a small additional capital cost of implementing the improved harvester head control and training the harvest operators.

The primary industry collaborator is Forestry SA, but it is expected that Gunns, FPC, FEA and Midway will be interested also in implementing the technology. The attitude to adoption by the operators is likely to be positive as it actually makes their job easier. This has been observed in the project to date as well as being supported by the literature on the subject in non–Australian jurisdictions (Mark Brown, pers. comm., Sep 2008).

Summary of Benefits
A summary of the principal benefits emanating from the project is provided in Table 4.

Table 4: Summary of Principal Benefits

Economic	Environmental	Social
Lengths of logs and quality of logs both improved with regard to needs of the market	Nil	Small proportion of benefits likely to be passed along value chain to consumers
Reduced level of downgrading of logs that are outside specifications		

Quantitative Analysis of Costs and Benefits

Scenario Without the Research Investment (the counterfactual)
If the CRC program had not proceeded, it would have been unlikely that the harvester head control potential would have been exploited quickly and effectively to any extent in Australia, largely due to the constraints identified earlier.

There already has been some limited implementation independent of the CRC by some CRC members & non-members. But the advantage of CRC involvement is the opportunity to centralise effort and apply expertise particularly from overseas experts. The combination of these benefits will result in earlier and more effective implementation (Jim O'Hehir, pers. comm., Sep 2008).

It is estimated that the CRC investment has resulted in benefits being brought forward by four years and any such benefits without the project would have been only about 60% of the magnitude of the benefits compared with the CRC investment.

Scenarios With the Research Investment
Probability of success of the project
It is assumed that the chance of technical success of the project is quite high; the estimate is 80%.

Additional costs incurred
Use of the technology will require some operator training to ensure effective adoption. Some operators have taught themselves but will not always have covered the full level of understanding that is really required. Other operators will not have had the opportunity to use more modern harvesters that incorporate the technology but as contractors replace

equipment and upgrade programs more operators will be exposed to the new technology (Jim O'Hehir, pers. comm., Sep 2008).

Apart from the cost of the project itself, other costs involved in securing the benefits are therefore included. These costs include:

- the training and management cost of operators at $2,000 per year each (ongoing)
- the re-programming of $2,000 per harvester per year (ongoing)

The average capacity of a harvester (across both thinning and final harvest) is assumed to be about 75,000 cu m per annum. Clearfelling would probably be higher than 75,000 cu m per annum and thinning probably lower.

Increased recovery of wood
Implementation in other jurisdictions indicates that increased value recovered in the logs harvested from using harvester measured lengths and diameters is estimated at between 2% and 4% (Mark Brown, pers.comm., Sep 2008). If recovery of the pine log resource is improved by 2%, this would be worth about $2-$5 million per year, depending on the region and provided the additional recovery applies to all pine harvested each year. To be conservative the assumption made in the analysis is that 2% additional recovery is worth $2 million per year in added profits.

Extent and timing of adoption
Uptake of the technology could be expected to be significant with companies such as ForestrySA, Gunns, FPC, FEA and Midway already quite interested. These first two companies would represent 60-75% of all pine log harvesting in the Green Triangle Region of SE South Australia and SW Victoria (if Auspine is assumed to be part of Gunns).

A demonstration of the benefits of optimisation by some in the pine industry would soon lead to adoption by most companies. Some harvesting contractors are engaged by more than one grower so training operators to the benefit of CRC members would eventually flow through to non members via contractors. Contractors have their own state and federal associations and this would provide an additional forum for knowledge transfer of the benefits of the adoption for the contractor i.e. a more competitive bid through offering additional value adding to forest growers (Jim O'Hehir, pers.comm., Sep 2008).

It is assumed that all pine log harvesting operations would be using the harvester head control technology by the year ending June 2014. Adoption is assumed to commence in the year ending June 2009 at a level of 10% of all pine log harvesting.

The total amount of pine logs expected to be harvested in Australia in future is shown in Table 5.

Table 5: Anticipated Volume of Pine Logs Harvested in Australia in Future

Period	Estimate of Pine Sawlogs Harvested (thousand cu m per annum)
2005-09	10,079
2010-14	10,303
2015-19	10,544
2020-24	10,395
2025-29	10,775
2030-34	12,292
2035-39	12,150
2040-44	11,791
2045-49	11,854

Source: Australia's Plantation Log Supply, BRS, 2007

Assuming 10 million cu metres of pine logs are harvested per annum in future years, with 10% adoption, and each harvester cutting 20 cu m per hour, 12 hours per day, 310 days per year, this would require about 13 harvesters @ 75,000 cu m per annum each. Hence re-programming may cost $2,000 x 13 =$26,000 per annum. Operator training may cost $2,000 x 2 x 13 = $52,000 per annum. Total additional costs each year would therefore be $78,000 per annum at 10% adoption. Benefits at 10% adoption would be about $200,000 per annum

Summary of Assumptions

A summary of the assumptions made in the analysis is provided in Table 6.

Table 6: Summary of Assumptions

Item	Assumption	Source
Assumptions with the project		
Probability of technical success	80%	Agtrans Research
Capacity of a harvesting machine	75,000 cu m per annum	Agtrans Research
Added reprogramming costs	$2,000 per harvester per annum	Agtrans Research
Added operator training	$2,000 per operator per annum	Agtrans Research
Number of operators per harvester machine	2	Agtrans Research
Increased wood recovery due to harvester head control	2% per annum	Mark Brown

Value of 2% wood recovery at full adoption	$2 m per annum	Mark Brown
Year adoption commences	2008/09	Mark Brown
Initial adoption level	10% of pine log harvesting	Mark Brown
Maximum adoption level	100% of pine log harvesting	Mark Brown
Number of years to maximum adoption	6	Mark Brown
Counterfactual (that is, without the project)		
Benefits and costs	Potentially the same as those for the 'with project' scenario	Agtrans Research
Effectiveness of counterfactual outcomes	60% of benefits of those in the 'with project' scenario	Agtrans Research after discussions with Mark Brown
Year adoption commences	2012/13, that is, a lag of 4 years	Agtrans Research
Number of years to maximum adoption	6	Mark Brown

Results
The period of analysis was for 30 years after the first year of investment. The results are expressed in 2007/08 dollar terms and all benefits and costs are discounted to 2007/08. The results for the cost-benefit analysis are reported in Table 7.

Table 7: Results of Cost-Benefit Analysis for Investment in Harvester Head Control (2007/08 $ terms)

Investment criteria	5% Discount Rate	10% Discount Rate
Present Value of Benefits ($m)	6.49	4.14
Present Value of Costs ($m)	0.34	0.34
Net Present Value ($m)	6.15	3.80
Benefit–Cost Ratio	19.0	12.0
Internal Rate of Return (%)	71	

Sensitivity Analysis
Sensitivity analyses were carried out on a range of variables and results are reported in Tables 8 to 10. All sensitivity analyses were performed using a 5% discount rate with benefits taken over a thirty year period from the start of the investment. All other parameters were held at their base values.

Table 8 reports the sensitivity of the investment criteria to the assumption on the probability of technical success.

Table 8: Sensitivity of Investment Criteria to Probability of Success
(Discount Rate of 5%)

	Probability of Technical Success		
Investment Criteria	**60%**	**80% (Base)**	**100%**
PV of Benefits ($m)	4.87	6.49	8.11
PV of Costs ($m)	0.34	0.34	0.34
Net Present Value ($m)	4.53	6.15	7.77
Benefit Cost Ratio	14.3	19.0	23.8
Internal Rate of Return (%)	60	71	80

The investment breaks even at a 5% discount rate even when the probability of success falls to 4%.

Table 9 shows the sensitivity of the investment criteria to the effectiveness of the use of harvester head control equipment in the 'without CRC research' situation. While the benefit-cost ratio and the net present value declines significantly as the effectiveness of the counterfactual situation increases, the internal rate of return is largely unchanged due to the relatively small level of costs and the nature of the benefit flows. Even when the effectiveness reached without the CRC investment is assumed to be equal to that from the CRC project (100%), the CRC investment still achieves positive returns due to the benefits accruing four years earlier.

Table 9: Sensitivity of Investment Criteria to Effectiveness of Use of Harvester Head Control Equipment Without the CRC Project
(Discount Rate of 5%)

Investment Criteria	**100%**	**60% (Base)**	**20%**
PV of Benefits ($m)	2.99	6.49	9.99
PV of Costs ($m)	0.34	0.34	0.34
Net Present Value ($m)	2.65	6.15	9.65
Benefit Cost Ratio	8.8	19.0	29.3
Internal Rate of Return (%)	69	71	73

Table 10 shows the sensitivity of the investment criteria to the assumption regarding the improved recovery of wood. The investment breaks even at a 5% discount rate when the wastage avoided falls to 0.9%.

Table 10: Sensitivity of Investment Criteria to Wood Wastage Avoided
(Discount Rate of 5%)

Investment Criteria	1%	2% (Base)	3%
PV of Benefits ($m)	1.08	6.49	11.90
PV of Costs ($m)	0.34	0.34	0.34
Net Present Value ($m)	0.74	6.15	11.56
Benefit Cost Ratio	3.2	19.0	34.9
Internal Rate of Return (%)	20	71	98

Conclusion

Given the assumptions made, the evaluation shows that the investment by the CRC in the project on optimised log merchandising with mechanical harvesters is likely to produce a healthy economic return. The analysis has allowed for some improvement from harvester head control without the CRC project. The key benefits assumed with the CRC project are the earlier realisation of benefits from a coordinated and focused approach involving industry as well as a more effective result than otherwise.

Acknowledgments
Mark Brown, University of Melbourne
Jim O'Hehir, Forestry SA

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APPENDIX 5: EVALUATION OF ELECTRIC/DIESEL HYBRID TECHNOLOGY ON A CONVERTED 6X6 TRUCK

Project Reference Information

Title	Dates and Investigator(s)
Evaluation of electric/diesel hybrid technology on a converted 6X6 truck	Start date: 1 May 2008
	Completion Date: 30 July 2010
	Principal Investigator(s): Mark Brown, University of Melbourne (in conjunction with Cliff Hall of Innovative Transport Solutions and Mark Diedrichs and Chris Hibbs of Timbercorp Limited)

Background

The program to which this initiative belongs is focused on field research to lower the cost and improve the efficiency, effectiveness, and safety of forest harvesting and transportation operations. A second focus of the program is to build capacity in forest harvesting and transport operations. The program is carried out in close association with the industry CRC partners involved in both native forest and plantation forest operations.

Transportation of material from forests to processing facilities and markets is a high cost and energy intensive operation. Reduction in liquid fuel consumption in such operations is important for both cost and greenhouse gas reductions.

An emerging technology that appears to offer great opportunity to reduce costs and emissions for heavy vehicles working in a start-stop application is diesel/electric hybrid drives. Several truck makers are producing diesel hybrid models but the market is still quite small overall.

One of the initial challenges of introducing hybrid technology is the need to purchase new equipment with the dedicated, high cost hybrid technology included. The cost of this equipment replacement is often hard to justify when the economic benefits of the hybrid technology are not well defined for a particular application, when existing equipment is not due for replacement and the reliability of such new equipment remains an unknown.

Cliff Hall, a technology developer from New South Wales has developed a unique hybrid solution that offers most of the benefits of other hybrid solutions but can be implemented at a much lower cost by converting existing diesel vehicles. Before this project commenced, this solution was an idea on paper ready for prototype testing.

There are three applications in the forest industry that have potential for use of the new hybrid technology. These include normal haul trucks, forwarders/skidders and shunt vehicles. Given the highest return from hybrid technology is expected from stop-start applications, the normal haul trucks are expected to have the smallest gain so for an initial examination of the technology they were not seen as ideal. The application in forwarders/skidders will involve more complicated installation and the operations are far more variable than trucks, therefore it was also less then ideal for an initial trial.

Shunt trucks represent a true stop-start application that could stand to gain significant fuel efficiency from hybrid technology. In addition the conversion is relatively simple to engineer and, if the technology is seen to work well in the application at an acceptable cost, it can also address an issue for the forest industry in that the commonly used 6X6 trucks are hard to find. As such the evaluation test will be carried out with a truck that is converted from a 4X6 normal haul truck to a 6X6 shunt truck using hybrid technology. This study is intended to be both a test of the 6X6 application as well as a test of concept for the hybrid conversion technology and if the results are positive could flow on to other applications in forestry.

The innovation pioneered by Cliff Hall of Innovative Transport Solutions is focused on the retrofit of a bolt-on device to an existing diesel truck motor that transforms the truck into being driven by hybrid power. The project funded by CRC Forestry and Timbercorp is testing and implementing the hybrid truck for forest operations and is expected to lower both the operating cost and carbon footprint of assembling and transporting wood material within forests.

The specific application is as follows. Some forest operations are processing wood material into wood chips within plantation forests. The chips are placed in wagons which are moved to roadsides by 6X6 diesel vehicles; the loaded wagons are then detached and the vehicle returns with an empty wagon to the site of the chipping for refilling with the process then being repeated. The loaded wagons at the roadside are connected to road trucks for long distance hauls. The shunt trucks are dedicated trucks and are subject to harsh conditions continually towing empty and loaded trailers through the forest.

The electric motor is attached to the front axle and powers the vehicle at time of added load; at other times the power source for the electric motor is recharged. This increases the efficiency and prolongs the life of the conventional motor.

Project Objectives

The specific objectives of the project are:

- Determine if the hybrid conversion concept is practical and functional.
- Test the functional capabilities of the converted hybrid 6X6 shunt truck against currently acceptable 6X6 diesel trucks to confirm it can perform the task.
- Determine the fuel efficiency gains and emission reduction potential of the technology in a 6X6 shunt truck application.

- Evaluate the short to medium term reliability and costs of the hybrid conversion technology.

Project Costs

A summary of the resources invested by the CRC and others in the evaluation of the hybrid shunt truck is shown in Table 1.

Table 1: CRC Investment in Hybrid Shunt Truck Development (nominal $)

Year Ended June	Total CRC funds (cash and in-kind)	Innovative Transport Solutions	Timbercorp	Total
2008	83,333	75,000	10,000	168,333
2009	58,333	3,500	8,000	69,833
2010	37,000	3,500	4,850	45,350
Total	178,666	82,000	22,850	283,516

Source: Forestry CRC

Project Description

The evaluation of the hybrid conversion technology will be carried out in four distinct phases over a 27 month period. Phase one will determine the costs of the hybrid vehicle and its setup as the basis for economic comparisons. Phase two will include some specific functional tests on turning and pulling capabilities to ensure the hybrid truck is able to complete the required operational tasks. Phase three will be a detailed evaluation of operating cost, performance and reliability in the short to medium term to complete the economic evaluation as well as the assessment of environmental impacts. Phase four will be a medium to long term evaluation of operating costs and reliability to better understand maintenance costs.

Phase one

During the conversion to a hybrid vehicle, the cost of the original vehicle and all components fitted and their costs will be recorded, including best estimates of future costs based on experience in the initial conversion (likely improvements and increased volumes). Also estimated will be the investment of time and money by the operating company for the final preparations of the converted truck in preparation for use in operations.

All these initial and preparation costs will be compared against the costs of the last three to six 6X6 trucks acquired based on information from Timbercorp and will include all preparation costs. The comparison will look at both simple purchase setup costs and annual distribution of these costs based on projected lives for the two different trucks.

Phase two
The phase two functional tests for the hybrid truck versus the normal 6X6 diesel truck will include the turning radius under different conditions (e.g. slope and surface type, with and without trailers etc). Pulling strength of the two trucks will also be evaluated with trailers of different loads and via the time taken to tow loaded trailers over a set distance.

Phase three
Phase three will include the automatic collection of data with multidat, operator input on work functions and stop codes on the multidat and the completion of daily manual forms to record maintenance and fuel use. Each truck will be equipped with a multidat computer with GPS that will record such information as travel distance and speed, idle time, electric motor in use, charge being sent to battery, transmission in drive etc.

Other information will be recorded by the user such as work function (under chipper, pull empty, pull loaded, other, etc.), reason for any delays, and operator identification. Each truck also will have manual forms to be completed daily and returned to CRC Forestry weekly. Information will include fuel up data, maintenance data, and operator comments, requests, concerns, and ideas.

Phase four
This phase of the project will continue to collect data similar to that in phase three for an 18 month period after the detailed operational tracking.

Outputs

A summary of the principal outputs (both outputs achieved to date as well as those planned) from the project is reported in Table 2.

Table 2: Summary of Principal Outputs

Principal Outputs to Date
• Shunt truck has been purchased and modified
• All hybrid components have now been installed except the battery
Expected Outputs (Not Yet Achieved)
• Confirmation from performance testing that the hybrid vehicle will be able to carry out the shunting functions effectively
• Fuel, emissions, time efficiency, and maintenance cost comparisons with existing shunt trucks
• Results of performance testing in a commercial operation and comparisons made with the existing shunt trucks operated by Timbercorp
• Assessment of potential of use of hybrid technology for skidders and forwarders if positive fuel benefits are demonstrated for the shunt trucks

Outcomes

A summary of the principal outcomes anticipated from the project is reported in Table 3.

Table 3: Summary of Principal Outcomes

Principal Outcomes
Principal Outcomes to Date
• No outcomes to date as project has only just commenced
Expected Outcomes (Not Yet Achieved)
• Shunt trucks operated by Timbercorp at hardwood plantations at Albany WA and in the Green Triangle
• Shunt trucks operated by Timbercorp at lower cost than alternatives and with lower greenhouse gas emissions
• Shunt trucks operated by other companies with lower fuel and maintenance costs and greenhouse gas emissions
• Extension of range of suitable trucks for conversion
• Greater likelihood of use of hybrid technology by forwarders and skidders

If the technology proves technically and economically viable, its use will most likely be restricted to Timbercorp in the first instance. Other operators do chip in the forest (ITC (with blue gum plantations) and Forestry SA (pine residue)) are two examples, though neither currently use shunt trucks. If the technology proves successful for Timbercorp in this proof of concept project, its application in forwarders and skidders (used in every operation) and normal 6X4 haul trucks will be explored.

Benefits

Economic
The principal potential benefit from the project will be reduced cost of transport to roadside of wood chips produced in the field. The expected reduced costs will be contributed by reduced fuel costs, possibly reduced maintenance costs, and possibly reduced capital investment. These benefits will accrue to Timbercorp in the first instance and, in the longer term, any other company growing hardwoods or softwood for pulp where wood chips are produced in the field and where shunt trucks are used.

Environmental
There would be environmental benefits from this investment with regard to reduced energy consumption with associated lower levels of greenhouse gases (carbon dioxide) emitted from trucks due to the diesel savings with the hybrid power system.

Social
There would be no direct social impacts of the investment.

Adoption
It is assumed that, given satisfactory results from the project, that adoption of the technology will be the Timbercorp operation in the Green Triangle and at Albany in Western Australia.

Summary of Benefits
A summary of the benefits emanating from the investment is provided in Table 4.

Table 4: Summary of Principal Benefits

Economic	Environmental	Social
Reduced cost of in-forest transport of wood chips for pulp hardwood plantations where chipping takes place in the field	Contribution to Australian Government targets for lowering greenhouse gas emissions	Nil

Quantitative Analysis of Costs and Benefits

Scenario Without the Research Investment
Without the research investment it is assumed that diesel shunt trucks would have prevailed in the future. Shunt trucks would continue to use 45,000 litres of diesel per truck per annum.

Also, as 6X6 trucks were purchased by Timbercorp second hand, and these trucks were becoming scarce to purchase (due to demand from the mining sector), then the price of second hand 6X6 trucks may have increased over the next five years. Such a price increase is not considered in the following valuation of benefits.

It is understood that Timbercorp currently have about 15 shunt trucks working in their Western Australian operations. However, the company is likely to require a further 30 or more shunt trucks for their harvest operations commencing soon in the Green Triangle region. It may be expected that each shunt truck would last for 10 years before being replaced.

Timbercorp is harvesting approximately 0.5 million tonnes of wood chips per annum in Western Australia and the harvest in the Green Triangle will be about 1.5 million tonnes per year within three years.

Scenarios with the Research Investment

Fuel savings
Fuel savings due to the hybrid vehicle could be 10-15% per annum. At a 12.5% saving, then 5,625 litres per annum could be saved which could be valued at $7,000 per truck per annum if diesel is valued at $1.32 per litre net of fuel tax credits. It is likely also that the price of diesel will rise in the future due to the Australian Government's policy response to global warming by reducing greenhouse gas emissions via a carbon emissions trading scheme.

Maintenance savings
It is expected that the life of the transitional drive line will be significantly extended, and maintenance costs could fall. Any savings in diesel motor or drive maintenance costs are assumed to be offset against the increased cost of maintaining the electric motor and the third drive. The motor itself is maintenance free but wiring, battery and control systems will probably require attention (Mark Brown, pers. comm., Sep 2008). Hence, there could be a marginal fall in maintenance costs. Any maintenance cost saving is not valued in this analysis.

Capital savings
There may be a saving in purchase costs of second hand trucks with the potential to purchase 4X6 trucks rather then 6X6 trucks. In this case, the only additional costs of the hybrid trucks would be the conversion from the 4X6 compared to the 6X6 and the addition of the electric motor and battery.

On the road costs for either conversion are expected to be within 10% of each other based on the prototype costing. The 4X6 purchase price would be expected to be 20% to 30% lower than the 6X6. However, in that case demand could drop for the 6X6 and as a result its value. With some volume of production by Innovative Transport Solutions, the hybrid should be able to be priced at around $85,000. Timbercorp currently purchases second-hand 6X6 trucks for $85,000 as a minimum (Mark Diedrichs, pers. comm., Sep 2008).

As there is still some uncertainty about the overall capital savings, this potential cost reduction is not valued in the following analysis. The assumption is that the total hybrid truck on the road costs (purchase of a 4X6 truck plus conversion costs) will be equivalent to the purchase of a second hand 6X6 truck.

Environmental benefits
The emissions savings are based on direct fuel savings in the operation (each litre of diesel saved reduces CO_2 emissions by 2.7 kilograms). Life cycle aspects have not been accounted for in this analysis but the only change in the lifecycle aspect is the electric motor and battery. At 2.7 kg CO_2 saved per litre, this is equivalent to 15 tonnes of carbon dioxide equivalent saved per truck each year. At a carbon price of around $20 per tonne, this would be equivalent to about $300 per truck per annum. This saving is considered a benefit to the environment (Australia) and not captured by Timbercorp.

Adoption
The number of shunt trucks that could be operating for Timbercorp in 2 years time may be of the order of 25 as Timbercorp increases harvesting operations due to more of their plantations being harvested. Benefits therefore could be delivered quite rapidly.

In the longer term the whole fleet of shunt trucks (about 50-60) could be hybrids. It is unlikely that Timbercorp will replace their existing diesel vehicles immediately when the hybrid truck is available. It is assumed that their replacement with hybrids will span a period of ten years.

Adoption will depend primarily on the magnitude of the cost savings from implementing a reliable and effective hybrid technology.

Risks
The primary risk lies with the technology development. There is a chance that the technology will not perform as predicted. Allowance has been made for this in the current analysis through applying a probability of a favourable technical and economic outcome of 70%. Another risk is that new low cost hybrid trucks are developed by existing companies due to economies of size in manufacture that are suitable for shunt operations and are more fuel efficient than the retrofitted hybrid. However, this risk is considered low due to the high cost of new vehicles and has not been accounted for in the quantitative analysis.

Summary of Assumptions
A summary of the assumptions made in the analysis is provided in Table 5.

Table 5: Summary of Assumptions

Item	Assumption	Source
Probability of success		
Probability of a technically and economically viable innovation	70%	Agtrans Research
Additional costs of the hybrid truck		
Cost of retrofitting additional hybrid technology approximately equivalent to saved purchasing costs from the 4X6 truck	Additional capital costs or savings assumed to be zero	Agtrans Research after discussions with Mark Brown
Financial benefits from fuel saving		
Fuel saved assumed to be 12.5% of annual diesel usage (12.5% of 45,000 litres per annum)	5,625 litres per annum per truck	Agtrans Research after discussions with Mark Brown
Value of diesel to	$1.70 per litre less $0.38	Agtrans Research after

commercial forestry	per litre fuel tax credit	discussions with Mark Diedrichs
Environmental benefits		
Diesel emissions	2.7 kg carbon dioxide per litre of diesel	Australian Greenhouse Office (now Department of Climate Change)
Carbon dioxide emissions saved	5,625 litres of diesel saved per truck, equivalent to about 15 tonnes carbon dioxide per hybrid truck per annum	From above
Illustrative price of carbon	$20 per tonne of carbon dioxide	Australian Government (2008)
Adoption		
Number of hybrid vehicles operating by 2009/10	5	Agtrans research after discussions with Mark Diedrichs
Number of hybrid vehicles operating by 2010/11	40	
Number of hybrid vehicles operating by 2020/21	55	

Results
The period of analysis was for 30 years after the first year of investment. The results are expressed in 2007/08 dollar terms and all benefits and costs are discounted to 2007/08. The results for the cost-benefit analysis are reported in Table 6.

Table 6: Results of Cost-Benefit Analysis for Investment in Hybrid Shunt Truck (2007/08 $ terms)

Investment criteria	5% Discount Rate	10% Discount Rate
Present Value of Benefits ($m)	3.78	2.13
Present Value of Costs ($m)	0.28	0.27
Net Present Value ($m)	3.50	1.86
Benefit–Cost Ratio	13.7	7.9
Internal Rate of Return (%)	49	

The proportion of the present value of benefits derived from the fuel saving is 96% with only 4% emanating from the reduction in greenhouse gas emissions.

Sensitivity Analysis
Sensitivity analyses were carried out on a range of variables and results are reported in Tables 7 to 9. All sensitivity analyses were performed using a 5% discount rate with benefits taken over a thirty year period from the start of the investment. All other parameters were held at their base values.

Table 7 shows the sensitivity of the investment criteria to a change in the assumption regarding probability of success.

Table 7: Sensitivity of Investment Criteria to Probability of Success
(Discount Rate of 5%)

	Probability of Technical and Economic Success		
Investment Criteria	**40%**	**70% (Base)**	**40%**
PV of Benefits ($m)	2.16	3.78	5.40
PV of Costs ($m)	0.28	0.28	0.28
Net Present Value ($m)	1.88	3.50	5.12
Benefit Cost Ratio	7.8	13.7	19.6
Internal Rate of Return (%)	34	49	61

The probability of success for the investment to break even at a 5% discount rate is 5%.

Table 8 shows the sensitivity of the investment criteria to a change in the assumption regarding fuel savings.

Table 8: Sensitivity of Investment Criteria to Fuel Savings
(Discount Rate of 5%)

	Fuel Savings		
Investment Criteria	**7.5%**	**12.5% (Base)**	**25%**
PV of Benefits ($m)	2.27	3.78	7.56
PV of Costs ($m)	0.28	0.28	0.28
Net Present Value ($m)	1.99	3.50	7.28
Benefit Cost Ratio	8.2	13.7	27.4
Internal Rate of Return (%)	35	49	75

The fuel savings from the hybrid trucks that would be necessary for the investment to break even at a 5% discount rate is under 1% per truck per annum.

Table 9 shows the sensitivity of the investment criteria to a change in the capital cost per truck due to the introduction of the hybrid technology.

Table 9: Sensitivity of Investment Criteria to Additional Capital Costs
(Discount Rate of 5%)

	Additional Capital Cost per Hybrid Truck ($)		
Investment Criteria	**-30,000**	**0 (Base)**	**+30,000**
PV of Benefits ($m)	5.70	3.78	1.86
PV of Costs ($m)	0.28	0.28	0.28
Net Present Value ($m)	5.43	3.50	1.58
Benefit Cost Ratio	20.7	13.7	6.7
Internal Rate of Return (%)	92	49	19

The additional capital cost per shunt truck that could be borne by the investment to break even at 5% would be just under $55,000 per truck.

Conclusion

Given the assumptions made, the evaluation shows that the investment by the CRC and others is likely to provide a significant return. The investment is relatively small and the risk is spread between the private sector and the CRC. Of course the eventual rate of return will depend on the technical and economic information that emanates from the research.

The assumptions made in this analysis are conservative. As such they may underestimate the actual benefits that may come from the investment. For example, it is possible that there may be some initial capital cost savings associated with the hybrid shunt truck. Sensitivity analysis has demonstrated that the results are relatively robust to variations in many of the assumptions made.

Other benefits may exist in future if companies other than Timbercorp adopt the technology or if the technology is later expanded to be applicable to skidders and forwarders which are commonly used in most forestry operations.

Acknowledgments

Mark Brown, University of Melbourne
Mark Diedrichs, Timbercorp Limited

References

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APPENDIX 6: IDENTIFICATION AND ADAPTATION OF LEADING TECHNOLOGY FOR TRACKING AND MANAGEMENT OF AUSTRALIAN FOREST OPERATIONS

Reference Information

Code and Title	Dates and Investigator(s)
Identification and Adaptation of Leading Technology for Tracking and Management of Australian Forest Operations	Start date: 1 December 2008
	Completion Date: 30 June 2012
	Principal Investigator(s): Mark Brown, University of Melbourne

Background

The program to which this initiative belongs is focused on field research to lower the cost and improve the efficiency, effectiveness, and safety of forest harvesting and transportation operations. A second focus of the program is to build capacity in forest harvesting and transport operations. The program is carried out in close association with the industry CRC partners involved in both native forest and plantation forest operations.

Most forest harvesting systems in Australia now rely on sophisticated harvesting machines requiring a large capital investment. However, some studies, albeit limited in number, have suggested machine utilisation rates are between 79% and 85% and that unrecorded observations have been made as low as 60%.

One area of fruitful endeavour in forest industries of other countries has been on-board tracking of machine movements. This has led to higher machine utilisation and associated productivity gains. Such tracking technology can result also in lowered operating costs such as fuel and maintenance cost and enhanced safety and environmental management systems.

This potential area of improvement is being addressed by this project in an Australian context through exploring machine tracking equipment, conducting industry trials, the adaptation of data management and reporting software, and the development of a machine tracking and management system selection and implementation guide as well as data analysis software.

The project focuses on on-board computer recording of performance of mobile equipment used in harvesting in order to increase machine utilisation and so lower costs of harvesting for a proportion of Australian harvesters operating in softwood plantations, hardwood native forests and hardwood plantations. The project is to consider machines operating up to ‘on truck‘ and may even include truck movement.

The project will commence in December 2008, provided fuding is made available. Some small amount of R&D in this area has already been carried out by the CRC but it has been peripheral to this prospective project.

Project Objectives

The objectives stated for the project are:

- Explore the existing state of the art equipment and implementation methods for forest equipment tracking and management;
- Identify those best suited to the Australian context through consultation with Australian forest industry stakeholders;
- Conduct trial implementations with at least two collaborating industry partners;
- Adapt data management and reporting software, combine appropriate data collection tools to address unique data needs and define an Australian specific implementation strategy based on industry stakeholder feedback and trial results; and
- Develop and deliver to industry a machine tracking and management system selection guide, an implementation guide and basic supplemental data analysis spreadsheets/software for unique Australian needs.

Project Costs

A summary of the financial resources invested by the CRC and partners in the project is shown in Table 1.

Table 1: CRC Investment in On-Board Machine Tracking Systems (nominal $)

Year Ended June	Total CRC Funds (a) ($)	Forest and Wood Products Australia (b)	Industry Collaborators (a)	Total
2009	26,467	60,000	36,000	122,467
2010	61,441	0	72,000	133,441
2011	48,491	180,000	69,000	297,491
2012	52,651	110,000	67,500	230,151
Total	189,050	350,000	244,500	783,550

Source: Forestry CRC Proposal to Forest and Wood Products Australia
(a) Cash and in-kind
(b) Cash

Project Description

The project will be carried out in close cooperation with selected industry co-operators including Forestry SA, Timbercorp Limited and Vic Forests. First, the co-operators' needs and expectations will be identified and these needs assessed against the existing technology available for mobile equipment tracking and management. The availability of different systems will be explored internationally. Secondly, the best fit technologies with industry needs will be identified and these systems then purchased with industry co-operators.

Three field trials will follow with co-operators, with an attempt made to include a representative mix of machines and operation types. Tracking equipment will be installed and the machines tracked regularly with modifications made to the tracking equipment as appropriate. This stage will be particularly valuable to identify constraints and improvement to the tracking system and the type and quantitiy of information being collected.

Formal tracking is to commence six months after the initial trials and this second stage of tracking will be occur during normal management of commercial operations. Data analysis and reporting tools will then be developed.

The selection guide will be developed to cater for the different needs and operations of different industry sectors. This will assist forest harvesters in their selection of the various on-board systems available and the guide will be available in hard copy form as well as through a web based database search tool.

An implementation guide will then be developed in consultation with industry. This guide will be in hard copy as well as quick reference cards and job aids designed for use in the field.

In addition, information will be provided to industry via a one day workshop to be held across four regions.

The on-board computerised performance monitoring is activated with the ignition of the harvester. Performance data that can be assembled includes distance travelled, weight lifted, average speed, mechanical disruption, day shift versus night shift productivity comparisons, hours worked, time standing still, fuel consumption etc. A number of work codes exist that can be used to monitor activity regarding harvesting, transporting, loading etc. A GPS unit may be added later to assess tracks being followed, optimal routes etc.

One of the key challenges is to process the data and produce reports that can be used in a practical manner. The project is meant to equip the forest industry to tackle the use of this technology effectively in house so the intention is to keep data analysis tools simple and low cost. However, there is also the possibility of building further on the trial experience and link with international collaboration. This could result in the development of a service system that industry could subscribe to and have the data management effected by the service, with possibly a higher detail of reporting and combined with other compnaies' data in continual benchmarking reports. In this regard Australia may join with New Zealand, South African and Canadian interests to develop software for a range of computers that can extract and organise implications of forest machine data into a report format.

With either the service or the in-house approach the companies will still need the results of this work to support technology selection and to select the service level they need.

Outputs

A summary of the principal outputs (both outputs achieved to date as well as those planned) from the project is reported in Table 2.

Table 2: Summary of Principal Outputs by Project

Planned Outputs Not yet Achieved
• A machine tracking and management system selection guide including an interactive web tool
• An implementation guide for on-board recording
• Data analysis software
• Four regional one-day workshops

Outcomes

A summary of the principal outcomes anticipated from the project is reported in Table 3.

Table 3: Summary of Principal Outcomes by Project

Planned Outcomes Not Yet Achieved
• Increase in utilisation and/or productivity of forestry equipment up to 20%
• Increase in machine availability of at least 5%
• Increased fuel efficiency
• Increased operator safety and operator satisfaction
• Adoption of on–board recording and reporting of forest machinery by 20% of the industry in the first year of the availability of the technology and management know-how

Benefits

The principal benefit from this investment will be the increased utilisation of all harvest machinery. This will result in lowered cost of harvesting and assembly per unit of wood before it is transported from the forest. As forest harvest costs make up a significant proportion of total forestry costs, a small increase in harvesting productivity could be very large in terms of cost reduction.

Primary beneficiaries from the investment are likely to be the forest owners as well as harvest operators. The likely benefits are identified in a triple bottom line framework as follows:

Economic
Benefits would be an improved level of utilisation and availabilty of harvesting equipment with associated higher productivity and lower costs per tonne of wood harvested.

Productivity gain per machine may be instigated in some instances by the mere fact that the operator is aware that performance of the machine (and then to a large extent the operators own performance) is being recorded by the computer.

In other instances the machine recording may be able to identify declining productivity with increasing hours worked, inefficient route selection, higher than average idle time or fuel consumption for the same operation, machines with specific maintenance issues etc. Appropriate management responses can be applied to operators or machines with such information.

Also, data analysis may lead to rejigging the balance of capacity and improved scheduling and machine functions. Delays in operations may be decreased through bottlenecks being identified

Environmental
There could be some environmental benefits from this investment from reduced carbon dioxide emissions if fuel use is reduced in some machine operations or the overall activity of all machines is reduced through improved work flow.

Social
There could be potentially increased satisfaction for operators knowing that performance is being optimised or safety issues are being addressed. Also, there may be savings in human and social costs if accident frequencies are lowered.

It is likely that a portion of the benefits from improved utilisation would be passed along the value chain in the form of a lower cost to consumers.

Summary of Benefits
A summary of the principal benefits emanating from the project is provided in Table 4.

Table 4: Summary of Principal Benefits

Economic	Environmental	Social
• Lowered costs of harvesting in both softwood and hardwood plantations • Lowered costs of harvesting in some native forest logging	• Reduced carbon dioxide emissions due to fuel cost savings	• Increased satisfaction of harvest operators • Potential for reduced accidents in harvest operations

Quantitative Analysis of Costs and Benefits

Scenario Without the Research Investment

Increased Harvesting Productivity

Without the CRC research investment in this area, there may have been some harvest productivity improvements achieved from informal observations of machine and operator performance. For example, machine maintenance records would have identified machines with above average problems and costs. For the purposes of this analysis however, it is assumed that the average cost of harvesting without this project will remain much the same in the future as it is today.

Cost of harvesting

The cost of mechanical harvesting (all activities) is assumed to be $25 per tonne of wood ready for transport from the forest. This cost will vary with the technology employed, thinning or clear felling, the tree type and density, terrain etc.

Annual harvest estimate for the future

Table 5 provides estimates of the quantities of wood harvested from plantations in the future. These estimates are based on the existing plantings and with these plantations being renewed on the same land as they are harvested. It is assumed that 100% of the plantation wood would be subjected to mechanical harvesting.

Table 6 shows the harvest from native broadleaved forests over the past seven years. For the purposes of this analysis, it is assumed that the harvest from native forests in the future will be equivalent to that for 2006-07, although it is recognised that future harvests could decline. Also, not all native forest wood would be mechanically harvested. To allow for these uncertainties, it is assumed that only 4 million ha of native forest wood is subject to mechanical harvesting in the future.

Taking an average for plantation wood of 25 million cu metres per year and for native forest wood of 4 milllion cu m per year, the total wood harvested mechanically is estimated at approximately 29 million cu metres per annum. For purpose of this analysis it is assumed that one cu metre of wood is equivalent to one tonne.

Table 5: Estimates of Plantation Wood Harvested in Future (thousand cu metres per annum)

Period of Years	**Softwood**		**Hardwood**		**Total**
	Pulp	Sawlogs	Pulp	Sawlogs	
2005-09	5,444	10,079	4,596	224	20,343
2010-14	5,308	10,303	13,759	358	29,728
2015-19	5,376	10,544	12,823	582	29,325
2020-24	4,896	10,395	14,599	1,100	30,990
2025-29	4,723	10,775	14,402	1,238	31,138
2030-34	4,868	12,292	12,313	1,766	31,239
2035-39	4,933	12,150	15,658	1,819	34,560
2040-44	5,042	11,791	13,928	1,625	32,386
2045-49	5,341	11,854	15,260	1,397	33,852

Source: BRS (2007)

Table 6: Logs Harvested from Broadleaved Native Forests (thousand cubic metres)

Year	**Harvest Quantity**
2000-01	10,802
2001-02	9,831
2002-03	10,316
2003-04	10,092
2004-05	9,868
2005-06	8,577
2006-07	8,503

Source: ABARE (2007)

Scenarios With the Research Investment

Probability of success

This analysis assumes the project receives the funding it has applied for from FWPA. However, as the project has not commenced there is still uncertainty about the success of the project. The probability of success once funded is assumed to be 70%.

Increased Harvesting Productivity

The target for this project is to increase productivity by 10% for those machines that adopt machine tracking. Assuming this target is optimistic, for the purposes of this analysis, the productivity gain for that part of the industry that adopts the technology is assumed to be 5%. There is some evidence to suggest that a 1% increase in productivity of harvest machines can reduce the cost of harvesting and movement of logs onto trucks by 1% (Mark Brown, pers.comm., Sep 2008). Hence a 5% productivity gain is asssumed equivalent to a 5% cost reduction.

Cost of adoption of the technology

Apart from the project costs, it is assumed that there will be additional costs incurred by industry in implementing the recording and reporting systems. Assumptions are made with regard to each of the following: capital cost of purchase and installation, maintenance of logging equipment (ongoing), cost of training operators (ongoing), operator time in inputting some data (ongoing), and staff time involved in analyses and reporting (ongoing).

Purchase and installation costs

The cost of purchase of a computerised tracking system will vary with the type of system that is purchased and this will vary between forest harvest contractors. While systems will vary from $1,000 to as much as $10,000 plus about the same again for installation costs (Mark Brown, pers. comm., Sep 2008), the average cost for purchase and installation is assumed to be $11,000 per machine. This is probably an overestimate as prices are likley to come down over time and most adoptees are likely to choose the lower cost options.

Potential number of machines employed

The number of machines in a harvest group (machines that work together in a specific harvesting operation) varies from company to company and between operation types as well. For example, Timbercorp has 5 harvesters, 2 forwarders, 2 chippers and 2 shunt trucks per team, while ITC has a feller buncher, skidder and flail/chipper in each team (both for Eucalyptus plantations). In native forests, SEFE has 3 processors, one fellerbuncher and one forwarder in a team and Forestry Tas has 2 escavators, a feller buncher, a processor and a skidder (both in native forests). Each group has a different annual output (Mark Brown, pers.comm., Sep 2008).

For purposes of this analyis, it is assumed there are three machines (harvester, skidder or forwarder, loader) in each harvest group and each group harvests 120,000 cu metres per annum. If the potential quantity of wood harvested mechanically is 29,000,000 cu m per annum, then the number of machine groups required would be about 242. The potential number of machines employed therefore would be 3 x 242 = 726.

Maintenance of on-board logging equipment

It is assumed that this cost would be $500 per machine per annum.

Cost of training operators

It is assumed that this cost would be $1,000 per operator per annum. In all likelihood, there may be a higher cost for training in the first year but this may contract as operators became more familiar with procedures. It is assumed there would be 1.25 operators for each machine.

Operator time in inputting data

It is assumed that this would be 5 minutes per day for 200 days per annum for each machine, equivalent to 17 hours per annum. If an operator's hourly rate is $40 per hour the input cost per machine would be $667 per machine per annum.

Staff time in analysis and reporting
It is assumed that the analysis and reporting time would be carried out weekly through proprietary software and/or a tailor made spreadsheet program developed in the project. The assumption is that this this would take 1 hour per week for each manager regardless of the number of machines and would increase by 10 minutes per machine after the first 4 or 5 machines (Mark Brown, pers., comm., Sep 2008). This estimate is simplified to 10 minutes per machine per week. Time is costed at an hourly rate of $50 per hour.

Adoption by industry
The extent of adoption in the future will depend on the success of the trials in producing data and reports that lead to higher machine productivity. If successful and productivity is increased by 5% as assumed in this analysis, the likely adoption should be significant. Over time, it is assumed that a maximum of 20% of mechanical harvesting of forests will employ the technology. The capital cost of implementing the technology is low, and due to the large capital and operating cost of machines, the benefits are potentially high. It is assumed that adoption commences in the year ending June 2013 (the year after the project concludes) and increases linearly to the 20% maximum in 5 years, that is by 2017.

Summary of Assumptions
A summary of the assumptions made in the analysis is provided in Table 7.

Table 7: Summary of Assumptions

Item	Assumption	Source
Probability of success	70%	Agtrans Research
Average cost of harvesting	$25 per cu metre	Various including estimate by Mark Brown
Wood harvest quantity for potential mechanical harvesting	29 million cu metres per annum	Adapted from ABARE (2007) and BRS (2007)
Productivity increase from installing tracking equipment on harvest machines	5%	Mark Brown
Cost reduction as a proportion of productivity increase	100%	Mark Brown
Purchase and installation costs for tracking equipment	$11,000 per machine	Based on a range of costs from Mark Brown
Capacity of one harvester group (3 machines) per annum	120,000 cu metres per annum	Agtrans Research after discussions with Mark Brown
Number of machines required to harvest 29 million cu metres per	726 including harvesters, skidders and loaders	By calculation from above

annum		
Maintenance of on-board tracking equipment	$500 per machine per annum	Mark Brown
Cost of training operators	$1,000 per operator per annum	Agtrans Research based on discussions with Mark Brown
Number of operators for a harvester group	1.25 operators for each of 3 machines	Agtrans Research based on discussions with Mark Brown
Operator time in inputting data	5 minutes per day for 200 days per year @ $40 per hour	Mark Brown
Staff time in analysis and reporting	Ten minutes per machine per week @ $50 per hour	Agtrans Research after discussions with Mark Brown
Maximum adoption rate	20% of machines involved in mechanical harvesting	Mark Brown
Year of first adoption	2012-2013	Agtrans Research
Year of maximum adoption	2016-2017	Agtrans Research

Results
The period of analysis was for 30 years after the first year of investment. The results are expressed in 2007-08 dollar terms and all benefits and costs are discounted to 2007-08. The results for the cost-benefit analysis are reported in Table 8.

Table 8: Results of Cost-Benefit Analysis for Investment in Machine Tracking Systems (2007-08 $ terms)

Investment criteria	5% Discount Rate	10% Discount Rate
Present Value of Benefits ($m)	45.18	23.04
Present Value of Costs ($m)	0.68	0.60
Net Present Value ($m)	44.49	22.44
Benefit–Cost Ratio	66.0	38.3
Internal Rate of Return (%)	86	

Sensitivity Analysis
Sensitivity analyses were carried out on a range of variables and results are reported in Tables 9 to 11. All sensitivity analyses were performed using a 5% discount rate with benefits taken over a thirty year period from the start of the investment. All other parameters were held at their base values.

Table 9 shows the sensitivity of the investment to a change in the assumptions regarding the productivity gain. The productivity gain for the investment to break even at a discount rate of 5% is below 1% (0.44%).

Table 9: Sensitivity of Investment Criteria to Productivity Gain
(Discount Rate of 5%)

Investment Criteria	**1%**	**5% (Base)**	**10%**
PV of Benefits ($m)	6.19	45.18	93.91
PV of Costs ($m)	0.68	0.68	0.68
Net Present Value ($m)	5.51	44.49	93.23
Benefit Cost Ratio	9.0	66.0	137.3
Internal Rate of Return (%)	28	86	119

Table 10 shows the lack of sensitivity of the investment to a change in the assumptions regarding the capital cost of the tracking system. The break even cost for the investment to break even at a discount rate of 5% is very high at $626,000 per machine.

Table 10: Sensitivity of Investment Criteria to Capital and Installation Cost of Loggers per Machine
(Discount Rate of 5%)

Investment Criteria	**$5,000**	**$11,000 (Base)**	**$25,000**
PV of Benefits ($m)	45.61	45.18	44.16
PV of Costs ($m)	0.68	0.68	0.68
Net Present Value ($m)	44.93	44.49	43.48
Benefit Cost Ratio	66.7	66.0	64.6
Internal Rate of Return (%)	89	86	81

Table 11 shows the sensitivity of the investment to a change in the assumptions regarding the industry maximum adoption rate. The break even maximum adoption rate for the investment to break even at a discount rate of 5% is a very low 0.3%

Table 11: Sensitivity of Investment Criteria to Maximum Level of Adoption
(Discount Rate of 5%)

Investment Criteria	**5%**	**20% (Base)**	**40%**
PV of Benefits ($m)	11.29	45.18	90.36
PV of Costs ($m)	0.68	0.68	0.68
Net Present Value ($m)	10.61	44.49	89.67
Benefit Cost Ratio	16.5	66.0	132.1
Internal Rate of Return (%)	45	86	114

Conclusion

Given the assumptions made, the evaluation shows that this investment by the CRC is likely to provide a high net present value and a high rate of return. The key assumptions that drive these high returns are the productivity gain and its translation into a cost redution in harvesting and the relatively low costs of equipment and associated use and maintenance of the tracking system.

As there are fuel savings likely from the reduced costs, there are also benefits likely from reduced carbon dioxide emssions, but these would be only small relative to the productivity gains. In addition there may be safety benefits arising from the data capture. Neither of these two sets of benefits have been valued in the analysis.

The expected net present value of the R&D investment is $44 million, with a benefit cost ratio of 66 to 1.

Acknowledgments

Mark Brown, University of Melbourne

References

ABARE (2007) "Australian Forest and Wood Products Statistics", September and December Quarters 2007, Canberra.

BRS (2007) "Australia's Plantation Log Supply 2005 – 2049 ", Bureau of Rural Sciences, Department of Agriculture Fisheries and Forestry, Canberra.

APPENDIX 7: PROGRAM 4: TREES IN THE LANDSCAPE

Reference Information

Project Code and Title	Dates and Investigator(s)
Project 4.1: Water quality and quantity	Start date: July 2005
	Completion Date: June 2012
	Principal Investigator(s): Pat Lane and Don White
Project 4.2: Biodiversity	Start date: July 2005
	Completion Date: June 2012
	Principal Investigator(s): Brad Potts
Project 4.3: Communities	Start date: July 2005
	Completion Date: June 2012
	Principal Investigator(s): Jacki Schirmer
Project 4.4: Industry Pest Management Group	Start date: July 2005
	Completion Date: June 2012 (dependent on annual renewal of project)
	Principal Investigator(s): Mamoru Matsuki and Treena Burgess
Project 4.5: Socio-economic impacts of land use change in the Green Triangle and Central Victoria	Start date: July 2006
	Completion Date: June 2009
	Principal Investigator(s): Jacki Schirmer

Background

The fourth program of the CRC for Forestry is titled 'Trees in the Landscape' and focuses on developing forestry practices that meet agreed environmental certification requirements and foster constructive community engagement.

It is contended by the CRC that such practices will provide security for the forest industry's long-term 'licence-to-operate' in the Australian landscape, and build international recognition of sustainable forest practices for product marketing.

Internationally there has been pressure to improve forest practices, and the concept of forest certification emerged from the Earth Summit Conference in 1992. The initial international certification scheme was the Forest Stewardship Council (FSC) that was established in 1993. FSC's purpose is to encourage sustainable forestry practices worldwide by setting forth principles, criteria and standards that span economic, social and environmental concerns (www.fsc.org).

An Australian Forestry Standard (AFS) has also been developed following discussion on the progression from Environmental Management Systems to a forest management standard after the Regional Forest Agreement process was nearing completion across Australia (Agtrans Research & eSYS Development, 2007). The main criteria in the AFS are consistent with the Montreal Process criteria for sustainable forest management. While the Montreal Process is focussed on national level reporting, the same principles have been applied in the development of the AFS that is applicable at a forest management unit level.

Like the FSC, the purpose of becoming AFS certified is to demonstrate, through third party certification, compliance with commonly agreed criteria for sustainable forest management (environmental, social, economic and cultural), so facilitating access to international markets and allowing local forest products to compete against imported certified timber (Agtrans Research & eSYS Development, 2007).

Demonstration of adherence to such certifications will also be of value in allowing the area of plantations in Australia to continue to grow, while ensuring that community standards with respect to environmental and social goals are maintained.

Despite the certification, there remains conflict within the community, industry and government regarding the continuation of the industry (native forest logging) in some areas, and the expansion of the industry in others (plantation forestry). Program 4 of the CRC has been developed in order to improve the science, policy and procedures associated with key areas of concern to the community, industry and government.

The program comprises five projects which are:
4.1 Water quantity and quality
4.2 Biodiversity
4.3 Communities
4.4 Industry Pest Management Group
4.5 Land use change

Each of these projects (with the exception of 4.4) is made up of a number of subprojects. The subprojects are located in a variety of states, and across native forests, softwood plantations and hardwood plantations.

Project Objectives

The objectives of each of the five projects are presented in Table 1.

Table 1: Objectives for Program 4 Projects

Project	Objectives
4.1 Water quality and quantity	• Provide data for prediction of the impact of forest harvesting and other operations on stream ecosystems. • Provide soundly based prescriptions and recommendations for management of riparian zone buffers for maintenance of water quality and stream health. • Provide a catchment processes model suitable for the development of integrated agricultural-tree cropping systems with water benefits.
4.2 Biodiversity	• Develop strategies, prescriptions and tools to sustain or enhance biodiversity values of production forest landscapes, including procedures for the cost-effective monitoring of biodiversity values. • Prescriptions to enable key pests and pathogens to be managed in a sustainable manner using the principles of integrated pest management and in ways that reduce reliance on the use of chemicals.
4.3 Communities	• Understand the costs and benefits of commercial forestry. • Understand community attitudes in regard to commercial forestry, and how these change. • Develop feasible and effective strategies for industrial partners to engage local communities. • Provide guidelines and tools to support participatory modelling to inform stakeholder dialogue about trade-offs between production, water, biodiversity, visual amenity and other community requirements. Case studies aim to demonstrate the utility of this approach and to build the confidence of all stakeholders (including industry) in this form of engagement.
4.4 Industry Pest Management Group	• Provide research and prescriptions to enable key insect pests of *Eucalyptus globulus* plantations to be managed in a sustainable manner using the principles of integrated pest management.
4.5 Land use change	• Develop and communicate a comprehensive understanding of land use, industry and socio-economic change across the Green Triangle and Central Victorian region since 1991, and how different parts of the community perceive these changes. • Develop and communicate strategies for improved

	community engagement and modelling tools to assist in planning activities related to land use change.

Project Costs

A summary of the financial resources invested by the CRC in the Program is shown in Table 2.

Table 2: Total Investment in Forestry CRC Program 4
(nominal $)

Year Ended June	CRC and Partners Investment (Cash)	CRC and Partners Investment (In kind)	Total funds ($)
2006	733,691	1,698,675	2,432,366
2007	1,776,388	4,019,867	5,796,255
2008	1,713,684	4,088,177	5,801,861
2009	1,969,467	4,732,352	6,701,820
2010	2,057,207	4,629,867	6,687,074
2011	1,793,326	4,082,351	5,875,678
2012	1,283,112	2,576,962	3,860,074
Total	11,326,878	25,828,251	37,155,129

Source: Forestry CRC

Project Description

Project 4.1 consists of five subprojects, which are briefly described below:

- Subproject 4.1.1 Integrating forestry and agriculture for productivity and environmental benefits in medium to low rainfall zones: This subproject is based in Western Australia and seeks to apply existing knowledge to designing integrated combinations of trees and agricultural systems for reversal of hydrologic imbalance as a cause of salinisation. The subproject will collect data and quantify the benefits of such systems in terms of tree and pasture water use.
- Subproject 4.1.2 Impacts of forest harvesting and re-establishment on stream yield and water quality: The subproject will use case study research catchments in Tasmania and Victoria to draw together observations of stream conditions pre and post harvesting. Previous data and new observations will be included. There will be a focus on the reasons for differences in the scale and timing of catchment responses due to climate, terrain and stand conditions.
- Subproject 4.1.3 Impacts of forest management on stream yield, water quality and hydrological processes in the riparian zone: The ultimate aim of the subproject is to provide predictive tools and management guidelines for forest management with respect to water quality and quantity impacts. The management activities include fuel reduction burning and thinning in native forests; as well as water

quality protection and stream health maintenance with respect to fertilisation and harvesting in plantations. Also the physical processes on the hillslope and within the riparian zone that are used to modulate runoff and nutrient generation and transport are considered.

- Subproject 4.1.4 Impacts of forest harvesting and management on stream health: A conceptual model of the responses of stream systems to forest management practices will be developed, that will integrate data from subprojects 4.1.2 and 4.1.5. The focus will be on the degree to which forestry operations in upper catchment areas have downstream effects on stream biota and channel/sediments.
- Subproject 4.1.5 Commercial forestry in the riparian zones of farms: The subproject will develop guidelines for establishing streamside forest plantations for protecting stream water quality and producing wood in catchments that will remain predominantly agricultural. The project will examine institutional and economic obstacles, develop methods for their management, and quantify the impacts on water yield and quality and other stream characteristics.

Project 4.2 consists of ten subprojects grouped into three themes. Each of the ten subprojects is briefly described below:

Group 1: Monitoring and management of biodiversity in forestry landscapes

- Subproject 4.2.1 The biodiversity benefits of alternative silvicultural systems in wet eucalypt forests: The project will compare pre and post harvest surveys of a variety of lifeforms in several silvicultural systems being evaluated for use in wet eucalypt forests. This project will focus on a long-term study site in Tasmania (Warra).
- Subproject 4.2.2 Biodiversity outcomes of plantation expansion into agricultural and native forest landscapes. The research will be focused on blue gum plantation nodes in WA and the Green Triangle, as well as retained habitats resulting from forest practice prescriptions in Tasmania. The project will assess the biodiversity values of the native forest remnants in plantation landscapes and contrast them with remnants in agricultural landscapes. It will also examine landscape-level biotic interactions that affect the risks of pest and disease outbreaks, and evaluate the persistence and effectiveness of retained habitat. Cost-effective strategies for management of these remnants for their biodiversity benefits will be formulated.
- Subproject 4.2.3 Sustaining biota dependent on the decaying log habitat in production forestry landscapes: This is a project in Tasmania to develop prescriptions for ensuring sufficient suitable decaying log habitat is available in production forestry landscapes to sustain dependent biota.
- Subproject 4.2.4 Tools for monitoring and assessing biodiversity: The subproject involves synthesising other studies to provide robust methods for monitoring biodiversity using structural indicators, indicator species, and molecular tools.
- Subproject 4.2.5 Management of threatened flora and fauna in production landscapes: The project will develop management objectives, prescriptions/plans and actions for threatened flora and fauna in production forestry landscapes in Tasmania.

Group 2: Gene pool management

- Subproject 4.2.6 Management of the risk of gene flow from eucalypt plantations: The project provides the biological data and decision support system to assess and manage the risk of genetic pollution of native forest gene pools from eucalypt plantations (focus on *E. nitens* and *E. globulus*).
- Subproject 4.2.7 Management of genetic resources: The project will develop gene pool management strategies focussing on *E. regnans*, *E. oblique* and *E. globulus*. Baseline data will be provided for monitoring genetic diversity in managed native forests and breeding/deployment populations for certification purposes. Genetically based guidelines for seed sourcing will be developed for use in *E. regnans* and *E. oblique* native forest silviculture.

Group 3: Sustainable management of key pests

- Subproject 4.2.8 Integrated management of browsing mammals: The subproject will develop an integrated pest management framework for protecting young plantations and regenerating native forests from marsupial browsers. The subproject will draw on other studies being undertaken by the University of Tasmania and Forests Tasmania.
- Subproject 4.2.9 Protecting plantations from damaging outbreaks of defoliating insects using lethal trap trees: The subproject will develop an operational deployment strategy for optimising the spatial arrangement of lethal trap trees in plantations for cost-effective protection against damaging outbreaks of defoliating insects. This will offer an alternative to aerial spraying.
- Subproject 4.2.10 Improving *Mycosphaerella* resistance in deployment populations of *E. globulus*: The subproject will develop strategies to enable the selection of *E. globulus* germplasm for deployment in areas of high disease risk.

Project 4.3 has four subprojects that are described below.

- Subproject 4.3.1 Costs and benefits of commercial forest industry: The subproject will develop a profile of different industry segments, at different stages and in different locations with the purpose of conducting a comprehensive analysis of the full social and economic costs and benefits of commercial forestry for local and regional communities.
- Subproject 4.3.2 Better understanding of community attitudes to commercial forestry: The project will use a combination of longitudinal studies and visualisation technology to explore the attitudes of different community segments to plantation forestry and develop strategies for better community engagement.
- Subproject 4.3.3 Designing feasible and effective strategies for industry partners to engage with local communities: This project will develop a strategy using information generated in 4.3.1 and 4.3.2 that will be used in the CRC's communication and outreach strategies.
- Subproject 4.3.4 Participatory modelling of forested landscapes: The subproject will utilise a method used overseas that has been shown to be an effective way to engage stakeholders and resolve land use conflict. The subproject will draw on case studies in Australia to develop guidelines for effective participatory

modelling, and to develop a library of resource materials to facilitate participatory modelling in the Australian context.

Project 4.4 is based in Albany, Western Australia. It is the location for an industry pest management group (IPMG) that provides on-ground research support, prescriptions and technology transfer required for the integrated management of insect pests in *E. globulus* plantations. The work is also to be extended into the Green Triangle.

Project 4.5 follows up on an earlier land use study conducted in 2000 that was based in Victoria, and expands the geographic coverage of that study to include the lower south east of South Australia, and also profiles a wider range of types of land use change in detail. The project is to be conducted under four subproject themes.

- Subproject 1 Attitudes and values survey: This will involve the use of a quantitative survey to explore the attitudes of different community segments in the Green Triangle and Central Victorian regions to different aspects of plantation forestry, and to other land use changes in the region. This will result in comparisons of perceptions of the different types of land use change occurring in the area.
- Subproject 2 Quantify and analyse land use, industry and socio-economic change in the region using independent data: Independent data on socio-economic change in the region will be collected and analysed to understand the influence of plantation forestry and other types of land use on socio-economic change in the region. The data will then be used to compare different regions to identify if the establishment of plantations, and other types of land use change, are associated with distinct socio-economic changes different to those in other regions.
- Subproject 3 Understand shifts in the landholder population: a survey of landholders will be carried out to identify why and when landholders choose to sell or lease their properties for enterprises such as plantation forestry, and where they shift to when they leave their properties.
- Subproject 4 Develop community engagement and participatory modelling tools to support better communication and planning by the community regarding land use change: This component of the project has not yet been funded and will be developed further pending other work being undertaken by the CRC in this regard (in particular, Project 4.3)

Table 3 summarises the location and industry focus of each of the subprojects.

Table 3: Location and Industry Focus of Each Subproject

Subproject number	Location	Industry sector
4.1.1	WA	Hardwood plantations
4.1.2	Tas and Vic	Native forest and softwood plantations
4.1.3	Vic	Native forest and plantations
4.1.4	Tas and Vic	Native forest and plantations
4.1.5	Tas	Agroforestry
4.2.1	Tas	Native forest
4.2.2	Tas, WA and Green Triangle	Hardwood plantations
4.2.3	Tas	Native forest and plantations
4.2.4	Tas, WA and Green Triangle	Native forest and plantations
4.2.5	Tas	Native forest
4.2.6	Tas, WA, Green Triangle, NSW and Qld	Hardwood plantations
4.2.7	Tas, Vic (minor work in NSW & SA)	Native forest
4.2.8	Tas	Hardwood plantations
4.2.9	Tas	Hardwood plantation
4.2.10	Tas	Hardwood plantations
4.3 (all subprojects)	Tas and SW WA	Mostly plantations (softwood and hardwood)
4.4	WA and Green Triangle	Hardwood plantations
4.5	Vic and Green Triangle	Plantations (mainly hardwood)

Outputs

A summary of the expected principal outputs from each of the five projects is reported in Table 4.

Table 4: Summary of Principal Outputs by Project

Project	Principal Outputs
4.1 Water quality and quantity	To June 2008, significant progress has been made in all of the sub-projects and a number of scientific findings have resulted. In addition, the project has produced at least: • 16 refereed journal articles

	• 4 refereed conference proceedings • 11 unrefereed conference proceedings • 2 book chapters • 6 confidential reports • 8 public reports • 16 conference presentations • 15 other presentations • 2 other communications • 6 media articles • 2 field days/workshops The expected general outputs include: • Tools to predict the effect of forestry activities on water yield and quality and to determine management strategies for sustainable water outcomes. • Strategies and guidelines for establishment and management of forests and tree crops that maintain productivity with optimal water outcomes. • Improved capability to model the effect of forestry activities on catchment water balances and stream health. • Greater knowledge of silvicultural practices on water use to inform community debate. • Best management practices for maintenance of water quality and quantity values.
4.2 Biodiversity	To June 2008, significant progress has been made in all of the sub-projects and a number of scientific findings have resulted. In addition, the project has produced at least: • 84 refereed journal articles • 4 refereed conference proceedings • 4 unrefereed conference proceedings • 20 books and/or book chapters • 38 confidential reports • 14 public reports • 17 theses • 106 public presentations • 6 newsletters • 2 CD/DVDs • 37 other communication activities • 20 media activities • 117 conference presentations • 14 technical notes • 40 field days/workshops The project organised and hosted a major international conference in

	2007-08 titled "Old Forests, New Management: Conservation and use of old-growth forests in the 21st Century". A hard copy of proceedings from the workshop was produced and is also available for download on the web. The expected general outputs include: • Revised prescriptions for native forest silviculture and management of coarse woody debris. • Prescriptions for non-lethal strategies for controlling marsupial browsing integrated into pest management strategies. • Decision support system for assessing the risk of gene flow from plantations into native forest gene pools and strategies to manage this risk. • Prescriptions for managing key pests and pathogens, including more socially acceptable strategies for controlling marsupial browsing. • Prescriptions for the integrated management of threatened, keystone and dominant taxa in production landscapes, including genetically based adaptive models for eucalypt seed sourcing.
4.3 Communities	To June 2008. The project had produced at least: • 1 refereed journal article • 2 confidential reports • 4 public reports • 4 conference presentations • 2 other presentations • 14 media activities • 1 field day/workshop • 2 newsletters Specific outputs to date from Project 4.3 include: • The statistical profile has been completed. • The first forest industry survey has been completed and analysed. The findings of the first survey included: o An estimated 6,300 people were employed in the forestry industry on average over 2005-06, with 5,870 full-time equivalent employees (representing 3.08% of Tasmania's employed labour force). o The majority of forest industry workers live either in the same local government area (LGA) as their place of employment, or an adjacent LGA. o Forest industry workers often work in several locations during any one year. o Forest industry workers are predominantly male (88.4%). o Forest industry workers are younger than the average for the Tasmanian workforce.

	- For growers and processors, 34% of known expenditure took place in local and adjacent LGAs, 43% in other Tasmanian LGAs, and 23% outside Tasmania. - Contractors and consultants on average undertook 50% of their business expenditure in the same LGA in which their business is located, a further 23% in LGAs immediately adjacent to their office LGA, and 22% in other Tasmanian LGAs. Only 5% of expenditure occurred outside Tasmania. - A second and third survey is being/will be carried out in 2008 and 2010 to enable improved identification of changes in forest industry employment and spending over time. • The results of the first survey were released in June 2008, with considerable media attention in Tasmania. • The report 'A brief guide to effective community engagement in the Australian plantation sector' was published in May 2008 (subproject 4.3.3) • Two preliminary reports analysing the demographic and land use change statistics for study regions in Tasmania and WA were completed and distributed as internal reports in December 2007. • The 2008 survey of residents across Tasmania and WA has commenced. • Advisory Group meetings have been held that include a range of stakeholders from the agricultural sector, local government, forest industry and regional development organisations. The expected general outputs include: • Analysis of the direct and indirect socioeconomic costs and benefits of commercial forestry for regional communities in selected regions. • Improved methodologies for understanding community attitudes related to commercial forestry and the regional context in which it operates, and an improved capacity for CRC industrial partners to explore those attitudes. • Strategies for how CRC industry partners can improve their engagement with immediate neighbours of commercial forestry, other local landholders and their wider communities. • Guidelines for conducting participatory modelling in the context of Australian forested landscapes. • Resources for participatory modelling (e.g. library of submodels).
4.4 Industry Pest Management Group	Outputs over the life of the project will include: • Prescriptions for managing key pests • Database of observational data • Standardised assessment methodology for insects in blue gum

	plantations • A series of workshops and presentations has also been held in association with Project 4.2
4.5 Land use change	Specific outputs to date include: • Release of the report 'Living with land use change: different views and perspectives' in March 2008 • Completion of a draft research report 'Understanding residents' views on land use change' based on a survey undertaken in 2006-07 • A draft research report titled 'Impacts of land use change to farm forestry and plantation forestry: a landholder survey' was complete in June 2008. • 4 newsletters • 25 media activities • 1 field day/workshop Overall deliverables from the project will be: • Analysis of attitudes and values towards plantation forestry and other land use changes in the region. • Detailed profile of land use, industry and socio-economic change occurring in the region over 1991 to 2006. • Detailed profile of change in the plantation industry and 2-3 other selected land use industries. • Improved understanding of the reasons landholders choose to lease or sell land for plantation forestry, and the changes they make subsequently to their lives. • Recommendations for improving communication between the plantation industry and other groups. • Information sheets/booklets for dissemination of project results to community groups, local government and other relevant organisations.

Outcomes

A summary of the principal outcomes from each of the five projects is reported in Table 5.

Table 5: Summary of Principal Outcomes by Project

Project	Principal Outcomes
4.1 Water quality and quantity	Expected outcomes from the project include: • Adoption by wood producers of practices which conform to certification standards and help to maintain their licenses to operate. • Potential for changes to codes of practice or certification standards.

	• Improved achievements of water quality or water yield objectives. • An improved ability to predict water quality and quantity responses to a range of forestry practices. • Closing key research gaps in current forest-based hydrologic analysis.
4.2 Biodiversity	The outcomes will be the use of the information and outputs identified above for monitoring and managing biodiversity in production landscapes. Examples of these potential uses include: • Genetic and biological tools for monitoring sustainability criteria, including reporting against Montreal requirements and other certification standards. • Strategies to maintain the long-term biodiversity values of production landscapes and manage the biotic interchange between plantations and adjacent native communities. • Sustainable strategies for managing populations of pests, weeds and pathogens of tree crops which reduce reliance on chemicals. • The target audience for subproject 4.2.5 is those involved in planning and implementing management actions for the conservation of threatened biota, and biota of high conservation significance, in areas subject to production forestry activities. These include forest managers, forest consultants, forest practice Officers and forest contractors. The results will be used in the continual improvement of decision support systems and other planning tools including range maps and strategic management plans. • The target audience for subproject 4.2.6 comprises foresters, forest planners, forest practice officers, regulatory authorities and government agencies. Risk assessment with respect to gene flow should be incorporated into industry planning decisions (involves a role for industry and regulatory agencies). • The target audience for subproject 4.2.7 comprises forest planners and managers responsible for seed sourcing for native forest silviculture, agencies involved in vegetation restoration, regulatory agencies, land managers, planners and consultants, *E. globulus* breeders and plantation growers.
4.3 Communities	Outcomes to date include: • The results of the first industry survey are now forming the basis for communication and planning about forest industry employment and spending for Tasmania forest industry partners and government agencies, and are being used by the Federal government in assessing the social impacts of the industry. • The report published from subproject 4.3.3 is being used by forest industry partners to help improve community engagement practices.

	The expected future outcomes from the project are: • For industry partners, a greater understanding of the social and economic costs and benefits of commercial forestry, and people's changing attitudes to forestry. This will inform the forestry policies and practices of industry partners so that effective community engagement strategies are implemented and the direct and indirect outcomes of forestry are optimised. • For land-use planners and the wider community, an improved understanding of the commercial and practical context in which forestry operates. A more informed dialogue between communities, companies and governments will increase the likelihood that a shared view of best commercial forestry can be developed (i.e. less conflict over commercial forestry). • Strategies, guidelines and resource materials for participatory modelling in Australian forested landscapes.
4.4 Industry Pest Management Group	The service is used by the IPMG industry partners for training, monitoring, research and maintenance of a eucalypt pest data base. Expected outcomes include: • Sustainable strategies for managing populations of pests on *E. globulus* plantations. • Implementation of project know-how and strategies for maintaining forest certification of the forest estates managed by the project participants. • Better achievement of pest control objectives.
4.5 Land use change	Expected outcomes include: • For industry partners, a greater understanding of the social and economic costs and benefits of different types of land use change, and people's changing attitudes to plantations and other types of land use change. This will inform the policies and practices of industry partners so that effective community engagement strategies are implemented. • For land-use planners and the wider community, an improved understanding of the impacts of different types of land use change, enabling development of informed policy and practice relating to land uses such as plantations.

Benefits

Each of the individual projects and subprojects within this program will potentially result in specific benefits. Table 6 briefly summaries the nature of the potential benefits from each of the five projects.

Table 6: Summary of Potential Benefits by Project

Project	Potential Benefits
4.1 Water quality and quantity	Potential benefits from the project include: • Improved water quality (groundwater and surface water) in native forest and plantation forest areas. Improved water quality provides biodiversity benefits, as well as benefits to downstream users (e.g. agriculture, communities, recreation). The improved water quality relates to a number of contaminants including salinity, sediment, fertiliser and chemicals. • Reduced impact of forestry operations on water quantity (both groundwater and surface water). • Demonstration of a continuous improvement approach to minimising the impact of forestry on the environment and other water users. • Maintenance of certification standards, ensuring continued ability to operate as well as continued market share from those consumers requiring such certification.
4.2 Biodiversity	Potential benefits from the project include: • Improved biodiversity in native forest and plantation areas (including regions surrounding plantations). The biodiversity relates to both flora and fauna. • Benefits will result from improved management as well as improved monitoring abilities for biodiversity, and therefore improved management feedback and reporting. • Maintenance of genetic diversity in native populations of eucalypts is a key biodiversity benefit. • Maintaining the ability to manage pests, weeds and pathogens with a reduced reliance on chemicals may provide an economic benefit to plantation owners and other community members as well as improvements in biodiversity, water and increased social acceptability • Reduced reliance on lethal control tactics for marsupial browsers will increase social acceptability of plantations. • Maintenance of certification standards, ensuring continued ability to operate as well as continued market share from those consumers requiring such certification.
4.3 Communities	The potential benefits from the project are: • Reduced conflict between stakeholders in forest industries and communities, resulting in reduced time and resources spent on conflict resolution. • Reduced stress on stakeholders (particular community members) due to reduced conflict. • Optimisation of industry's ability to meet community standards with regards to environmental and social outcomes, ensuring

	continued ability to operate as well as continued market share from those consumers requiring such certification
4.4 Industry Pest Management Group	Potential benefits include: • Economic benefits to foresters through economic and sustainable strategies for managing populations of pests on *E. globulus* plantations. • Maintenance of certification standards, ensuring continued ability to operate as well as continued market share from those consumers requiring such certification.
4.5 Land use change	Potential benefits include: • Reduced conflict between stakeholders in forest industries and communities, resulting in reduced time and resources spent on conflict resolution. • Reduced stress on stakeholders (particular community members) due to reduced conflict. • Optimisation of industry's ability to meet community standards with regards to environmental and social outcomes, ensuring continued ability to operate as well as continued market share from those consumers requiring such certification.

As Table 6 has demonstrated, there will be significant specific environmental, economic and social benefits from the individual subprojects and projects funded as part of Program 4. Also significant will be the benefits from the PhD component of the projects. For example, Project 4.2 alone has 32 PhD students involved in its research. The training of these researchers will result in the availability of an extensive range of skills to the industry. The number of papers and presentations being created from the Program is also fulfilling the broader objective of the CRC with regard to its communications effort, and ensuring adoption of improved practices into the Forest Practices Codes.

In addition, all of the projects and subprojects are seeking to contribute to an overall goal of maintaining the forest industry's licence to operate within the community. This relates to all three sectors of the industry (native forest harvesting, softwood plantations, and hardwood plantations).

There is a history of conflict over resource use in Australia, including relating to forestry. As noted by Schirmer et al (undated) there have been a number of high profile conflicts in this area, that have resulted in the formation of the Greens political party, and a number of environmental organisations, industry associations and timber community organisations. These organisations continue to participate in politics and society relating to forestry issues. Schirmer et al (undated) acknowledge how complex such conflicts are, and that they involve questions not only of science, but also values, lifestyle and class conflicts. It is acknowledged by these authors that some degree of conflict is necessary and can be healthy in these types of debates.

The overall benefit from the Program 4 projects will be a contribution to reducing conflict through a more informed debate between stakeholders in the forestry industry. This will be through:

- the provision of scientific evidence,
- improvements to the definition of best management practices and demonstration of a continuous improvement forest industry policy,
- improvements to practices and indicators associated with certification, and
- an improved understanding of the demographic, social and political environment in which the forestry industry is operating.

Reduced conflict, improved communication and improved best management practices will ensure the licence to operate for the industry is maintained, and that the industry can continue to grow sustainably.

Summary of Benefits

A summary of the benefits emanating from the five projects in Program 4 is provided in Table 7.

Table 7: Summary of Principal Benefits

Economic	Environmental	Social
Maintenance of licence to operate for industry, resulting in maintenance of a sustainable industry	Improved water quality and/or avoided water quality degradation	Better informed stakeholders of forestry impacts and community aspirations
Maintenance of market access due to maintenance of certification and standards	Improved biodiversity and/or avoided biodiversity degradation	Reduced stress to stakeholders involved in the forest industry
Saved time and resources expended in conflict resolution	Avoidance of impact on reducing water quantity (groundwater and surface water)	
Improved ability to sustainably manage pests		
Future land use that maximises economic returns subject to informed social preferences.		

Quantitative Analysis of Costs and Benefits

The investments in Program 4 will ultimately contribute to the maintenance of access to the forest resource (both native and plantation) through demonstrating to the community underlying science and also demonstrating concern for improvement to forest management. Demonstrating responsibility and improving communications (together with meeting certification standards at least cost) will contribute to ensuring continued access to native forests, and continued ability to purchase land for plantation forestry.

While it is recognised that each of the individual subprojects may have quantifiable benefits, a top-down approach to valuing the benefits is taken here. The benefits quantified are:

- Avoidance of excessive future restrictions on access to native forest logging, and
- Avoidance of excessive future restrictions to land available for hardwood plantation forestry (excessive is defined here as restrictions that limit economic benefits, while not actually improving ecological/social benefits)

Benefits not quantified include:

- Market maintenance due to certification
- Environmental benefits such as improved biodiversity and water quality
- Reduced time and resources spent on conflict resolution
- Development of skilled researchers through the involvement of the large number of PhD students

The avoidance of excessive future restrictions on access to land available for softwood plantation forestry is not valued in the analysis. This is largely because of the long-term nature of softwood forestry where trees don't mature for 28 years or more. There are therefore no benefits from new plantings during the life of the analysis. In addition, the total area of softwoods is increasing at a much slower speed than hardwood plantations, as most establishment occurs on land that has previously been used for growing softwoods.

Native Forest Logging

Without scenario

Community conflict regarding native forest logging is mostly related to concerns about the negative impacts such operations might have on biodiversity and water quality. However the availability of the native forest resource is important for allowing the forest sector to meet domestic and export demand for native timbers and wood products (Montreal Process Implementation Group, 2008).

Over recent years, the area of land available for harvest from native forests has decreased due to the increase in area of forests being placed into public nature conservation reserves. Most states have plans in place to gradually increase over time the area of native forests being placed into such reserves, as the planting of hardwood plantations increases to provide an alternative timber resource.

In each state, a level of sustainable harvest has been calculated and is used to manage the volume harvested annually. This level of sustainable harvest is calculated using a wide range of factors and is reviewed periodically. Australia's State of the Forests Report 2008 (Montreal Process Implementation Group, 2008) states that the average sustainable yield from public and private native forests has declined in all states except Tasmania between 2003 and 2008. This is due to reductions in the area of native forest available for harvesting and improved information on forest yields. There are also substantial requirements in native multiple-use public forests to maintain non-wood values.

It is anticipated that in the future, the level of sustainable yield harvested from native forests (public and private) will continue to decline. ABARE (2008) reports that the volume of hardwood logs harvested from native forests in Australia was 10.8 million cubic metres in 2000/01, and had reduced to 8.6 million cubic metres in 2005/06, and 8.5 cubic metres in 2006/07 (almost 3% per annum average reduction). For the purposes of this analysis, it is assumed that without the research this volume will decrease by at least 2% per annum, commencing in the year ended 2007/08 and continuing until the end of the analysis (2034/35). It is further assumed that without this research, there is a 50% probability that in the future the volume of allowable sustainable harvest may be reduced even further, to an excessively low level. That is, there is a probability that uncertainty about whether best management practices are being followed, or conflict based on perceptions rather than facts, will lead to the level of resources harvested being reduced, while not actually contributing to any increase in positive environmental outcomes. It is assumed this reduction in the volume of sustainable harvest would be an additional 2% (making a total reduction of 4%) starting in the year 2010/11.

With Scenario

With the research, it is assumed the initial 2% decrease still occurs, but that the probability of the additional 2% reduction in volume is reduced from 50% to 20%.

The value of wood from native forests is assumed to be $16 per green tonne (Forestry Tasmania, 2008). It is assumed that on average for hardwoods, 1 cubic metre is equivalent to 1 green tonne. Harvesting is additional to this, and is assumed to be $25 per cubic metre. Therefore the value used in the analysis is $41 per cubic metre at forest gate, that is, before transport to mill.

The benefit lost in the without project scenario is assumed to be the gross value of log production (at the forest-gate), rather than only profit. It could be argued that if the additional trees are never harvested, then it is only the profit that is lost, because the industry does not lose the money it would have expended on capital, land, labour and other inputs. However, it could also be argued that in the case of the forestry industry, the capital, labour and other inputs that are displaced by the contraction in the industry, should be valued. This is because communities are often established around and can be economically and socially reliant on, the forestry industry. Thus it could be argued that these resources can not be applied in other parts of the economy without considerable costs. The subprojects within Project 4.3 are finding evidence to support this contention.

Further, if the native forest harvest is reduced and there is no increase in timber production from other domestic sources, Australia will need to import more timber.

Plantation forestry – hardwoods

Without scenario

The area of hardwood plantations being established has been increasing steadily over recent years. Initially some plantings were aimed at being a potential resource to replace timber from the native forest resource, access to which is gradually being reduced. In addition the national strategy 'Plantations for Australia: The 2020 Vision' which was launched in 1997 contained a notional target of trebling the national plantation estate to a total of about 3 million hectares by 2020. However, long rotations necessary for timber, and the current economics of production have resulted in the establishment of quick growing hardwood plantations based on export of woodchips. Much of the investment in hardwood plantations has been through managed investment schemes, and about 86% of hardwood plantations are privately owned (BRS, 2007).

The National Plantation Inventory (NPI) update report for 2007 (BRS, 2007) shows the total area of hardwood plantations established per annum for 2002 to 2006 for each State. These areas are presented in Table 8.

Table 8: New Areas of Hardwood Plantations Established (hectares per annum)

Year	**2002**	**2003**	**2004**	**2005**	**2006**
ACT	0	0	0	0	0
NSW	1,830	1,770	2,012	3,308	7,432
NT	165	1,250	4,461	5,668	9,391
Qld	8,234	1,853	4,618	8,860	5,279
SA	4,448	589	3,888	5,860	5,522
Tas	9,656	9,485	11,585	10,000	18,530
Vic	12,093	8,029	11,858	10,266	10,606
WA	12,754	5,403	7,829	21,589	10,516
Total	49,180	31,379	46,263	65,551	67,277

While the annual area being established has increased over the last five years, the NPI update in 2008 predicts that the hardwood plantation expansion rate may decline within a few years as the plantations planted in the 1990s are harvested, and these sites will be available for replanting. The data shows that the area of hardwood plantations established annually has averaged almost 52,000 hectares per year over the last five years, and it is assumed in this analysis that the five year average that will continue to be the rate of expansion in the future.

For the purposes of this analysis, it is assumed that without the research there is a 50% probability that the rate of expansion is 10% less than that predicted above (52,000 hectares), due to the unavailability of the additional land required. It is assumed that such an unavailability of land leads to a reduction in the level of wood resources available, but does not lead to improved environmental and social outcomes. Rather, the unavailability of the land was due to conflict or decisions based on incomplete knowledge and understanding.

With scenario
It is assumed that with the research, the probability of this 10% reduction in the area of expansion is reduced from 50% to 20%.

It is further assumed that the hardwood plantations grow at a rate of 17 cubic metres per hectare per annum, and is harvested 12 years after planting (Ferguson et al, 2002). The project outputs first have an impact on the area planted in the year 2010/11, and this land is harvested in the year 2022/23 The value of wood is assumed to be $32 per green tonne (Forestry Tasmania, 2008). It is assumed that on average for hardwoods, 1 cubic metre is equivalent to 1 green tonne. Harvesting is additional to this, and is assumed to be $25 per cubic metre. Therefore the forest-gate value used in the analysis is $57 per cubic metre.

Summary of Assumptions
A summary of the assumptions made in the analysis is provided in Table 9.

Table 9: Summary of Assumptions

Item	Assumption	Source
Native Forestry		
Annual yield from native forests in 2006/07	8,503,000 cubic metres	ABARE, 2008
Reduction in annual yield from native forests	2% per annum until 2034/35	Agtrans assumption
Average value of logs from native forests at forest gate	$41 per cubic metre	Adapted from Forestry Tasmania, 2008
Probability of additional 2% reduction in yield without research	50%	Agtrans assumption
Probability of additional 2% reduction in yield with research	20%	Agtrans assumption
First year of impact of research	2010/11	Year after research is completed
Hardwood Plantation Forestry		
Area of annual expansion of hardwood plantation area	52,000 hectares	Average of last five years, BRS 2007
Average growth rate for hardwood plantations.	17 cubic metres per hectare per annum	Ferguson et al, 2002
Years to harvest	12 years	Ferguson et al, 2002
Average value of logs from hardwood plantations at forest gate	$57 per cubic metre	Adapted from Forestry Tasmania, 2008
Probability of 10 % reduction in expansion without research	50%	Agtrans assumption

Probability of 10% reduction in expansion with research	20%	Agtrans assumption
First year of impact of research	2010/11	Year after research is completed

Results
The period of analysis was for 30 years after the first year of investment. The results are expressed in 2007/08 dollar terms and all benefits and costs are discounted to 2007/08. The results for the cost-benefit analysis are reported in Table 10. The results show that the investment criteria are quite sensitive to the discount rate due to the long time-frames involved until the benefits from the hardwood plantations are realised, at the time of harvest.

Table 10: Results of Cost-Benefit Analysis for Investment in Program 4
(2007/08 $ terms)

Investment criteria	5% Discount Rate	10% Discount Rate
Present Value of Benefits ($m)	106.61	46.48
Present Value of Costs ($m)	35.72	34.27
Net Present Value ($m)	70.88	12.20
Benefit–Cost Ratio	3.0	1.4
Internal Rate of Return (%)	12.1	

The proportion of the present value of benefits derived from the native forestry component is 19%, with 81% derived from the increased hardwood plantation access.

Sensitivity Analysis
Sensitivity analyses were carried out on two variables and results are reported in Tables 11 and 12. The sensitivity analyses were performed using a 5% discount rate with benefits taken over a thirty year period from the start of the investment. All other parameters were held at their base values. Table 11 shows the sensitivity of the investment criteria to the probabilities of the reduction in expansion/harvesting in the 'with scenario' for both native forests and hardwood plantations. It shows that if the probability is reduced form 50% in the without scenario, to only 40% in the 'with scenario', that the investment criteria only almost break-even.

Table 11: Sensitivity of Investment Criteria to Probability of Reduced Expansion/Harvesting in the 'With Research Scenario'
(Discount Rate of 5%)

Investment Criteria	10%	Base (20%)	40%
Present Value of Benefits ($m)	142.14	106.61	35.54
Present Value of Costs ($m)	35.72	35.72	35.72
Net Present Value ($m)	106.42	70.88	-0.19
Benefit-Cost Ratio	4.0	3.0	1.0
Internal Rate of Return (%)	14.3	12.1	5.0

Table 12 demonstrates the sensitivity of the investment criteria to the assumed reduction in the area of plantation to be established every year. The base scenario assumes there is a probability of a 10% reduction in the annual area of new plantings. If this assumed possible reduction is reduced to 5%, the investment is still positive, with a benefit cost ratio of 1.8 to 1. If the possible reduction is as high as 30%, then the benefits increase significantly, with a net present value of $279 million and a benefit-cost ratio of 7.8 to 1.

Table 12: Sensitivity of Investment Criteria to Possible Reduction in the Annual Area of New Hardwood Plantations Established
(Discount Rate of 5%)

Investment Criteria	5%	10% (Base)	30% per annum
PV of Benefits ($m)	63.58	106.61	278.73
PV of Costs ($m)	35.72	35.72	35.72
Net Present Value ($m)	27.85	70.88	243.01
Benefit Cost Ratio	1.8	3.0	7.8
Internal Rate of Return (%)	8.9	12.1	18.1

Conclusion

There is a diverse scope of research being funded through Program 4 of the CRC, ranging from water quantity and quality issues, through biodiversity, pest management and community understanding. These individual areas of research are expected to lead to a wide range of specific outputs and subsequent benefits. However, together this body of work seeks to contribute to the common goal of maintaining the industry's licence to operate. It is seeking to do this through improving science and best management practices, as well as improving the communication and understanding between various stakeholders in the forest industry, and forest communities.

The analysis demonstrates that given the assumptions made, and at a 5% discount rate, the investment will achieve a net present value of $71 million and a benefit-cost ratio of 3 to 1. It should be remembered however, that there are a number of significant direct benefits from this body of research that have not been quantified, and are therefore not accounted for in the investment criteria. This includes the biodiversity and water quality benefits, conflict resolution benefits, and education benefits.

Acknowledgments
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