Processing

Increasing the Value of Forest Resources through the Development of Advanced Engineered Wood Products

Project number: PNB407-1516

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Forest & Wood Products Australia

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by

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Executive Summary

The principal objective of this project was to deliver and validate technologies to transform low-value forest resources and sub-optimum quality logs into high-value construction and appearance products suitable for Australian and international markets. The project was designed to achieve this objective through a methodology that focused on forest resource, new technologies, market and economic aspects. Critical to the project design was direct participation and guidance by forest industry stakeholders.

The resource assessment study indicated that a substantial volume of forest resource within Australia's native forest and hardwood plantations is potentially suitable for rotary veneer processing using spindleless lathe technology. However, access to and utilization of, these logs will depend on many factors including: accommodating Government policies and log supply agreements; potential alterations in the code of practice for native forest harvesting; silviculture; tree marking and sales practices; diversion of logs from other uses; and development of appropriate log specifications. The resource assessment study also identified that the creation of a new market for currently under-utilised small diameter logs may assist in supporting improved silvicultural management in both native forests and plantations.

Processing small diameter spotted gum (*Corymbia citriodora*) and white cypress pine (*Callitris glaucophylla*) logs into rotary veneer using new spindleless veneering technology was demonstrated to yield more acceptable recoveries compared to traditional sawing approaches. The resulting veneer and especially the spotted gum veneer contained visual qualities and mechanical properties well suited to the manufacture of veneer-based engineered wood products (EWPs).

A comprehensive product and market assessment revealed that the new 'mid-rise timber' construction sector provides significant market opportunities for a wide range of structural (and appearance) timber products, both sawn and engineered. More specifically, opportunities for higher structural performing EWPs may provide attractive opportunities for many of Australia's high strength hardwood species, due to the resulting higher structural loads with the increased building heights involved. In addition, a reflection on traditional markets occupied by Australia's native forest species identified further opportunities for veneer-based EWPs in electricity network cross-arms, road and rail bridge components and large dimension post and beams. The project steering committee identified a number of potential 'best bet' products taking into account the strengths and weaknesses of the available timber feedstocks, outcomes of the forest assessments, results of the project processing studies and an understanding of potential products and markets. The 'best bet' product groups included laminated veneer lumber (LVL) based products and mass-panels (e.g. veneer-based mass panel or mass plywood panels (MPP)). The LVL product group was prioritised by the committee for further product development during the project. Opportunities for resource blending within LVL products was also prioritised.

The project demonstrated the technical feasibility of manufacturing LVL products from blending veneers from species such as spotted gum, hoop pine (*Araucaria cunninghamii*) and white cypress pine using a variety of different construction strategies. The pure spotted gum and the blended spotted gum and hoop pine LVL products were shown to be superior in structural properties, compared to many currently commercially available LVL products in the market. An LVL construction type comprising either 100% cypress pine or 100% spotted gum was found to be resistant to subterranean termite attack. However, having a durable species (white cypress pine or spotted gum) as a face and back veneer in the LVL construction type did not provide protection for the inner hoop pine veneers in a blended product.The project did show however, that plywood made with hoop pine core veneers and white cypress pine face and back veneers offered some termite resistance if the hoop pine

veneer thickness is kept thin. Alternating white cypress pine and hoop pine veneers further improved the termite resistance.

The economic assessment of veneer and LVL production from hardwood logs in the subtropics of eastern Australia revealed that, in decreasing order of impact on profitability, the strategic and tactical investment decisions are: (1) the product manufactured (level of value-adding); (2) processing scale; (3) log procurement strategy (log types processed); and (4) facility location (proximity to the forest). There are strong returns to value-adding, with the manufacture of two-stage LVL products generally projected to be highly profitable. In contrast, the production of green and dry veneer for market was not financially viable, assuming market prices achieved in Australia for commodity veneer, such as radiata pine. Profitable sale of veneer would require market prices in the order of $371/m^3$ and $545/m^3$ for green and dry veneer, respectively. Such prices may be achieved if veneer markets develop that value the positive attributes of these resources, such as the superior mechanical properties and natural durability of subtropical Australian hardwoods.

Log geometry was found to substantially affect recovery of marketable veneer from log volume, the volume of marketable veneer produced per hour of operation, and the financial performance of rotary veneer and LVL manufacture. Because of their relatively low stumpage price and relatively large log diameter, optional (B-grade) sawlogs (35 cm SEDUB) were identified as the optimal log type for veneer and LVL production. However, maximising the net present value of an investment in LVL manufacture from subtropical eastern Australian native forest hardwood logs was found to require large proportions of log volume in small, non-traditional log types. Therefore, establishment of hardwood LVL manufacturing facilities does represent an opportunity to develop new markets for small logs, and could help facilitate the silvicultural treatments necessary to increase the productivity of private native forests in the region.

Consistent with expectations, mean mill-delivered log costs per cubic metre were found to rise with increasing processing scale and distance of the resource from the processing plant. If the veneering facility was located at least 50 km from any log resource, mean mill-delivered log costs can be up to $30/m^3$ of log higher than for a facility located proximate to the resource. A single integrated facility processing logs into veneer and then LVL was found to be most profitable, with much stronger returns being earned when the facility is located closer to the log resource. However, if technical or logistical constraints prevented a single integrated facility being located close to the log resource, then the financial analysis highlighted opportunities for profitable distributed production of LVL, with veneer produced close to the forest and then manufactured into LVL at an alternative location.

The project has provided a wealth of new knowledge for the Australian industry and identified many technical and economic opportunities for industry to consider that can utilize forest resources that are currently under-valued and underutilized, for the manufacture of high-performing value-added engineered wood products. Active participation of key industry stakeholders through the duration of the project and the commercial investigations that have occurred in parallel with the project demonstrates strong industry interest in the subject. Further collaborative effort is required to advance the definition of target markets, allowing further product development focus that optimizes species selection, lay-up strategies, manufacturing protocols and final product performance criteria. This effort would have the best chances of success, demonstrated by product commercialization, by close partnership with industries ready to adopt and develop the necessary practices required to produce the new product(s). Specialist marketing expertise would add significant value to further efforts to better enable genuine ‘new’ markets (markets not currently occupied by a wood product) to be identified and developed as well as ‘substitute’ markets (markets historically or currently occupied by wood products of some description) to be targeted. Continued economic assessment is also necessary to guide decision making.

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Chapter 1: Introduction

The key research question that this project sought to address was:

How can the productivity and profitability of the Australian forest and forest product sector be enhanced through the adoption of engineered wood technologies that target the efficient use of low-value, under-utilised forest resources?

The forest industry in Australia is still predominantly based on traditional sawing production systems and traditional products. Additionally, apart from a relatively small quantity of mostly plywood and glulam, the existing engineered wood products (EWPs) industry in Australia is mainly centred on softwood resources.

Opportunities for EWPs have not yet been fully explored for all resource types and forest qualities. Advantages of EWPs compared to traditional sawn products include increased value-adding, efficient resource utilisation, ability to use low-grade wood and small piece sizes, greater selection of product dimensions, as well as compatibility with modern day building systems. EWPs exhibit uniform and predictable mechanical properties that are analogous to steel and concrete, particularly in non-residential construction markets; however, they also have far superior and increasingly well recognised sustainability credentials.

The principal objective of this project was to deliver and validate technologies to transform low-value forest resources and sub-optimum quality logs into high value construction and appearance products suitable for Australian and international markets. The project was designed to achieve this objective through a methodology that focused on forest resource, new technologies, market and economic aspects.

Forest Resource

Increasing levels of conservation Australia-wide, have led to a reduction in the area of native forest available for commercial timber production. This in turn has led to a decrease in the availability of large diameter, high quality sawlogs used for traditional solid wood products. As a result, there is a growing interest in EWPs as a practical alternative (Forestry Tasmania, 2014).

The Australian forest industry also produces substantial volumes of wood (log and processed) that does not meet target product requirements and therefore could be suited to alternative EWPs. For example, in the native forest sector in Australia, most sawmills recover less than 40% of the input log volume as saleable product, and in all native forests there are significant proportions of non-sawlog trees (residual or pulp wood) whose traditional markets are low-value and provide minimal opportunities for value-adding. Additional to this are the large quantities of wood that because of unsuitability for conventional products remain unprocessed or are sold in marginal recovery outlets.

In regards to plantation hardwoods, ABARES (2016) report that in the period 2025-2029, plantation hardwood sawlog supply is expected to increase to an average of 715,000 cubic meters a year. A significant proportion (probably around 50% or 358,000 cubic meters a year) is expected to be of low quality and not suitable for conventional sawn board markets.

The Australian hardwood sector is however largely constrained because of its relatively small and dispersed production volumes resulting in insufficient critical mass to fully exploit market opportunities. This is one of the clear benefits of this collaborative project which brought interested industry stakeholders together to clearly understand the opportunities of their resource in these emerging EWP product markets. Whilst the desirable properties of hardwoods are well known (appearance, strength, durability, hardness, etc.) there are some ill-informed perceptions and scepticism about the ability to manufacture hardwood engineered wood products (e.g. gluing, jointing, product grade, size and weight). These issues were examined, addressed and defined in this project in order to clarify the exact manufacturing requirements and opportunities. The development of new technologies will help remove barriers allowing industry to prosper and grow in this new market opportunity.

In softwood mills, up to 35% of the sawn production typically is categorised as fall-down grade with limited market opportunities. Using ABARES (2016) forecasts for plantation softwood log production, by 2025 an estimated 1.8 million cubic metres of low quality, non-structural plantation softwood sawn timber will be produced annually, valued at around $180 million a year, resulting in a loss for that proportion of production. Available volumes of plantation hoop pine are increasing due to a lack of commercial interest and capacity, despite unique and commercially attractive wood qualities. Also despite having some unique qualities, white cypress pine struggles in its traditional market due to displacement by exotic pine, which can be more efficiently produced.

New Technologies

Optimised combinations of different forest resources using new technologies to produce innovative EWPs (mixed grades, composite hardwood/softwood products, etc.) will maximise the economic and market potential of the Australian forest and forest product industries by allowing greater and more profitable utilisation of the available but variable forest resources. Currently such products are only being produced to a very small extent in Australia, although internationally they have been commercially adopted.

Prior to this project, the Queensland Department of Agriculture and Fisheries (DAF) Forest Product Innovations had trialled alternative methods such as spindleless lathes for processing small logs, improving recovery rates by six times compared to traditional sawing (McGavin *et. al* 2014a and 2014 b, McGavin *et. al* 2015). These methods have not been previously trialled across the range of available forest resources and could assist industry in maximising recovery and market potential.

Economic and market aspects

This project also investigated the profitability of the new technologies through an economic analysis and market feasibility study. This included scenarios for varying production capacities, processing methods, product and resource types. The economic analysis was expanded across the value chain to demonstrate the enhanced profitability for forest growers, processors/manufacturers and end-users.

Report aims and structure

There were five broad aims of this project:

1. To undertake a resource analysis to identify the spatial extent, resource condition, productive capacity and availability of small peeler logs in Australian native forests and hardwood plantations.
2. To determine the appropriate processing methodologies for small diameter logs.
3. To conduct a product development analysis to determine the market feasibility of various engineered wood products (EWPs) and the identification of the ‘best bet’ products to guide project product development activities.
4. To identify the mechanical, durability and fire-resistance properties of the selected EWPs.

5. Provide an extensive economic analysis of the financial feasibility of veneer and EWP production using sub-optimum quality log resources.

The report is presented as a series of chapters based on key project milestones. Detailed aims, methodology and results are reported in each of these chapters enabling each chapter to be read independently.

Chapter 2 provides details of a forest resource assessment undertaken to determine the quantities, qualities and locations of logs potentially suited for rotary-peeling using spindleless lathe technologies. This assessment had a particular focus on: (1) native hardwood and cypress from both crown and private native forests in Queensland; (2) small-diameter sub-optimal quality logs not suited for compulsory sawlogs, poles or girders; and (3) current and forecasted future supplies.

Chapter 3 expands on the forest resource assessment reported in the Chapter 2 and reviews at a national level, the underutilised, small-diameter native forest and plantation hardwood resources potentially available for rotary-peeling using spindleless lathe technologies.

Chapter 4 reports on a study which investigated the suitability of rotary veneer processing of small-diameter native forest logs and compared the product recovery to traditional sawmill processing. Also included in the chapter is an analysis of wood properties (i.e. density and modulus of elasticity) measured on the recovered rotary veneer to guide potential engineered wood product (EWP) selection.

Chapter 5 details different structural EWPs currently being produced globally and their use in Australia, along with a preliminary market assessment to identify potential market opportunities for high performance EWPs in the emerging non-residential construction market.

Chapter 6 reports on a preliminary investigation exploring the opportunity to blend durable white cypress pine and non-durable hoop pine veneers in a plywood construction to produce a product which offers termite resistance.

Chapter 7 summarises the decision making process undertaken by the Project Steering Committee whereby a number of identified ‘best bet’ products were considered and prioritised, setting the direction for further investigations by the project.

Chapter 8 presents the mechanical properties of laminated veneer lumber (LVL) produced from blending spotted gum or white cypress pine with hoop pine veneers. Six different LVL lay-up strategies were implemented to manufacture 12-ply LVL from the three species to demonstrate the influence of construction strategy and species contribution to manufactured product mechanical properties.

Chapter 9 extends the market assessment reported in Chapter 5 with a specific focus on LVL based products (e.g. hardwood LVL, blended hardwood and softwood LVL, mass LVL panels) and the potential market that may exist for these product types when made from veneers recovered from small-diameter sub-optimal quality logs, particularly in mid-rise timber construction sector.

Chapter 10 details the key mechanical properties of cross-banded LVL manufactured from blending spotted gum and hoop pine veneers. Such properties tested included density, edgewise and flatwise bending, static Modulus of Elasticity (MoE) and Modulus of Rupture (MoR), tension and compression strength perpendicular to the grain, and longitudinal-tangential shear strength.

Chapter 11 investigated the termite resistance of six different LVL lay-ups produced from blending spotted gum or white cypress pine with non-durable hoop pine veneers.

Chapter 12 extends the preliminary termite resistance investigations reported in Chapter 6 and reports the findings from an extensive study trialling the termite resistance of LVL manufactured from various construction strategies using white cypress pine and non-durable hoop pine of varying veneer thicknesses.

Chapter 13 presents a preliminary analysis of the fire performance of six different LVL lay ups produced from blending spotted gum or white cypress pine with hoop pine veneers. The fire performance analysis focused on using standard test methods defined by the Australian Standards framework to provide a reference fire performance of different LVL constructions.

Chapter 14 provides an overview of the electrical network cross-arm market and the potential for LVL cross-arm products.

Chapter 15 provides reflections on market opportunities and the commercialisation status of various products developed during the project.

Chapter 16 quantitatively and systematically investigates the impact of log geometry on gross margins from rotary veneer production. Varying levels of sweep, taper, ovality and log diameter were analysed to determine a given log's veneer recovery. The volume of veneer that can be produced per hour from rounded logs with alternative diameters was also assessed. The chapter introduced a metric to support log procurement decisions, the maximum that can be paid for mill-delivered logs ($MDLC_{max}$) with alternative log geometry, while achieving a specified target gross margin.

Chapter 17 presents a model to estimate mean mill-delivered log costs to a spindleless rotary veneering facility and how this affects gross margins from the sale of veneer. Several veneer processing scales, log type and forest resource distribution scenarios are analysed.

Chapter 18 describes the development of a discounted cash flow financial model to evaluate the financial performance of manufacturing green veneer, dry veneer, short-length LVL beams (a one-stage LVL product), and LVL cross-arms (a two-stage LVL product) from subtropical Australian native forest hardwoods over 30 years. This analysis determined the costs, revenues, and profits and net present value of producing veneers and LVL products for a range of log diameter sizes and veneer processing scales.

Chapter 19 extends the financial analysis in Chapter 18 by investigating the financial performance of veneer and LVL manufacture for four facility locations (i.e. forest resource distribution) and three log procurement (log type) scenarios. Opportunities for distributed production were also examined, where dry veneer would be produced at one location and then transformed into LVL at an alternative location. The analysis provided a comparison of the level of impact of the following four strategic and tactical investment decisions on NPV:

1. Where should the facility be located (proximity to the forest)?
2. Which types of logs should be procured?
3. What scale of production?
4. Which product should be manufactured?

Chapter 20 provides a project summary of each of the major project areas and recommendations for future work.

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Chapter 2: The availability of small-diameter peeler logs from Queensland's native forests

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Introduction

Veneer-based EWPs present an opportunity to successfully use native forest resources for higher value appearance and structural market applications. One of the major benefits of EWPs is that lower grade and variable materials can be used to produce stable, high performing structural and appearance products. EWPs can also more efficiently use feedstock of small dimension to produce larger dimension products.

Knowledge currently exists on the processing of larger logs from native hardwood forests into EWPs such as plywood. However, for smaller native forest hardwood and cypress pine logs, the potential to produce EWPs via processes such as rotary peeling has not been possible due to processing limitations in existing facilities. Recent research by Queensland Department of Agriculture and Fisheries (DAF) has demonstrated the potential to use emerging spindleless veneering technologies (Figures 2.1, 2.2 and 2.3) to process hardwood plantation logs with sizes and qualities previously considered unable to be efficiently processed.

Figure 2.1. New commercial spindleless lathe operation in Australia.

Figure 2.2. A small-diameter hardwood log being peeled with a spindleless lathe.

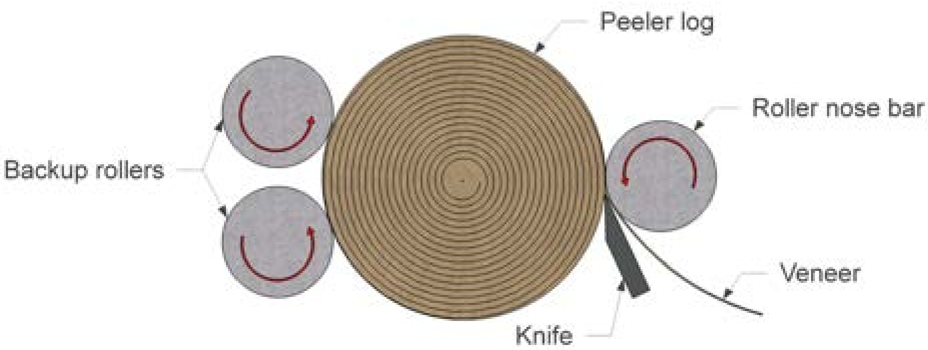

Figure 2.3. Spindleless lathe principles

This research revealed the possibilities for much higher recoveries using this method compared to traditional sawing methods to process plantation hardwood logs (McGavin *et al.* 2014a and b; McGavin *et al.* 2015a and b). However, very little is known about the suitability of this processing approach to convert small-diameter native forest logs into EWPs, and how much suitable forest resource might be available.

This chapter discusses a resource assessment relevant to Queensland forests; however, outcomes may be transferrable to other forest areas of Australia.

The main objectives of this work were to:

- Determine the quantities, qualities and locations of logs potentially suited for rotary-peeled veneer product manufacture using spindleless lathe technologies, with particular focus on:
    - native hardwood and cypress from both crown and private native forest;
    - small sub-optimal quality logs not suited for compulsory sawlogs, poles or girders; and
    - current and forecasted future supplies.
- Assist the decision making process regarding target EWP choices, market options, equipment requirements and investment in EWP processing and manufacturing facilities (Chapter7).

- Assist in determining appropriate locations for establishment of processing and manufacturing facilities.
- To contribute key data to future economic analyses (Chapters 16 to 19).
- To assist the tree and log selection processes for future processing studies (Chapter 4).

Queensland native forests encompass both hardwood and cypress forests on crown and privately owned land. Queensland has the largest forested area of any Australian state or territory with around 52 million hectares of native forest, of which around 80% is owned by the state (DAF, 2016). Of these 52 million hectares, there are approximately 20 million hectares of state-owned native forest available for commercial timber production (DAF, 2016). These forests occur on a range of land tenures, including state forests, timber reserves, extensive areas of leasehold land and some areas of freehold land where the state has retained ownership of the forest products (DAF, 2016). State forests comprise approximately three million hectares of Queensland's state-owned native forests and these are generally more productive than native forests on other state-owned tenures (DAF, 2016).

DAF Forest Products sells logs to regionally based processing companies in line with the Queensland Government's timber supply commitments. There is no certainty of crown log supply beyond these agreements.

Private native forests in Queensland are extensive, covering more than 10 million hectares across the state but generally are relatively low yielding. Of all the states, Queensland has the largest area of private native forest harvested for timber production (Ryan *et al*. 2006). The largest concentration of commercially important native forests located on privately owned land is in South-East Queensland where over one million hectares of native forests contain commercial timber species (DAF, 2016).

Within the various tenure categories in which log harvest is permitted, harvesting can be restricted by legislation, codes of practice and management plans. Reasons for these restrictions include conservation and management of biodiversity and heritage, and protection of the water supply. (ABARES, 2013).

Assessments of the quantities of native forest logs potentially available and suitable for rotary peeling using spindleless lathe technology needs to consider many factors including:

- grade quality and size requirements;
- government policies and regulations, codes of practice requirements restricting supply;
- alternative uses of logs of the same size and quality;
- commercial and non-commercial species and suitability for peeling;
- economic and market conditionse.g. increased or decreased harvesting of private forests during economic downturns or upturns in the agricultural industry;
- resource locations and distance to processing facilities and markets; and
- volumes required for achieving profitable scale.

This chapter discusses these factors and presents the results from the desktop analysis and field assessments.

Methodology

The methodology included the following two components:

- desktop analysis
- field work

Desktop analysis

The desktop analysis involved obtaining and assessing existing reports, data and information on relevant forest resource availability in Queensland in terms of species, volumes, qualities, locations, dimensions, current uses and potential suitability for veneer based EWPs. The analysis was undertaken in consultation with key organisations and experts (Table 2.1).

Table 2.1. Key people and organisations consulted for the desktop analysis.

Person	Organisation
Bill Gordon	DAF Forest Products
Jane Siebuhr	DAF Forest Products
Stuart Olive	DAF Forest Products
Chris Oppermann	DAF Forest Products
Trevor Beetson	DAF Forest Products
Neil Reinke	DAF Forest Products
Nathaniel Lindsay	DAF Forest Products
John Ludlow	DAF Forest Products
Jim Burgess	DAF Forest Industries
Dr Kerrie Catchpoole	DAF Forest Industries
Sean Ryan	Private Forestry Service Queensland
Dr Tom Lewis	Forestry Sciences, Horticulture & Forestry Science, DAF
Phil Norman	Landscape Sciences, DSITI
Kelly Bryant	Landscape Sciences, DSITI
Dr Michael Ngugi	Ecological Sciences, Queensland Herbarium

Field work

In order to address gaps in knowledge identified by the desktop analysis, field work was undertaken in selected native forests and processing facilities in Queensland. This field work focused on estimates of volumes of smaller logs suitable and potentially available for rotary peeling using spindleless lathe technology. The field work was undertaken in both hardwood and cypress forests and processing facilities.

Native hardwood fieldwork

Forest assessments

Crown forests

Plots were established in Gurulmundi State Forest (40 km north-west of Miles) and Allies Creek State Forest (50 km south of Mundubbera) in Queensland (Figure 2.4). Relevant background information was obtained from DAF Forest Products on the forests' history, silviculture, inventory and log timber sales.

In the Gurulmundi State Forest, plots were established in Management Unit Identifier (MUID) Y-MCFER01. DAF Forest Products advised that this forest MUID was representative of typical hardwood forest in this south-western Queensland region. The forest was dominated by spotted gum. The forest had previously received silviculture treatment; although no detailed records of the silviculture type was available. Harvesting had commenced in this MUID in 2013 and was ongoing at the time of plot establishment. DAF Forest Products advised that typical product harvesting rates for this MUID were as follows:

- Girders – 0.47 lm^3/ha
- Poles – 6.21 lm^3/ha
- Sawlogs – 10.71 m^3/ha

- Salvage – minimal quantities.

In the Gurulmundi State Forest, 10 plots were set up in a pre-harvest area and tree measurements were recorded. As well, three plots were set up in an area that had been recently harvested and measurements were taken only on residual harvest material.

In the Allies Creek State Forest, plots were established in MUID G-MMMU143. Eight plots were established in a forest that had been recently harvested and in this case, measurements were taken only on residual harvest material. DAF Forest Products advised that this MUID was representative of typical higher production hardwood state forest in this south-western Queensland region. The forest was dominated by spotted gum. The forest had previously received silviculture treatment in the 1960's and 1970's. Harvesting had commenced in this MUID and was ongoing at the time of plot establishment. DAF Forest Products advised that typical product harvesting rates for this MUID were as follows:

- Girders – 1.01 lm^3/ha
- Poles – 9.96 lm^3/ha
- Sawlogs – 10.90 m^3/ha
- Salvage – minimal quantities.

Figure 2.4. Map showing the location of study plots (red boxed).

With the exception of one plot that was 0.3 ha, all plots were 0.25 ha strip plots.

For the plots established in pre-harvest forest, all trees in the plot greater than 10 cm diameter at breast height over bark (DBHOB) were assessed for:

- diameter at breast height over bark (DBHOB) (converted to diameter at breast height under bark (DBHUB));
- classification – according to DAF Forest Products tree marking guidelines—sawlog, pole, girder, salvage, retained, habitat trees;
- merchantable log length and volume – sawlog, poles, peeler logs (Table 2.2), girders;
- dimensions and number of merchantable logs within each stem; and
- basal area (calculated from the data).

The specifications for peeler logs were similar to those currently used by a commercial peeler operation in Australia and are designed specifically for spindleless lathe processing of small hardwood logs. The specification used targeted logs that were of diameters less than that of logs typically used in a traditional sawmill operation. The log grading criteria used in the project are shown in Table 2.2.

Table 2.2. 'Small' peeler log specifications used for this study.

Grade criteria	Hardwood	Cypress
Minimum length	2.7 m and 1.5 m (with overcut allowance)	2.7 m and 1.5 m (with overcut allowance)
Minimum SEDUB	18 cm	16 cm
Maximum SEDUB	30 cm	30 cm
Core	Defective core should not exceed 6 cm	Defective core should not exceed 6 cm
External defect	No green knots > 6 cm; no dry knots > 3 cm. No more than one bump (i.e. occluded limbs) on visible half of the log within each 50 cm length; no more than one overgrowth (i.e. insect or logging damage) on visible half of the log within each 50 cm length; fluting acceptable where the hollows do not extend into the centre log diameter	No green knots > 9 cm; no dry knots > 4.5 cm. No more than two bumps (i.e. occluded limbs) on visible half of the log within each 50 cm length; no more than one overgrowth (i.e. insect or logging damage) on visible half of the log within each 50 cm length; fluting acceptable where the hollows do not extend into the centre log diameter
Maximum sweep	1/7 (14%) of SEDUB	1/7 (14%) of SEDUB
Ovality/taper	Log diameter 18–32 cm: maximum difference between longest and shortest axis (cm) ranging from 2.2–3.8 cm	Log diameter 16–32 cm: maximum difference between longest and shortest axis (cm) ranging from 2.2–3.8 cm
Spiral grain/grain	No spiral grain, no excessive free grain	No spiral grain, no excessive free grain

While the project focused on the use of small diameter logs,a size considered suitable for peeling using spindleless lathes currently in use in Australia,spindleless lathes can potentially peel logs up to 80 cm SEDUB. Therefore the resource availability estimates in the project are constrained by the log size specification adopted. The specifications were intentionally adopted to focus on log sizes not typically used and/or less favourable for other mainstream products such as sawlogs, larger poles and girders.

DAF Forest Products specifications were used for the other log categories.

Figures 2.5, 2.6 and 2.7 illustrate the Gurulmundi State Forest and plot assessments being undertaken.

Figure 2.5. Field assessments in Gurulmundi State Forest.

Figure 2.6. Field assessments in Gurulmundi State Forest.


Figure 2.7. Field assessments in Gurulmundi State Forest.

For the plots established in post-harvest forests, all residual post-harvest log material that remained was assessed to determine if it could provide logs that met the peeler log specifications described in Table 2.2 (Figure 2.8).


Figure 2.8. Post-harvest residual log assessments.

Private forests
Four strip plots (0.2 ha) were established in a private native forest at the Northcott property at Ironpot, about 60 km south-west of Kingaroy (Figures 2.4 and 2.9). This forest was again considered representative of typical private native forests in this region. Key features included:

- harvested extensively over the last 60 years for sawlogs, poles and sleepers;
- harvesting more intense during periodic downturns in the agricultural industry;
- dominated by spotted gum with an understorey of wattle and other miscellaneous non-commercial species;
- very little sawlog stems remain due to previous harvesting; however, the forest; remains overstocked with smaller diameter stems and would greatly benefit from silvicultural treatment to increase productivity; and
- property also used for cattle grazing.

All trees in the plot greater than 10 cm DBHOB were assessed for:

- DBHOB (converted to DBHUB);
- merchantable log length and volume – peelers; and
- dimensions and number of small peeler logs within each stem.

The specifications for peeler logs were those described in Table 2.2.

Figure 2.9. Field assessments in private hardwood native forest.

Log assessments at mills
In order to collect data on logs in mill yards that met the small peeler log specifications, assessments were undertaken at Parkside's mill at Wandoan (Figures 2.10 and 2.11). These assessments included recording the dimensions and numbers of logs meeting the small peeler log specifications (Table 2.2).

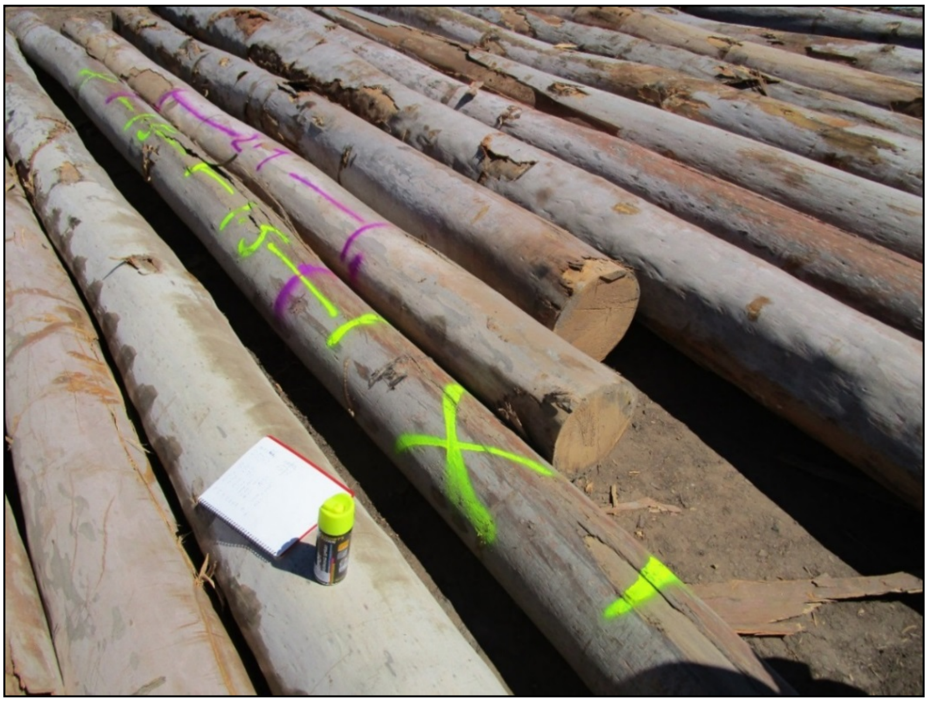

Figure 2.10. Log assessments at Wandoan mill.

Figure 2.11. Log assessments at Wandoan mill.

Cypress pine fieldwork

Mill assessments

According to DAF Forest Products, all available cypress pine potentially suitable as peeler logs from crown forests in Queensland are already being sent to sawmills in the region, therefore field work for the cypress pine component focused only on the logs available at these sawmills. DAF Forest products advised that peeler logs would have to be sourced from the existing crown sawlog allocations or from private forests. In order to collect data on logs in mill yards that meet the peeler specifications, assessments were undertaken at two cypress mills in Queensland—Hurfords at Chinchilla and Gersekowski sawmill at Cecil Plains

(Figure 2.12). Assessments were taken on random selections of logs in the log yard. These assessments included recording the dimensions and numbers of logs meeting the small peeler log specifications given in Table 2.2.

Figure 2.12. Log assessments at a cypress sawmill.

Results

General overview of Queensland's native forests

Queensland's native forests are extensive and diverse. They range from wet forests such as rainforest and wet eucalypt forest to dry eucalypt, cypress and acacia forests (Ryan *et al.* 2006). Of the commercial types used for timber production, by far the largest area is occupied by dry eucalypt forests (dry sclerophyll), that contains species such as spotted gum, ironbark, bloodwood, white mahogany, grey gum, forest red gum and gum topped box (Ryan *et al.* 2006). While wet eucalypt forests (wet sclerophyll forests) are more productive, they are less extensive and include species such as blackbutt, rose gum, tallowwood and brush box (Ryan et al. 2006).

Many of these forests are composed of mixed species. Most forest types are uneven aged, displaying a range of sizes or age classes within species (Ryan *et al.* 2006).

State forests comprise approximately three million hectares of Queensland's state-owned native forests and these are generally more productive than native forests on other state-owned tenures (DAF, 2016). According to ABARES (2013), the net harvestable area of public native forest in Queensland is around two million hectares. The net harvestable area represents the net area of available and suitable forest on multiple-use public native forest land after allowing for local and/or operational constraints on harvesting (ABARES, 2013). ABARES (2013) also advises that in 2010–2011 the forest area harvested annually from multiple-use public native forest in Queensland was 28,200 hectares and the five-year mean, 2006–07 to 2010–011 was 36,220 hectares.

Inventories undertaken by MBAC Consulting in 2003 concluded that the net available forest area for harvesting from private native forests in Queensland (South-East Queensland and Western Hardwood Regions) was around 2,137,717 hectares (MBAC, 2003a,b). This was the last comprehensive inventory undertaken; however a more recent project is currently being managed by DAF that will provide updated private native forestry inventory information for Queensland (FWPA, 2016).

Private native forests make a significant contribution to Queensland's forest and timber industry, supplying an estimated 60% of the domestically produced hardwood resource and less than 10% of the domestically produced white cypress pine resource (DAF, 2016). Many regional sawmills are reliant, or at least partially reliant, on the timber produced from these forests (DAF, 2016). Many productive private native forests are located on large properties where cattle grazing is the major focus of the enterprise (DAF, 2016). However, well managed private native forests can generate additional income for landholders and beneficial land management and environmental outcomes in conjunction with productive grazing systems (DAF, 2016). Selective harvesting practices are universally applied in private native forests in Queensland; however, a history of crop tree harvesting without follow up silvicultural treatment has tended to leave the majority of these forests in a relatively low productivity state (DAF, 2016). Excessive regrowth has caused huge competition between trees causing many stands to become essentially dormant. One reason that these forests are not being silviculturally treated is due to a lack of demonstrated markets for the thinned stems. Harvesting these logs to supply spindleless lathe peeling operations could offer a viable financial solution. Spindleless lathe peeling operations could also be beneficial in facilitating the silvicultural treatment of crown hardwood forest.

The most productive forests (both crown and private) are generally located in the southern part of the State and east of the Great Dividing Range, where rainfall and soil conditions are more favourable than the conditions in the western region of Queensland (DAF, 2016). Queensland's native forests are generally slower growing and less productive when compared to southern temperate forests (DAF, 2016). Native forests supply about 18% of Queensland's domestically sourced timber, of which approximately one third is cypress pine and two-thirds is native hardwood (DAF, 2016). The remaining 82% of Queensland's domestically sourced timber is obtained from plantations (DAF, 2016).

Figure 2.13 shows a map of the major forest resource areas of Queensland.

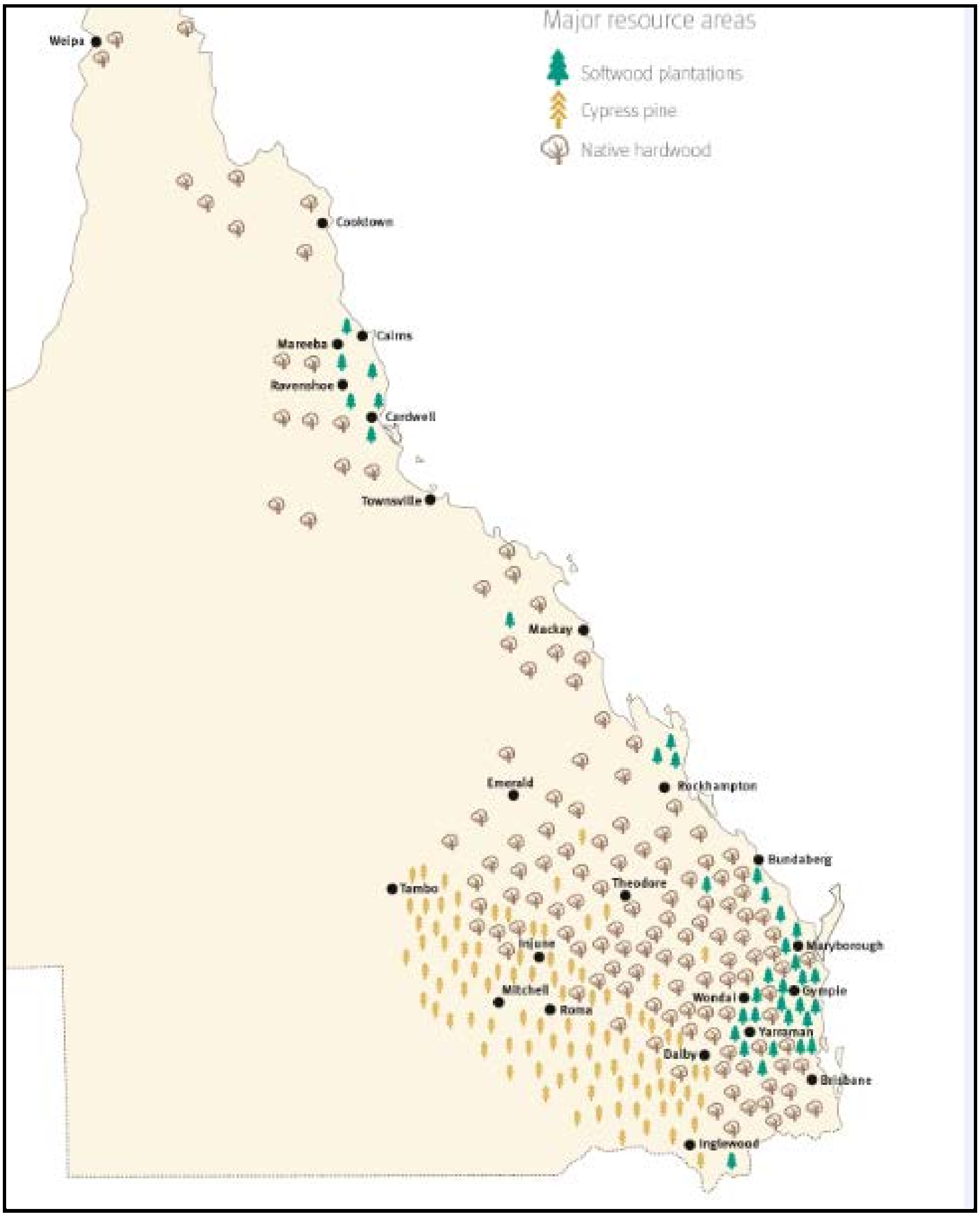

Figure 2.13. Major forest areas in Queensland (from DAF Forest Products, 2016).

Policy and regulation of Queensland's forests

Crown native forests

Management of Queensland's crown / State-owned native forests is divided between a number of agencies. The Forest Products business unit of DAF manages activities related to the supply of native forest timber products from State forests, timber reserves and other State-owned lands, as well as other tenures where native forest timber products have been reserved to or are owned by the State (DAF, 2017). Forest Products does this across Queensland under the authority of the *Forestry Act 1959* (DAF, 2017). Harvest plans are developed by Forest Products operational staff for native forest harvesting sites (DAF, 2017). As part of the harvest planning process, the impact of harvesting on all forest values including threatened species, soil, water and cultural heritage are assessed (DAF, 2017). Control measures to mitigate impacts are prescribed in accordance with the Department of National Parks, Sport and Racing‘s Code of Practice for Native forest Timber Production on the QPWS Forest Estate 2014 (DAF, 2017). Forest Products regularly monitor compliance with and review efficiency and effectiveness against legislation, policies, codes of practice and the Australian Standard for Sustainable Forest Management (DAF, 2017). As the custodians of the forest estate, Queensland Parks and Wildlife Service (QPWS) audit timber harvesting activities for compliance with the Code of Practice for native forest timber production on the QPWS forest estate 2014 (DAF, 2017). To maintain certification to the Australian Standard for Sustainable Forest Management, DAF Forest Products must regularly pass independent audits of their management system (DAF, 2017).

QPWS manages reservation and other non-commercial aspects of forest management in Queensland's State forests and timber reserves as the custodian (DAF, 2017).

Private native forests

Private native forests in Queensland are generally mapped as 'remnant regional ecosystems' or 'regrowth regional ecosystems' under the *Vegetation Management Act 1999*. There are also significant 'non remnant' areas of private native forest in Queensland (DAF, 2017).

Private native forest management and timber harvesting (forest practices) on mapped remnant or regrowth regional ecosystems areas are subject to the Code applying to native forest practice on freehold land and the *Vegetation Management Act 1999* (DAF, 2017). The Department of Natural Resources and Mines provides information about conducting 'forest practices' in private native forests in accordance with the Code applying to a native forest practice on freehold land and the *Vegetation Management Act 1999* (DAF, 2017).

Current and forecasted log supplies from Queensland's native forests

On an international perspective, many of Queensland's native forest timbers exhibit unique qualities such as strength, durability and feature. To date, the single biggest industry based on native forests in Queensland has been sawmilling (Ryan *et al.* 2006). Pole production, fencing, girders and landscaping have also utilised significant volumes of timber sourced from native forests (Ryan *et al.* 2006).

Crown forests

The Forest Products unit within the Department of Agriculture and Fisheries sells logs to regionally based processing companies in line with the Queensland Government's timber supply commitments. Queensland's native hardwood timbers, such as spotted gum are strong, dense and durable in exposed use. Therefore, they are well suited to a variety of uses including building construction, bridge girders, electricity poles, landscape applications and furniture (DAF, 2016). Logs supplied include native forest hardwood sawlogs, poles, girders, landscape and fencing timbers, other hardwood round timber and miscellaneous products. Cypress pine is another key commercial species for DAF Forest Products and they supply around 95% of Queensland's cypress log timber (DAF, 2016). Cypress pine is a moderately strong and durable timber with a light-brown, knotty appearance. It is used in house construction, including flooring and exposed uses such as decking, cladding and fencing.

Table 2.3 summarises the quantity of log timber removals from crown forest in 2015 and 2016 for each forest region shown in Figure 2.14. It also shows long-term estimates from DAF Forest Products to the end of the supply agreements.

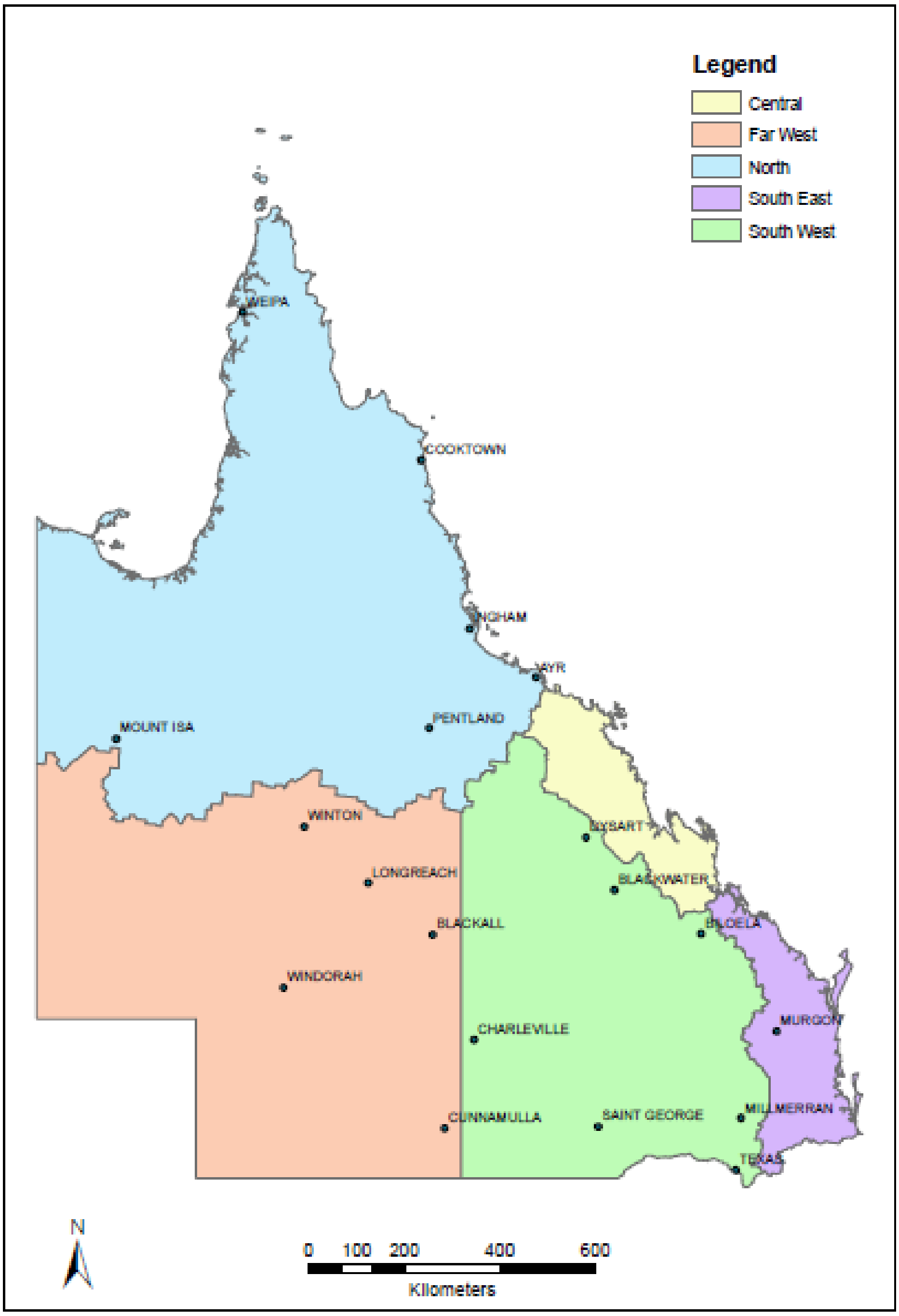

Figure 2.14. Major crown forest sale regions in Queensland (from DAF Forest Products, 2017).

Table 2.3. Crown forest log removals (DAF Forest Products, 2017).

Region	Product	Quantity (m³) by calendar year		
		2015	2016	Long-term estimate
South-East	hardwood sawlog	38,705	36,530	36,000 to 2024
	cypress sawlog	–	–	0
	pole/girder	7340	5755	7500 to 2024
	landscape and fencing timber	4450	4690	5000 to 2024
	other hardwood round timber	210	250	
	other log timber	2535	8435	
South-West	hardwood sawlog	41,770	45,760	45,000 to at least 2031
	cypress sawlog	122,455	120,865	125,000 to 2037
	pole/girder	7955	2480	5000 to 2031
	landscape and fencing timber	15,355	16,195	10,000 to 2031
	other hardwood round timber	3735	3450	
	other log timber	105	–	
North	hardwood sawlog	2540	8930	5000 to 20,000*
	cypress sawlog	–	–	0
	pole/girder	–	650	0
	landscape and fencing timber	85	335	500
	other hardwood round timber	25	70	
	other log timber	260	50	
Central	hardwood sawlog	1110	1535	1500
	cypress sawlog	–	–	0
	pole/girder	–	–	0
	landscape and fencing timber	3745	6905	2500
	other hardwood round timber	120	345	
	other log timber	–	–	
Far-West	hardwood sawlog	–	–	0
	cypress sawlog	–	–	0
	pole/girder	–	–	0
	landscape and fencing timber	–	–	0
	other hardwood round timber	–	–	0
	other log timber	–	–	0

* Depending on Cape York bauxite mining related salvage.

Table 2.3 shows that hardwood and cypress sawlogs are by far the most important product sold from crown forests in Queensland representing 81% of the total crown forest removals in 2016. The South-West region dominates crown forest log supply with 72% of the sales, followed by the South-East region with 21% of the sales.

The hardwood sawlog volumes are separated below in Table 2.4 into compulsory and optional log qualities.

Table 2.4 Crown forest compulsory and optional hardwood sawlog removals (DAF, 2017)

Hardwood sawlog volume (m³) by calendar year, region and log type								
Calendar year	South-East		South-West		Central		North	
	compulsory	optional	compulsory	optional	compulsory	optional	compulsory	optional
2005	27 230	16 475	57 745	16 675	810	270	2 805	185
2006	44 905	20 955	70 240	15 865	1 385	410	4 535	115
2007	49 290	17 195	59 710	20 335	1 995	365	2 760	125
2008	42 620	17 620	43 560	9 845	370	125	2 320	170
2009	43 020	19 330	31 955	7 775	1 210	560	1 330	135
2010	25 335	12 095	21 835	3 360	230	75	2 100	245
2011	30 945	12 005	29 530	3 105	95	–	1 275	165
2012	26 775	11 510	37 515	2 570	1 055	–	670	75
2013	33 930	13 405	36 860	2 705	1 120	0	1 630	110
2014	51 750	14 980	39 480	250	2 880	0	1 450	25
2015	28 845	9 855	40 740	1 030	1 110	0	2 435	10
2016	26 405	10 120	45 740	20	1 535	0	8 925	5

Table 2.4 shows that in 2016, 89% of the total hardwood sawlog supply was compulsory logs and 11% optional. Close to 100% of the optional hardwood sawlogs are sourced from the South-East region.

Compared to sawlogs, only relatively minor volumes of girders, piles and poles are harvested from crown forest (Table 2.5).

Table 2.5. Crown forest girder, pile and pole log removals (DAF, 2017).

Region	Product	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
South-East	girders	705	875	895	745	1285	680	655	975	1110	1350	1215	1510
	piles	685	95	35	45	15	20	-	-	0	1080	780	-
	poles	9910	10590	8725	4295	5560	5925	7670	6540	9485	6475	5340	4090
South-West	girders	–	–	–	–	–	–	–	–	465	1035	815	965
	piles	35	–	6360	2960	1795	–	–	–	0	205	1635	-
	poles	–	–	2085	720	605	–	–	–	200	1020	5500	1510
North	girders	120	10	–	–	–	0	–	–	–	–	–	110
	piles	410	345	70	280	45	35	-	60	-	10	-	-
	poles	–	–	–	–	–	–	–	–	–	–	–	535

Spotted gum is by far the most dominant hardwood species harvested from crown forests in Queensland accounting for approximately 75% of the log removals (Table 2.6); however, the species proportions vary by region (Table 2.7).

Table 2.6. Percentage of crown forest hardwood log removals by species in 2016 (DAF, 2017).

Species name	Percentage of removals 2016
spotted gum	74.7%
grey ironbark	6.2%
narrow-leaved red ironbark	4.9%
blackbutt	3.1%
forest red gum	2.9%
grey box	2.5%
broad-leaved red ironbark	2.1%
white mahogany	1.3%
Darwin stringybark	0.5%
tallowwood	0.4%
white stringybark	0.3%
grey gum	0.3%
red mahogany	0.2%
brush box	0.2%
rose gum	0.1%
remaining 12 species	0.3%

Table 2.7. Percentage of crown forest hardwood log removals by species and region in 2016 (DAF, 2017).

Forest region	Top three species in each region	Proportion of total in that region
South-West	spotted gum	94.1%
	narrow leaved red ironbark	5.0%
	other species	0.9%
South-East	spotted gum	43.1%
	grey ironbark	16.9%
	blackbutt	8.6%
North	Darwin stringybark	67.7%
	rose gum	18.7%
	red mahogany	5.0%
Central	grey ironbark	40.9%
	forest red gum	35.3%
	grey box	8.3%

Private forests

Compared to the crown forest situation, detailed data on log supplies and sales from private native forests in Queensland is very limited. According to DAF Forest Products (2016), private native forests in Queensland supply an estimated 60% of the domestically produced hardwood resource which equated to around 155 000 m^3 logs in 2014–2015 (based on 60% of the 2014-2015 total native forest log volume figures from ABARES (2016)). There is no data available state-wide on the breakdown of this log volume into different products or species.

Private Forestry Service Queensland (PFSQ, 2017) have established strip-line plots representing 248 ha within around 40000 ha of private native forest in Queensland within various forest types. Table 2.8 shows the top 10 hardwood species as a proportion of total merchantable stems in these plots. Once again, spotted gum is the dominant species; however, not to the same extent as for the crown forests commercial species log supplies from native forest. It is not known how well this data represents the wider private native forest region in Queensland.

Table 2.8. Species proportions in private native forest plots (PFSQ, 2017).

Species	Proportion
spotted gum	27%
pink bloodwood	10%
grey ironbark	9%
white mahogany	7%
blackbutt	6%
narrow leaved red ironbark	5%
tallowwood	4%
forest red gum	4%
turpentine	3%
grey gum	3%

According to DAF Forest Products (2017), approximately 120 000m^3 of the annual cypress log supply in Queensland comes from crown forests. This suggests that currently only around 6 300 m^3 of cypress logs per year are sourced from private forests.

Estimated peeler log supplies from Queensland's native forests

Crown forests

DAF Forest Products who manage the commercial operations in crown native forests was consulted about potential supply of logs meeting the small-diameter peeler log specifications outlined in Table 2.2.

According to DAF Forest Products, currently and for future supplies, the vast majority of potential small-diameter peeler logs from crown forests (both hardwood and cypress) would have to be drawn from the existing log removals from integrated harvesting operations under current supply agreements. Current harvesting operations in crown native forests produce logs for a very wide range of products including sawlogs (compulsory and optional), pole, piles, girders, other hardwood round timber, landscaping and fencing. According to DAF Forest Products, after taking into account the requirements of the Code of Practice, other regulations, current tree-marking guidelines and other product removals, very little log volume remains that would be suitable for peeling using spindleless lathes using the small-diameter peeler specifications adopted for this project.

Therefore, to source sufficient log volumes from crown forests suitable for peeling, according to DAF Forest Products, logs currently harvested for other products would need to be diverted to peelers.

Hardwood

Conversion of existing hardwood log removal data to annual peeler log supply estimates per region

In order to estimate potential small-diameter peeler log volumes available from crown forests, the field work and desktop analysis undertaken for this project established factors to convert existing crown log removal data for various products to small-diameter peeler logs. This was mainly based on discussions with DAF Forest Products staff plus assessments of logs in the forest and processing facilities to determine the volume that met the ultra-small and conservative peeler log specifications used for this study. It was also based on desktop analysis of data supplied from DAF Forest Products.

For compulsory and optional hardwood sawlogs, the volumes of these categories meeting the nominated peeler specifications was considered using the following the assumptions:

- Logs would have to meet the size and quality peeler specifications as per Table 2.2
  - Three different log length scenarios were considered:
    - Target only 2.7 m peeler lengths (and multiples thereof);
    - Target only 1.5 m peeler lengths (and multiples thereof); and
    - Target first a 2.7 m peeler length and then any additional 1.5 m peeler lengths if available.

Based on the field work and desktop analysis and using the specifications for peeler logs that were adopted for this project only a very small proportion of existing native forest hardwood sawlog removals meet the size and quality specifications for peeler logs (Table 2.9).

Table 2.9. The percent of crown hardwood sawlogs that meet the specifications adopted for peelers (2.7 m, 1.5 m and 2.7 and 1.5 m lengths).

Forest region	Log type	Percent of sawlogs that meet peeler specifications		
		2.7 m length	1.5 m length	2.7 m and 1.5 m
South-East	compulsory	0.55	0.82	0.60
	optional	5.48	6.83	5.48
South-West	compulsory	4.55	6.83	5.01
	optional	0	0	0
North	compulsory	5.49	8.25	6.05
	optional	1.57	1.96	1.57
Central	compulsory	4.04	6.07	4.45
	optional	0	0	0

The biggest constraint is excessive diameter, with the vast majority (around 90%) of hardwood sawlogs (Figures 2.15 and 2.16) being currently removed from crown forests being too big to meet the small-diameter log specifications for peeler logs adopted in this project. Overall the analysis suggested that only around 5% of the hardwood sawlog harvest from crown native forests would meet the specifications for peeler logs adopted in this project. This is primarily because the majority of the trees are harvested for their contained sawlogs and the trees marked for sawlog harvesting are principally 40+ cm DBHOB trees.

Furthermore, this assumes that all hardwood species harvested are suitable for peeling. If spotted gum only was considered, then the conversion factors shown above would reduce in accordance with the species proportions outlined in Table 2.7. However, if larger log sizes were considered, then much larger volumes of peeler logs would be available from diversion of crown hardwood sawlogs. It is noted that spindleless lathes can successfully peel logs up to 80 cm SEDUB; however, logs larger than 32 cm centre diameter under bark were not included in this project.

Table 2.10 shows the average centre diameter and length of compulsory and optional logs from the various forest regions in Queensland (DAF Forest Products 2016 data). Taking into account the centre diameter, length and taper, on average, sawlogs in all regions are much larger than the targeted small-diameter peeler log sizes adopted in the specifications for this study.

Table 2.10. Average centre diameter of crown hardwood sawlogs.

Forest region	Log type	Average centre diameter (cm)	Average length (m)
South-East	compulsory	51	7.9
	optional	42	6.2
South-West	compulsory	48	8.0
	optional	49	9.3
North	compulsory	39	8.0
	optional	41	2.4
Central	compulsory	38	6.0
	optional	40	2.1

Figure 2.15. Hardwood sawlogs.

Figure 2.16. Hardwood sawlogs.

For the other non-sawlog hardwood product removals from crown forest:

- The pole and girders were considered not available for use as peelers because they are considered more valuable being sold as poles and girders rather than peelers. Also, all of the girders and a certain proportion of the poles would be too big to meet the size specifications of peelers adopted for this project (Figures 2.17 and 2.18). Piles are potentially suitable for small-diameter peelers; however, in 2016, zero piles were harvested from crown forests in Queensland. This was mainly due to limited market demand, not because pile-quality stems were not available in the forest. Small-diameter peeler logs could offer an ideal alternative use for pile-quality stems.
- Consultation with DAF Forest Product staff, as well as assessments on typical hardwood landscaping and fencing logs, indicated that very little of this category would meet the specifications for peeler logs adopted for this project (Figure 2.19). This is mainly because of quality and size limitations.
- Other hardwood round timber is hardwood round timber less than 9.5 m with varying diameter classes. Discussions with DAF Forest Product staff suggested that some logs sold under this category could potentially meet the project specifications for peelers. For the analysis 25% of this category was considered available for peelers. More durable species than spotted gum, such as ironbark, are normally sold as other hardwood round timber. Also diameters can range from less than 15 cm SEDUB to over 35 cm SEDUB therefore not all would meet the project’s size specifications for peeler logs.
- Consultation with DAF Forest Products staff also suggested that most of the ‘other log timber’ category in Table 2.3 is made up of products such as wood chopping blocks, sandalwood and speciality timber, therefore it was not considered as being likely to be suitable for peelers.

Figure 2.17. Hardwood girders

Figure 2.18. Hardwood pole

Figure 2.19 Hardwood salvage logs used for landscaping, split fence posts and other products

Based on the conversion factors and other information discussed above, potential crown small-diameter peeler log supply/year based on typical crown log removals was estimated for each region. This data is shown in Table 2.11 below.

Table 2.11. Quantities (m^3) of existing crown hardwood log removals (all species) estimated to meet the small peeler log specifications adopted for this project

Region	2.7 m only target	1.5 m only target	2.7 m and 1.5 m
South-East	747	963	747
South-West	2 910	3 936	3 117
North	268	418	318
Central	147	177	153
Far-West	0	0	0
Total	4 072	5 494	4 335

Table 2.11 shows that targeting 1.5 m lengths produces greater volumes than targeting 2.7 m lengths. The South-West region provides the greatest quantities of peeler logs.

Table 2.11 highlights that very little of the existing hardwood log removals from crown forests (excluding poles) meets the specifications for small-diameter peeler logs adopted for this project. In total, across all the regions, only an estimated 4072 m^3, 5494 m^3 and 4335m^3 per year met the specifications depending on which length scenario is considered. Furthermore, this assumes that all hardwood species harvested are suitable for peeling. If spotted gum only was considered then the quantities shown above would reduce in accordance with the species proportion outlined in Table 2.7. However, if larger log sizes were considered, then much larger volumes of peeler logs would be available from crown forest hardwood log sale diversions noting again that spindleless lathes can successfully peel logs up to 80 cm SEDUB; however these larger logs were not included within the scope of the project. Also it is possible that larger volumes could be suitable for peeling if the permissible number of knots was increased and if the centre defect in the core was increased (depending on log diameter). In this study no green knot > 6 cm in size was allowed and the maximum size of the core defect was 6 cm irrespective of log size. Further work is needed to determine what volume would be available if the knot size and number of knots was increased.

This reflects the current tree marking of principally 40+ cm DBHOB trees for their contained sawlogs and the sale practice of prioritising supply of compulsory sawlogs which accept a minimum SEDUB of 30 cm and 25 cm in the South-East and South-West regions respectively, whereas the small peeler log specification adopted for this project accepts a minimum SEDUB of 18 cm up to 30 cm. If peeling operations were to commence targeting small-diameter logs, then depending on required commercial volumes, tree marking practices would need to change to facilitate the supply of small-diameter peeler logs.

DAF Forest Products has advised that total hardwood sawlog availability in the North region could be up to four times as high as current removals in this region, depending on outcomes from Cape York bauxite mining related salvage. This could increase availability of peeler logs in the North region.

Hardwood peeler log supply on a per hectare basis (from field work)

Plots established pre-harvest in crown forest

Table 2.12 shows the estimated quantities of logs for different products available from the Gurulmundi State Forest based on the plots established pre-harvest. Data is shown as estimated quantities available on a per hectare basis. Peeler log estimates are based on the ultra-small and conservative size specifications adopted for this project. Various scenarios are shown. These are:

- Scenario A – assuming all trees are available for harvesting and disregarding the Code of Practice and other requirements for habitat and retained trees.
- Scenario B – assuming that all 'habitat' marked trees are unavailable for harvesting.
- Scenario C – as currently tree-marked by DAF Forest Products for current harvesting and sale practices and in accordance with the Code of Practice – all trees marked 'habitat' and 'retained' are not available; however, trees marked for other products are available for peelers.
- Scenario D – as currently tree-marked by DAF Forest Products for current harvesting and sale practices and in accordance with the Code of Practice and logs intended for other products such as sawlogs and poles not available for peelers.
- Scenario E – assuming that all 'habitat' marked trees are unavailable for harvesting; however, all other trees are available as peelers as long as 50% of the basal area is maintained as per the basal area requirements in the Code of Practice.
- Scenario F – assuming that all 'habitat' marked trees are unavailable for harvesting; logs intended for other products such as sawlogs and poles not available for peelers; however, some trees marked 'retained' can be harvested for peelers as long as 50% basal area is maintained as per the Code of Practice.

Table 2.12. Estimates of log volumes per hectare based on plot data

Plot	Average DBHUB	Quantity of small peeler logs available (m^3/ha)						Quantity of sawlogs and poles available (m^3/ha)	
		Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F	Sawlog	Poles
1	23.1	13.6	13.1	4.0	0	13.1	7.2	2.8	7.8
2	25.1	11.1	11.1	0	0	11.1	8.7	17.9	0
3	25.7	9.5	9.5	2.3	1.4	9.5	1.4	27.1	14.3
4	21.8	11.5	11.5	0	0	11.5	9.6	14	5.7
5	21.4	20.1	20.1	0	0	20.1	17.8	13.6	3
6	34.6	10.9	10.9	0	0	10.9	0	27.5	20.3
7	38.4	8.4	7.5	0	0	7.5	1.9	19.3	34.6
8	34.2	9.8	9.8	1.7	1.7	9.8	1.7	16.5	8.4
9	32.8	1.2	1.2	0	0	1.2	0	14.9	0
10	25.3	9.1	9.1	0	0	9.1	2.1	11.8	0
Mean	28.3	10.5	10.4	0.8	0.3	10.4	5.0	16.5	9.4

Further inventory work is required to take into account the variability that exists in native forests across Queensland, however Table 2.12 shows that under the most typical current scenario(scenario D)where current tree marking guidelines and Code of Practice requirements are adhered to and logs already removed for sawlogs, poles and girders are not available for peeling, very minimal quantities of small-diameter peeler logs were available from the Gurulmundi crown forest – < 1 m^3/hectare on average. This reinforces the information provided by DAF Forest Products and discussed above, that based on current tree marking, harvesting and sale practices that in order to supply small logs from crown forests for peeling, they would mainly need to be diverted from other uses. It is also a result of the ultra-small and conservative peeler log specifications adopted which excluded logs larger than 30 cm SEDUB.

However, Table 2.12 shows that considerable volumes of small peeler logs (around 10.5 m^3/ha) are contained in the trees currently marked as 'retained' by DAF Forest Products staff (refer to scenarios A and B in Table 2.11 and Figures 2.20 and 21). These trees are marked as retained for various reasons – including achieving minimum residual basal area of 50%, water course protection, habitat trees, recruitment habitat trees, incidence of rare or threatened species, required for future growth and the next and subsequent selective harvesting events, and lack of sales or markets for all qualities of logs. For this volume to be accessed for peelers, it would require adjustments to the harvesting and tree marking rules and/or modifications to the Code of Practice.

Figure 2.20. An example of a "retained tree" ideal for peeling with spindleless lathes

Figure 2.21. Gurulmundi forest showing trees marked as poles, sawlogs and habitat trees. Also showing many unmarked "retained trees" ideal for peeling with spindleless lathes

Interestingly Table 2.12 also shows that in Scenario C—where assuming all Code of Practice requirements have been met and that only peeler logs are considered as the target product from trees marked for harvesting (for sawlogs, poles, girders etc.)—very little log volume meets the requirements of peelers – on average only around 0.8 m³/ha. This is mainly because the majority of the trees marked for sawlog, pole and girders are too big to meet the small-diameter size specifications for peelers intended for processing with spindleless lathes. Therefore, by far the greatest volume of potential peeler logs is contained in the 'retained trees' not suitable for sawlogs, poles or girders.

Table 2.12 shows that relatively high volumes of sawlogs and poles were available from the Gurulmundi forest plot area, around 16.5 m³/ha and 9.4 m³/ha respectively. Normally, as a rough rule of thumb, DAF Forest Products will consider an area as economically viable to harvest if the estimated sawlog volume is at least 3 m³/ha (DAF Forest Products, 2017). However, this can vary depending on many factors including forestry region, market demand for sawlogs and other products, productivity and quality of the forest.

Volume availability is only one important factor in assessing forest resources for potential peeler log supply. Another important factor is the range of log lengths and diameters available. Figure 2.22 reveals the log length distribution for the small-diameter peeler logs under Scenario B 90% of the peeler log lengths are 2.7 m or longer. These lengths are for full length logs recovered from each stem in the forest at the harvest site, therefore not merchandised to final lengths for input into peeling operation. Figure 2.23 shows the SEDUB distribution for the peeler logs under Scenario B.

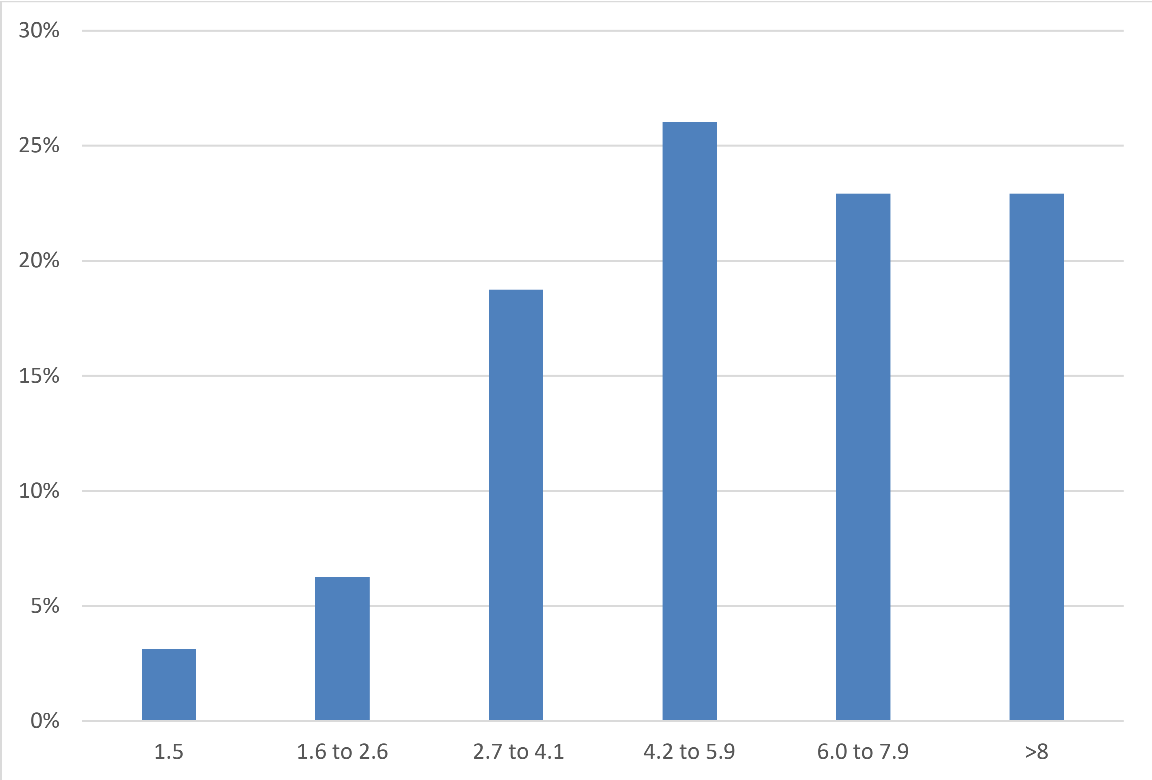

Figure 2.22. Peeler log length distribution under Scenario B

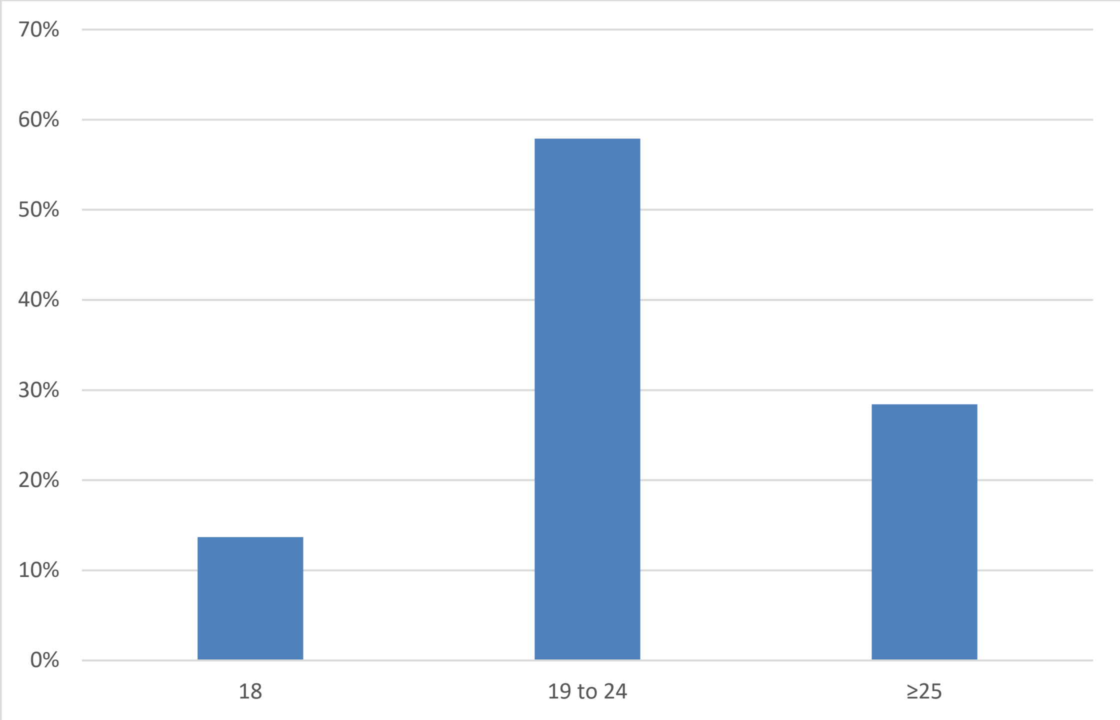

Figure 2.23. Peeler log SEDUB distribution under Scenario B

Under Scenario B the majority of the peeler logs SEDUB are in the range from 19 to 24 cm.

Plots established post-harvest in crown forest

Plots were also established in previously logged forest to establish how much of the residual logging residue from harvesting operations would meet the small-diameter peeler specifications (Figures 2.26, 2.27 and 2.28). Table 2.13 shows that very little of the logging residue met the requirements for small-diameter peelers, on average only 0.6 m^3/ hectare. Also, more than 85% of this volume was in log lengths less than 2.7 m as shown in Figure 2.24. Most of this peeler volume was less than 25 cm SEDUB (Figure 2.25).

Table 2.13. Estimates of log volumes per hectare from post-harvest residual logging residue

Plot number	Total peeler volume (m^3/ha)
11	1.70
12	0.30
13	0.00
14	0.20
15	0.20
16	1.10
17	0.80
18	0.88
20	0.40
21	0.40
22	0.30
Mean	0.60

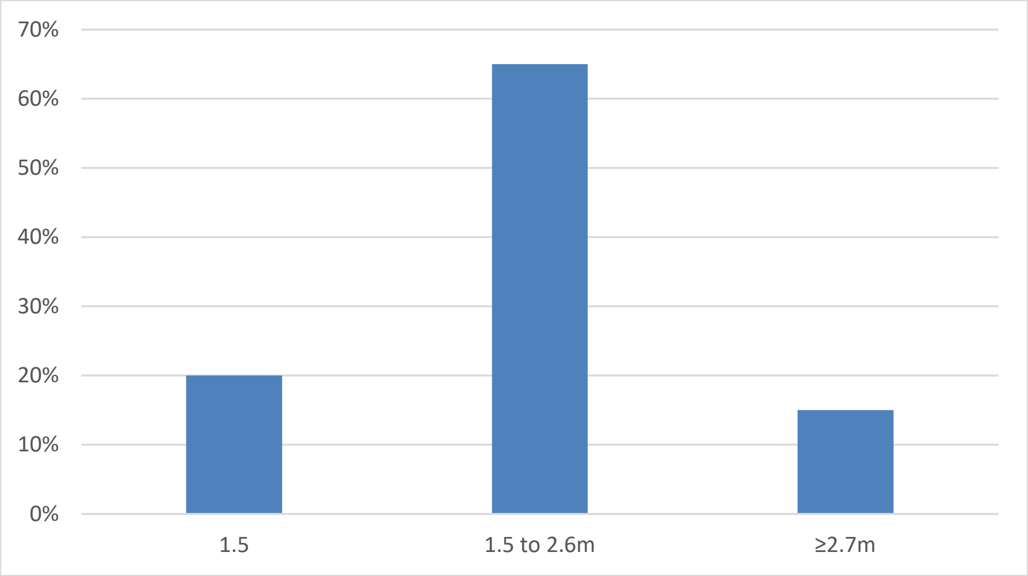

Figure 2.24. Peeler log length availability from post-harvest logging residue

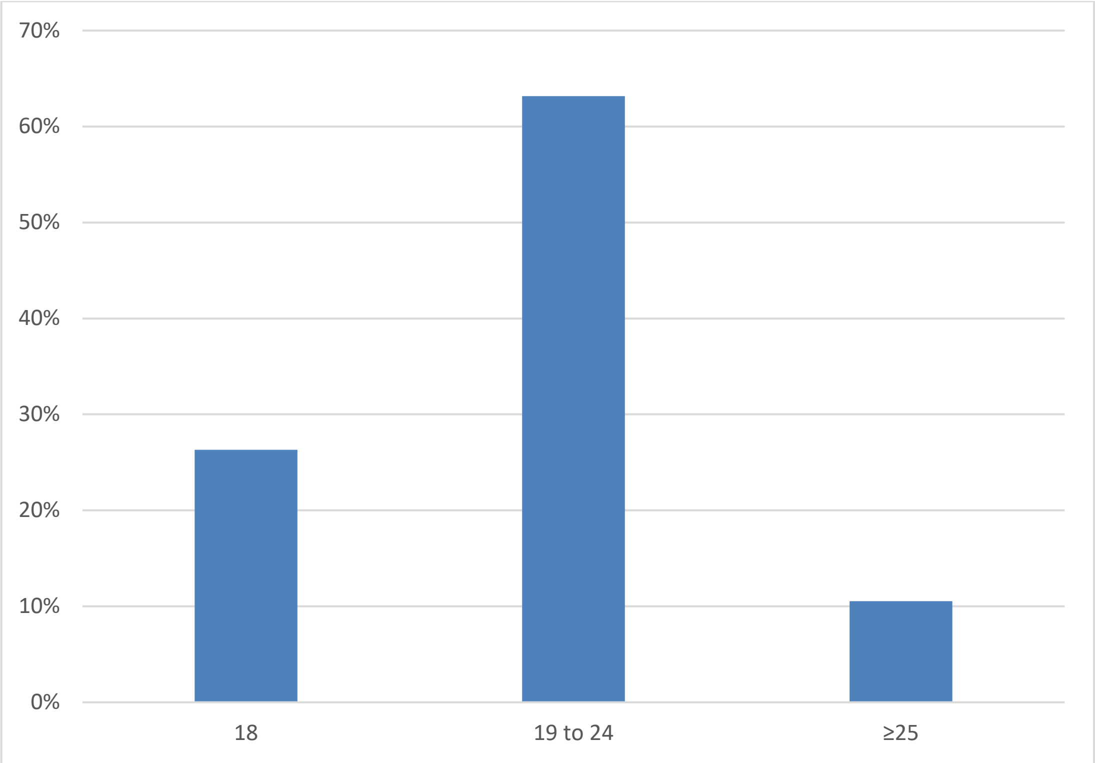

Figure 2.25. Peeler log diameter distribution from post-harvest logging residue

Figure 2.26. Post-harvest logging residue assessments

Figure 2.27. Post-harvest logging residue assessments

Figure 2.28. Post-harvest logging residue assessments

Plots established pre-harvest in private native forest

Four plots were established in private native forest at the Ironpot property near Kingaroy (Figure 2.29). Table 2.14 summarises the estimated small-diameter peeler volumes per hectare based on the assessments undertaken in these plots. These assessments were undertaken assuming that all standing trees were available for harvesting as peelers. These plots indicate significant volumes of small peeler logs are available from this private native forest (on average close to 14 m^3/ha); however, additional assessments would need to be undertaken to determine how representative these plots are of the larger private forest resource in Queensland which is known to be highly variable. Also, net peeler log recovery would also reduce after application of relevant regulations and consideration of other product types.

According to PFSQ (Ryan, pers. comm. 2017), much of the private native forest in Queensland is “locked up” or dormant and in need of silvicultural treatment. One impediment to silvicultural treatment of these forests is that the associated cost is unable to be offset due to the current lack of viable markets. Peeler logs could represent a viable market opportunity enabling the cost-effective silvicultural treatment of these forests. More work is required in this area.

Table 2.14. Estimates of peeler log volumes per hectare (from private native forest)

Plot	Estimated peeler volume (m^3/ha)
1	16.2
2	14.2
3	15.8
4	9.0
Mean	13.8


Figure 2.29. Private native forest plot at the Ironpot property

Cypress

The field work undertaken determined that around 60% of the logs in cypress pine sawmills met the quality requirements for small-diameter peeler logs. If this conversion factor is applied to the log supply figures from DAF Forest Products shown in Table 2.3, then around 75000 m³/year of crown cypress pine logs would be potentially suitable for peeling in the South-West region of Queensland. It is important to note that using these logs for peeling would reduce cypress volumes available for sawing by 60% because according to DAF Forest Products, there is no additional cypress log volume available that isn't already allocated to sawing. Crown forest cypress peeler logs would only be available from the South-West region of Queensland.

Another possibility for increasing supplies of cypress pine peeler logs and also reducing forest waste, is the utilisation of short length cypress log sections that are left in the forest (Figure 2.30). These sections result from 'butting' or 'topping ' of defective sections in cypress logs due to defects such as yellow doze, heart rot, windshake, excessive knots, bends and other defects. Current practices usually result in sections that are 1 m or less. Given that spindleless lathes can use short lengths to < 1.5 m, there may be some potential in using these short lengths for peeling, if field practices were adjusted to consider minimum peeler log lengths. Further inventory work to investigate this possibility is recommended. Markets for the resulting short length veneer would also need to be established.

Figure 2.30. Short length cypress sections left in the forest after harvesting

Private forests

Hardwood

Compared to the crown forest situation, detailed data on log supplies from private native forests in Queensland is very limited. According to DAF Forest Products (2016), private native forests in Queensland supply an estimated 60% of the domestically produced hardwood resource. Therefore, based on the current ratio of private to crown hardwood log supply, small-diameter peeler log supply from private native forests are assumed to be at least 1.5 times crown supply if current harvesting rates continue.

However, as mentioned earlier, considerable areas of private native forest are ‘locked up’ and are in need of silvicultural treatment to increase productivity. Many of the stems that could be removed as part of silviculture treatment would be suitable as small-diameter peelers. However, further inventory work is needed to provide more accurate estimates.

MBAC Consulting undertook a comprehensive inventory study of the private native forest resource in the South-East Queensland and Western Hardwood Region in 2003 (MBAC, 2003a,b). The report from this study highlights the substantial volumes of logs that are potentially available from the private native forest resource in Queensland which has the largest private native forest resource in Australia. Table 2.15 summarises the key data from this study.

Table 2.15. Queensland private native forest inventory data (MBAC, 2003)

Region	Net area (ha)	Potential Recoverable Volume (million m³)					
		Net recoverable commercial log volume	Compulsory sawlog	Optional sawlog	Pole/pile	Small round	Fencing
South-East	750 000	15.2	1.4	3.4	0.8	3.6	6.1
South-West	1 387 717	10.8	0.5	3.4	0.4	2.7	3.8

Table 2.15 shows that very substantial volumes of commercial logs are potentially available from the private native forest resource in Queensland—26 million cubic metres.

In the South-East Region, reducing the minimum sawlog size from 30 cm to 20 cm for compulsory logs and from 28 cm to 20 cm for optional sawlogs increased the sawlog volume to approximately nine million cubic metres (MBAC, 2003).

In the South-West Region, reducing the minimum sawlog size from 30 cm to 20 cm for optional logs and from 30 cm to 28 cm for compulsory sawlogs increased the sawlog volume from 3.9 to 6.4 million cubic metres. Spotted gum and ironbark represented 81% of the South-West volume (MBAC, 2003).

The study did not consider peeler logs; however, much of the significant additional log volume gained through consideration of smaller non-standard log sizes is likely to be suitable for small-diameter peeler logs.

The MBAC study is the most recent comprehensive inventory of private native forests in Queensland. However, a recent FWPA project managed by DAF is currently underway that will provide more updated estimates on private native forest inventory in Queensland (FWPA, 2016).

Cypress

Very little cypress pine is currently harvested from private native forests in Queensland with most harvested from crown forests. According to DAF Forest Products (2017), approximately 120000 m^3 of the cypress log supply in Queensland comes from crown forests. This suggests that in 2015–2016 around 6300 m^3 of cypress pine logs were sourced from private forests. Using the same conversion factor as for crown forests, an estimated 3 800 m^3 of small-diameter cypress pine logs per year from private native forests could be suitable for peeling assuming current harvesting rates apply. As for crown forests, most of this is expected to be produced in the South-West Region of the State. No information is available on the forecasted future supplies of cypress pine from private native forests.

Additional supply of peeler logs from Queensland's hardwood plantations

It was outside of the scope of this activity to analyse the potential supply of peeler logs from Queensland's hardwood plantations, however this plantation resource could add useful volumes of peeler logs to those supplied from native forests and increase the overall viability of spindleless lathe operations in Queensland.

Recent work by DAF Horticulture and Forestry Sciences, Forest Product Innovations has highlighted the potential to use emerging spindleless veneering technologies to process hardwood plantation logs with sizes and qualities previously considered unable to be efficiently processed (McGavin et al. 2014a and b, McGavin et al. 2015a and b).

In 2015, DAF commissioned a review of the hardwood plantation program in Southern Queensland. GHD Pty Ltd (GHD) (GHD, 2015) undertook this review. A summary of GHD's key findings relevant to the supply of peeler logs from hardwood plantations in Queensland is:

- There is currently 14500 hectares of hardwood plantation being managed by HQ plantations.
- This resource consists of spotted gum (62%), western white gum, 26%, Gympie messmate, 6%, Dunn's white gum, 4%, blackbutt and other hardwood species, 2%.
- Around 27000 m^3/year of standard and utility grade butt logs were estimated to be available from these plantations over a 25-year average supply/investment timeframe

starting in 2025, with 60% available in the first 10 years. There was also more than 33 000 m³/year of residual grade log available over the same timeframe. However, GHD did not discuss this as a suitable log grade for peeling. Most of the residual grade log volume is in small tops.

Figure 2.31 shows the projected average total-tree volumes for each region broken up by notional log product.

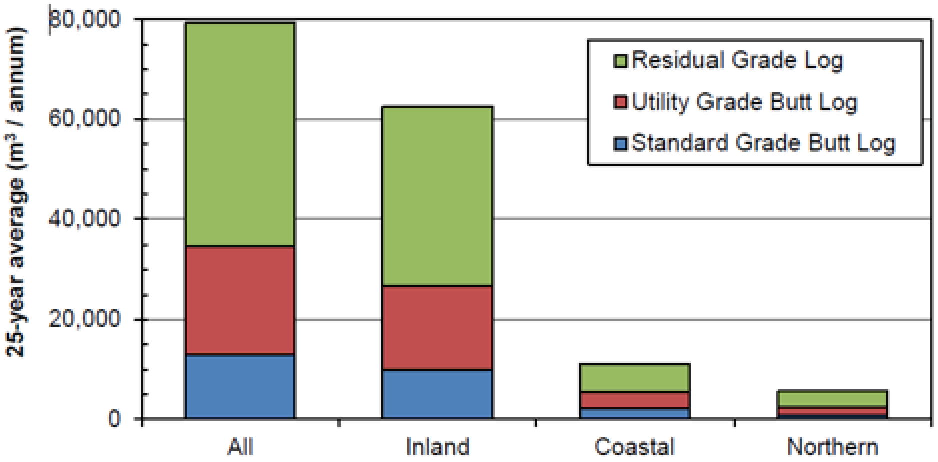

Figure 2.31. Projected average total-tree plantation hardwood volumes for each region broken up by notional log product (from GHD, 2015)

GHD did not consider this potential plantation log supply as being of sufficient scale to support greenfield investment in a dry veneer mill (minimum log input 50000 m³/yr) or in a plywood mill (minimum log input 100000 m³/yr). However, the review did not consider potentially more realistic smaller scale; however, still viable operations based on throughput volumes less than 30000 m³.

Conclusions

Substantial volumes of logs meeting the ultra-small peeler specifications adopted for this project are potentially available from native forests in Queensland and particularly in private native forests. However, in the case of hardwood forests most of this volume is currently left 'standing' in the forest for a number of reasons including:

- Current lack of 'demonstrated' viable markets for this log size and quality.
- Current tree marking, harvesting and sale practices focusing on mainstream larger log size products such as compulsory sawlogs, poles and girders.
- Part of the future growing stock for the next and subsequent selective harvesting events.
- Code of Practice and other regulations.

Current native hardwood forest sales are mainly for products such as sawlog, poles and girders because of existing market demand. It is possible that if demand for small peeler logs commenced, then there may be a shift in tree marking procedures to facilitate sales of the smaller peeler logs. This would need to consider economic viability for processors and forest managers.

Long-term supply of hardwood logs meeting the small-diameter peeler log specifications used is likely to be dominated by private native hardwood forest rather than crown hardwood forest.

Excessive unmanaged regrowth has caused many private native forest stands in Queensland to become essentially dormant with low commercial productivity. One reason that these forests are not being silviculturally treated is due to a lack of demonstrated markets for the small stems that need to be removed. Harvesting these logs to supply spindleless lathe peeling operations could offer a viable solution to this problem. Spindleless lathe peeling operations could also be beneficial in facilitating the silvicultural treatment of crown hardwood forest.

Long-term supply of cypress pine logs meeting the small-diameter peeler specifications used is likely to be dominated by crown forest rather than private forest. The vast majority of cypress peeler log supply would have to come from diversion of existing cypress sawlog operations.

This chapter discusses the results of a preliminary resource assessment based on limited case studies. Further inventory work and analysis is recommended to determine how representative the results are to the wider highly variable crown and private native forest estate in Queensland and to improve estimates of likely volumes available. Additionally, the study considered only small-diameter logs (< 30 cm SEDUB) which limited the resulting available volumes. Given spindleless lathes are able to process logs up to 80 cm, additional analysis including larger log sizes (assuming diversion from other uses such as sawlogs) would be expected to significantly increase the volume of logs suitable for rotary veneer processing. Further processing, product and market research could result in a new set of log specifications being developed that could significantly change the resource availability estimates.

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Chapter 3: The potential for Australia's native forest and plantation hardwood resources to supply small-diameter logs for rotary veneer processing

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Introduction

Veneer-based EWPs present an opportunity to successfully use native forest resources for higher value appearance and structural market applications. One of the major benefits of EWPs is that lower grade and variable materials can be used to produce stable, high performing structural and appearance products (Figure 3.1). EWPs can also more efficiently use feedstock of small dimension to produce larger dimensioned products.

Figure 3.1. Examples of veneer-based EWPs

Knowledge currently exists on the processing of larger logs from native hardwood forests into EWPs such as plywood. However, for smaller native forest hardwood and cypress pine logs, the potential to produce EWPs via processes such as rotary peeling has not been possible in the past due to processing limitations in existing facilities. Recent research by Queensland Department of Agriculture and Fisheries (DAF) has demonstrated the potential to use emerging spindleless veneering technologies (Figures 3.2, 3.3 and 3.4) to process hardwood plantation logs with sizes and qualities previously considered unable to be efficiently processed.

Figure 3.2. New commercial spindleless lathe operation in Australia

Figure 3.3. A small-diameter hardwood log being peeled with a spindleless lathe

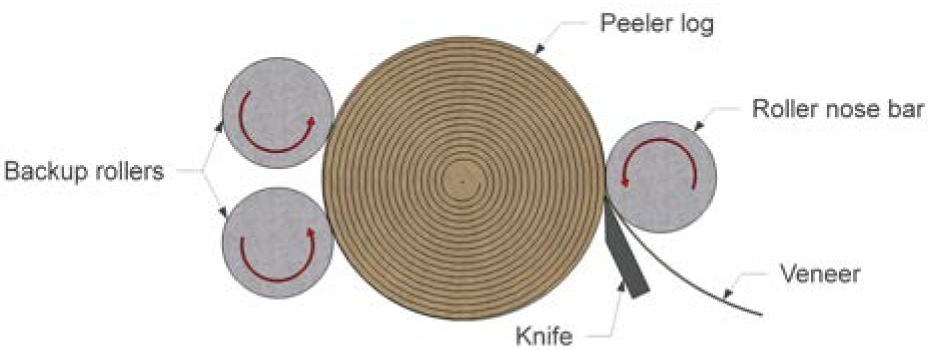

Figure 3.4. Spindleless lathe principles

Earlier research with plantation grown hardwood logs concluded that recoveries using a spindleless lathe were much higher than that achieved by traditional sawing methods (McGavin *et al*. 2014a and b; McGavin *et al*. 2015a and b). However, very little is known about the suitability of this processing approach to convert small-diameter native forest logs into EWPs, and how much suitable forest resource might be available.

This chapter discusses a resource assessment relevant to the national native forest estate. Chapter 2 discussed in detail the current resource situation in Queensland in relation to small-diameter peeler log availability from native forest. The work in Queensland included field case studies. This chapter discusses the results from a desktop analysis of available information concerning the national native forest and hardwood plantation resource. Some discussion on the results from the field case studies in Queensland is also included.

The main objectives of this work are to:

- Describe the quantities, qualities and locations of logs potentially suited for rotary-peeled veneer product manufacture using spindleless lathe technologies, with particular focus on:
    - native hardwood and cypress from both crown and private native forest.
    - smaller diameter, sub-optimal quality logs including logs (or portions of logs) that are available for harvesting and/or processing however they are not processed for standard, traditional target products because of size, quality, technical and economic reasons.
    - current and forecasted future supplies.
- Assist the decision making process regarding target EWP choices, market options, equipment requirements and investment in EWP processing and manufacturing facilities (Chapter 7).
- To contribute key data to the economic analyses (Chapter 16 to 19).
- Provide some information on the national plantation hardwood resource availability and suitability for rotary-peeled veneer product manufacture.

Australia's native forest wood and wood-based products are mostly sourced from multiple-use public forests in New South Wales, Queensland, Tasmania, Victoria and Western Australia (ABARES, 2013). Forests on land with leasehold and private tenure also contribute to supply in these states. Limited and periodic supplies are provided from leasehold and private tenures in the Northern Territory. By regulation, no commercial harvesting is carried out in native forests in the Australian Capital Territory or South Australia (ABARES, 2013).

In 2010–11, 36.6 million hectares of native forest in Australia was available and suitable for commercial wood production. Of this area, 7.5 million hectares was in multiple-use public forests and 29.1 million hectares was in leasehold and private forests (ABARES, 2013). However, when additional local restrictions to maintain and manage non-wood values are taken into account, the net harvestable area in multiple-use public native forest is 5.5 million hectares (ABARES, 2013).

Australia’s native forests encompass both hardwood and cypress forests on crown and privately owned land. Queensland has the largest forested area of any Australian state or territory with around 52 million hectares of native forest, of which around 80% is owned by the State (DAF, 2016).

Within the various tenure categories, in which wood harvesting is permitted, harvesting can be restricted by legislation, codes of practice and management plans. Reasons for these restrictions include conservation and management of biodiversity and heritage and protection of the water supply (ABARES, 2013).

Assessments of the quantities of native forest and plantation logs potentially available and suitable for peeling using spindleless lathe technology needs to consider many factors including:

- grade quality and size requirements
- government policies and regulations, codes of practice requirements restricting supply
- alternative uses of logs of the same size and quality
- commercial and non-commercial species and suitability for peeling
- economic and market conditionse.g. increased or decreased harvesting of private forests during economic downturns or upturns in the agricultural industry
- resource locations and distance to processing facilities and markets
- volumes required for achieving profitable scale
- effects of natural disasters such as fire and cyclones
- forest silvicultural practices

This report discusses these factors and presents the results from the desktop analysis and field work.

Methodology

The methodology included the following two components:

- desktop analysis
- field assessments (for Queensland only)

Desktop analysis

The desktop analysis involved obtaining and assessing existing reports, data and information on relevant forest resource availability in Australia in terms of species, volumes, qualities, locations, dimensions, current uses and potential suitability for veneer-based EWPs. The analysis was undertaken in consultation with key organisations and experts from across Australia (Table 3.1).

Table 3.1. Key people and organisations consulted for the desktop analysis

Person	Organisation
Claire Howell	ABARES
Jim Houghton	FWPA
Beau Hug	ABARES
Bruce McTavish	Vic Forests
Jane Charles	Forest Products Commission WA
Chaz Neuman	Forest Products Commission WA
Dean Williams	Sustainable Timber Tasmania (previously Forestry
Justin Crowe	Forestry Corporation of NSW
Tony Johnson	Forestry Corporation of NSW
Dr Chris Lafferty	FWPA
Dr Kerrie Catchpoole	DAF Forest Industries Qld
Bill Gordon	DAF Forest Products Qld
Jane Siebuhr	DAF Forest Products Qld
Stuart Olive	DAF Forest Products Qld
Chris Oppermann	DAF Forest Products Qld
Trevor Beetson	DAF Forest Products Qld
Neil Reinke	DAF Forest Products Qld
Nathaniel Lindsay	DAF Forest Products Qld
John Ludlow	DAF Forest Products Qld

Person	Organisation
Jim Burgess	DAF Forest Industries Qld
Sean Ryan	Private Forestry Service Queensland
Dr Tom Lewis	Forestry Sciences, Horticulture & Forestry Science,
Phil Norman	Landscape Sciences, DSITI Qld
Kelly Bryant	Landscape Sciences, DSITI Qld
Dr Michael Ngugi	Ecological Sciences, Queensland Herbarium

Field assessments

For Queensland only, in order to address gaps in knowledge identified by the desktop analysis, field work was undertaken in selected native forests and processing facilities. This field work focused on estimates of volumes of smaller logs suitable and potentially available for rotary peeling using spindleless lathe technology. The field work (Figures 3.5 and 3.6) was undertaken in both hardwood and cypress forests and processing facilities. A detailed description of the field assessment methodology is provided in Chapter 2.

Figure 3.5. Field assessments in Gurulmundi State Forest in Queensland

Figure 3.6. Post-harvest residual log assessments in Gurulmundi State Forest in Queensland

For the case studies undertaken in Queensland, the specifications for peeler logs were similar to those currently used by a commercial peeler operation in Australia and were designed specifically for spindleless lathe processing of small hardwood logs. The specification used targeted logs that were of diameters less than that of logs typically used in a traditional sawmill operation. The log grading criteria used in the project are shown in Table 3.2.

Table 3.2. 'Small' peeler log specifications used for the Queensland field studies

Grade criteria	Hardwood	Cypress pine
Minimum length	2.7 m and 1.5 m (with overcut allowance)	2.7 m and 1.5 m (with overcut allowance)
Minimum SEDUB	18 cm	16 cm
Maximum SEDUB	30 cm	30 cm
Core	Defective core should not exceed 6 cm	Defective core should not exceed 6 cm
External defect	No green knots > 6 cm; no dry knots > 3 cm. No more than one bump (i.e. occluded limbs) on visible half of the log within each 50 cm length; no more than one overgrowth (i.e. insect or logging damage) on visible half of the log within each 50 cm length; fluting acceptable where the hollows do not extend into the centre log diameter	No green knots > 9 cm; no dry knots > 4.5 cm. No more than two bumps (i.e. occluded limbs) on visible half of the log within each 50 cm length; no more than one overgrowth (i.e. insect or logging damage) on visible half of the log within each 50 cm length; fluting acceptable where the hollows do not extend into the centre log diameter
Maximum sweep	1/7 (14%) of SEDUB	1/7 (14%) of SEDUB
Ovality/taper	Log diameter 18–32 cm: maximum difference between longest and shortest axis (cm) ranging from 2.2–3.8 cm	Log diameter 16–32 cm: maximum difference between longest and shortest axis (cm) ranging from 2.2–3.8 cm
Spiral grain/grain	No spiral grain, no excessive free grain	No spiral grain, no excessive free grain

The resource availability estimates for the Queensland field studies are constrained by the log size specification adopted. The specifications were intentionally adopted to focus on log sizes not typically used and/or less favourable for other mainstream products such as sawlogs, larger poles and girders.

Results and discussion

Overview on spindleless lathes

Spindleless lathes were originally designed and developed for further processing of peeler cores produced from conventional spindled lathes. Spindleless lathes are also referred to as 'chuckless lathes' or 'centreless lathes'. While the approach has existed for decades, the commercial adoption remained very low due to spindleless lathes poor reputation for producing low quality veneer, mainly due to the variation in veneer thickness (McGavin, 2017).

In the last decade or so spindleless lathe technology has developed quickly, with it being widely adopted in countries such as China and Vietnam. This has been prompted by the rapidly growing availability of small-diameter forest resources, particularly from young fast-grown hardwood plantations (McGavin, 2017).

While spindleless lathes were originally developed to process the already pre-rounded peeler cores, many of the spindleless lathe operations today successfully use the lathes to directly process small-diameter, unrounded billets (Figure 3.7) (McGavin, 2017).

Figure 3.7. An example of a spindleless lathe

Spindleless lathes, as the name suggests, have no spindles. Rotary drive is provided by powered backup rollers. These are often supported from a driven roller nose bar. While spindleless lathes still produce peeler cores, their diameters are usually in the order of 20-50 mm. Figure 3.8 illustrates a peeler core produced from a standard rotary veneer spindle lathe and a peeler core produced from a spindleless veneer lathe (McGavin, 2017).

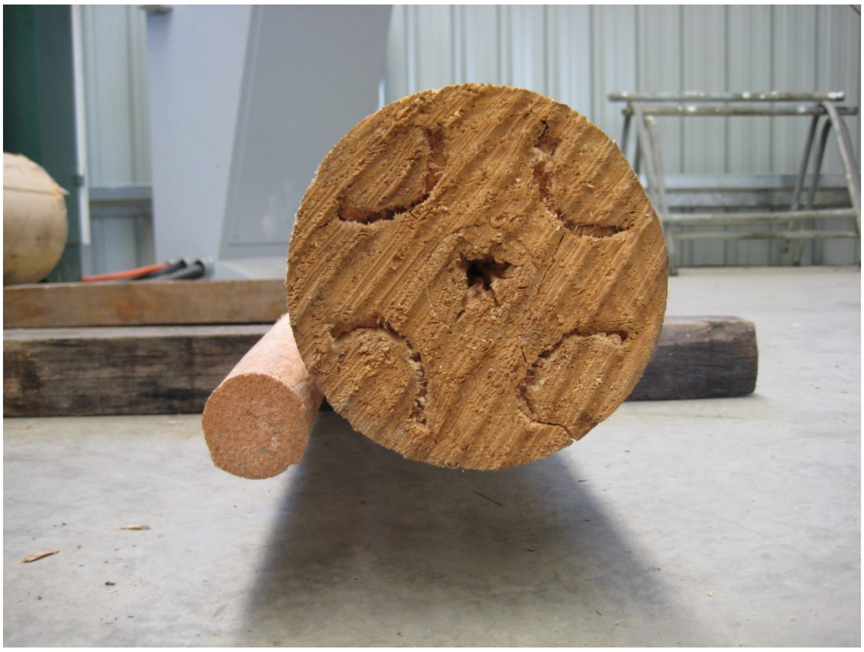

Figure 3.8. A 45 mm peeler core (left) produced from a spindleless veneer lathe compared with a 130 mm peeler core produced from a standard, commercial spindled lathe.

Without the reliance on spindles to hold the billet in position during the peeling process, billets peeled by a spindleless lathe are free from the stresses created within a relatively concentrated zone. Because of this, spindleless lathes are proving to be very successful in processing logs of a lower quality than previously considered possible (McGavin, 2017). Species more prone to end-splitting can be peeled with a reduced risk of the splits worsening during peeling. In fact, unlike spindles that force the splits further apart, the drive mechanism on a spindleless lathe effectively presses the splits together during peeling. The small peeler core size also means that billets with smaller starting diameters can be peeled. For these reasons, spindleless lathes have been adopted mostly where there is a large supply of small diameter and sub-optimum quality billets (i.e. from young, fast-grown hardwood plantations) (McGavin, 2017).

In recent years there has been a proliferation of rotary veneer processing plants worldwide, particularly in the Asia region, and especially in China and Vietnam. To a large extent this is due to the advantages of veneer-based products; however, technological advances in peeling techniques, especially using spindleless lathes, are also enabling the efficient processing of very small and young plantation hardwood logs (Leggate *et al.* 2017). Logs with small-end diameters less than 15 cm (and from trees less than five years of age) are being successfully converted into veneer-based products. In some regions, these operations are now so successful that peeling plants compete with pulpwood companies for the same quality log resource (Leggate *et al*. 2017).

Currently there is only one commercial operation in Australia using spindleless lathes for hardwood log processing. However, the Forest Product Innovations group from DAF at the Salisbury Research Facility have been undertaking research with spindleless lathes for more than 10 years (Figure 3.9). It has been demonstrated that it is possible to use spindleless veneering technologies to process hardwood plantation logs with sizes and qualities previously considered inefficient to process.

Figure 3.9. Spindleless lathe equipment and small-diameter peeler billets at the Wood Composites Facility, DAF Salisbury Research Facility

Log throughput volumes for spindleless lathes vary considerably depending on the specific equipment in use and other factors such as markets, labour costs and other economic factors. In South-East Asia, where they are common, there are many very small operations (<5000 m^3/yr), many medium size operations (5000–15,000 m^3/yr) and a handful of larger operations (>15,000 m^3/yr). Some mills will have more than one spindleless lathe in operation.

Log specifications for spindleless lathes

Apart from the one commercial operation in New South Wales, no log grade specifications have yet been developed for Australian log resources that are purposefully designed for processing with spindleless lathes. A large range of spindleless lathe equipment now exists and ideal log specifications may vary depending upon the system adopted.

Technically, spindleless lathe equipment options are available that could process logs less than 10 cm and as large as 80 cm in diameter. However, the ideal log size range for economic viability will be narrower.

Log specifications for spindleless lathe processing will need to be developed that suit the fundamental wood properties and characteristics of the different forest resources and that satisfy production and market requirements.

The log specifications adopted by the existing commercial spindleless lathe operation in New South Wales are designed for small hardwood logs less than 30 cm centre diameter under bark (CDUB), however with a minimum of 18 cm small-end diameter under bark (SEDUB).

There are other hardwood peeler log specifications in Australia, for example in Tasmania and New South Wales which are designed for use for conventional spindled lathe peeling operations and for particular markets and products. Spindleless lathes can process much smaller logs and usually logs with more defects compared to these other lathe types. Therefore, these existing peeler log specifications for other lathe types cannot be directly adopted for spindleless lathe operations.

Currently in Australia, spindleless lathes are being considered as an alternative processing option for native forest and plantation hardwood log sizes and qualities that are not ideal for sawing or for other traditional product options. Log specifications that were used for the resource assessment studies in Queensland were a modified version of the small hardwood log specifications used by the commercial spindleless lathe operation in New South Wales (Figure 3.10).

Figure 3.10. Small peeler logs conforming to the specifications used for the Queensland field studies

Australia’s native forests

General overview of Australia’s native forests[1]

National native forest land area and tenure

In 2011 Australia had 125 million hectares of forest, equivalent to 16% of Australia's land area (ABARES, 2013). Australia's forest cover is shown in Figure 3.11. Australia has about 3% of the world's forest area, and the seventh largest reported forest area of any country worldwide (ABARES, 2013).

Australia's forests comprise 123 million hectares of native forests (98% of the total forest area), 2.02 million hectares of industrial plantations, and 0.15 million hectares of other forests. Australia's native forests are dominated by eucalypt forests (92 million hectares; 75% of the native forest area) and acacia forests (9.8 million hectares; 8% of the native forest area). The area of rainforest is 3.6 million hectares (3%) (ABARES, 2013).

About two-thirds of Australia's native forest (81.7 million hectares; 66.6%) is woodland forest with 20 –50% crown cover (ABARES, 2013). The largest areas of forest containing cypress pine (*Callitris glaucophylla)*—an important commercial native softwood species—is in the inland central area of New South Wales and inland southern Queensland.

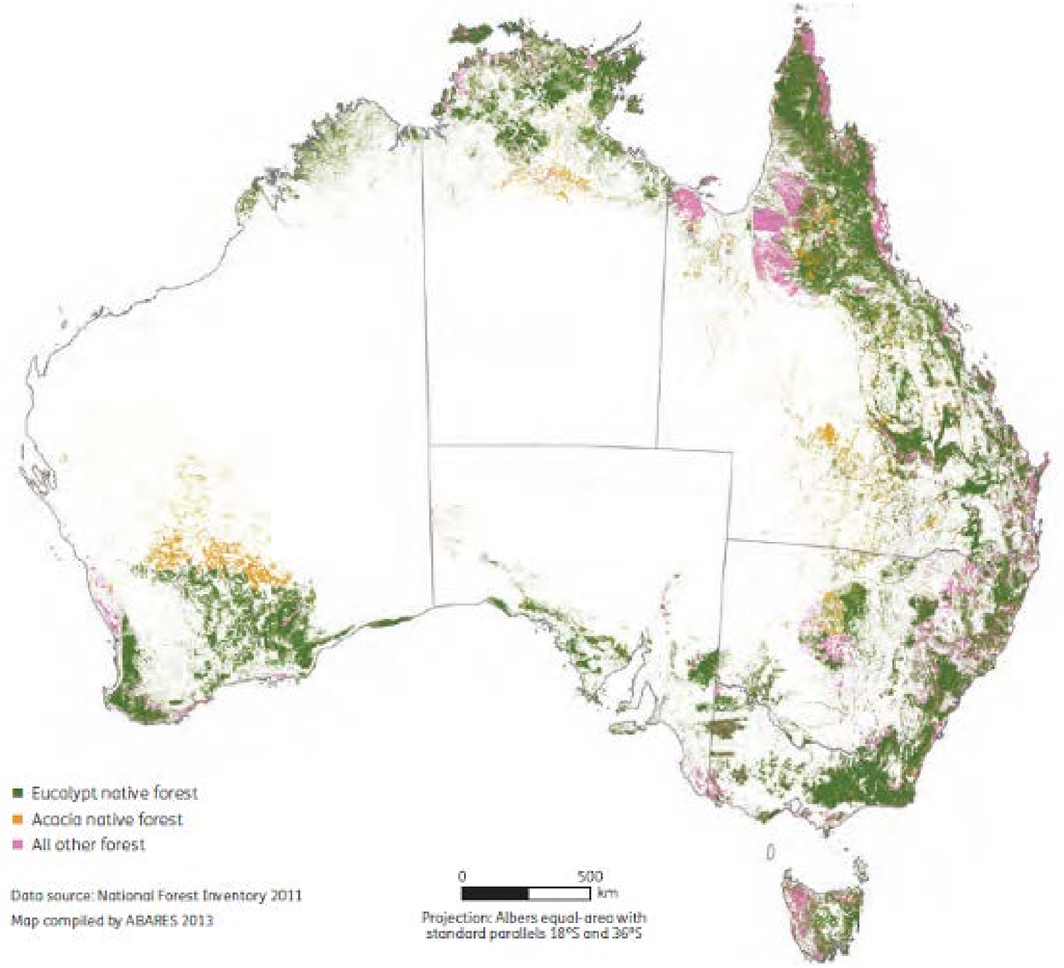

Figure 3.11. State of the Forest Report (SOFR 2013) reports Australia's total forest area as 125 million hectares, as shown in this map. Australia's 123 million hectares of native forests are dominated by eucalypt and acacia forests (ABARES, 2013)

[1] The information for this section is mainly sourced from the State of the Forests Report 2013 (ABARES, 2013)

An estimated 81.9 million hectares (66.8%) of Australia's native forest is privately managed on private and leasehold tenures, while 21.5 million hectares of native forest (17.5%) is in formal nature conservation reserves. A further 10.2 million hectares of native forest (8.3%) is in multiple-use public forests. The remaining native forest (9.0 million hectares, 7.4%) occurs on other Crown land or on land of unresolved tenure (ABARES, 2013).

The major source of native forest wood and wood-based products is multiple-use public forests in New South Wales, Queensland, Tasmania, Victoria and Western Australia. The majority of the Australian native forest estate on leasehold and private land, including forests used predominantly for extensive grazing, does not currently contribute significantly to national wood supply (ABARES, 2013).

The area of native forest, available and suitable for commercial wood production, determines the forest sector's capacity to meet demand for native forest wood and wood-based products. The availability of an area for wood production is determined by its tenure; state and territory regulatory frameworks, including Code of Practice for forests; and other requirements, such as the protection of soil, water values and biodiversity (ABARES, 2013). The area of native forest not legally restricted from wood harvesting decreased steadily over the period 2000–01 to 2010–11 as a result of the transfer of significant areas of multiple-use public forests to nature conservation reserves (ABARES, 2013). The suitability of an area of native forest for wood harvesting is also limited for commercial reasons, including the absence of tree species marketable in commercial quantities, low site productivity, isolation from markets or processing facilities, operational harvesting difficulties, and other infrastructure constraints (ABARES, 2013).

The total area of Australia's native forest, available and suitable for commercial wood production in 2010–11, was 36.6 million hectares, a decrease from 37.6 million hectares in 2005–06 (ABARES, 2013). Of this, 7.5 million hectares of public native forests is available and suitable for commercial wood production; however, when additional local restrictions to maintain and manage non-wood values are taken into account, the net harvestable area in multiple-use public native forest is 5.5 million hectares (ABARES, 2013). This represents a decrease by 46% from 1995–96 to 2010–11, from 10.1 million hectares to 5.5 million hectares. This is a direct result of significant amounts of multiple-use public native forest being transferred to nature conservation reserves (Davidson *et al*. 2008). The net harvestable area of public native forest in 2010–11 (5.5 million hectares) is 14% of the area of public native forest (ABARES, 2013). The area of multiple-use public native forest harvested annually in Australia decreased from 117,000 ha in 2006–07 to 79,000 ha in 2010–11, a decrease of 32% (ABARES, 2013).

A substantially larger area (29.1 million hectares) of leasehold and private tenure forest is potentially available and suitable for commercial wood production, but this is subject to landholder intent, markets, regulatory frameworks, and environmental constraints (ABARES, 2013).

A large part of the native forest estate on leasehold and private land contributes minimally to wood supply. This includes forests used predominantly for grazing, forests containing few marketable species in commercial quantities, forests isolated from markets, or forests where harvesting is not operationally feasible. There is relatively little commercial native forest harvested in the Northern Territory for a combination of these reasons (ABARES, 2013).

Figure 3.12 illustrates the commercial assessment of Australia's native forests across the various tenures as at 2011.

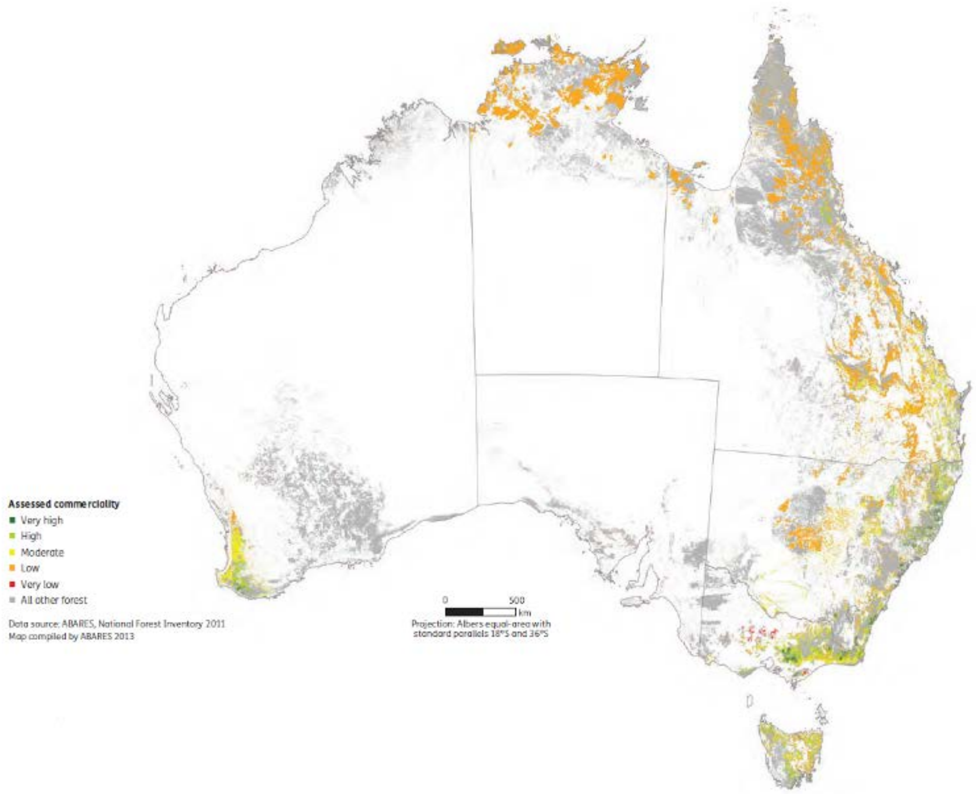

Figure 3.12: Commerciality of Australia's native forest, assessed across the leasehold, private and multiple-use public forest estate, 2011 (ABARES, 2013)

Notes: Forest 'available and suitable' for harvesting is forest with a commerciality rating of very low, low, moderate, high or very high. 'All other forest' includes forest of limited, possible or no commerciality; sandalwood; forest of unknown floristics and structure; conservation reserves where harvesting is excluded by covenant or regulation; plus forests on formal nature conservation reserves, other Crown land and land of unresolved tenure.

Commerciality is limited in the Northern Territory and northern Queensland because of accessibility and remoteness. As a consequence, only a limited amount of harvesting occurs in these areas.

National native forest log production

A total of 29,466 million cubic metres of logs was harvested in Australia in 2015–16, an increase from 26,532 million cubic metres in 2010–11 (ABARES, 2016a). The volume of hardwood logs harvested annually from native forests declined by 41% in the five-year period 2009–10 to 2014–15, from 6.589 million cubic metres to 3.895 million cubic metres (ABARES, 2016a). However, the volume of plantation hardwood logs increased in the same period by 86% from 4,555 million cubic metres annually to 8,461 million cubic metres annually (ABARES, 2016). In 2014–15, 46% of the Australian native forest hardwood log production was sawlogs and veneer logs and 49% was pulp logs (ABARES, 2016a). In the same year 3% of the plantation hardwood log production was sawlogs and 97% was pulp logs (ABARES, 2016a). Included in the ABARES classification of sawlogs are sawlogs, veneer and peeler logs, poles, piles, fencing and other log types not included elsewhere (ABARES, 2016a). In 2014–15 total Australian production of cypress pine sawlog was 177,000 m^3 (ABARES, 2016a). The majority of this was produced from Queensland crown forests that supplied 120,375 m^3 of cypress sawlogs in 2015–16 (DAF, 2016b). In 2015–16 New South Wales state forests produced 37,723 m^3 of cypress pine sawlogs (Forestry Corporation NSW, 2016a).

Between 1992–96 and 2006–11 the average sustainable yield from native forests declined nationally by 47%, and in all states except Tasmania. This decline was a consequence of increased reservation of public multiple-use native forests; increased restrictions on harvesting through prescriptions in codes of forest practice; revised estimates of forest growth and yield; and impacts of occasional, intense, broad-scale wildfires (ABARES, 2013).

The volume of sawlogs harvested from multiple-use public native forest in the period 1992–93 to 2010–11 was at or below the calculated sustainable yield in New South Wales, Tasmania, Victoria and Western Australia, and at or below the calculated sustainable yield or allowable cut in Queensland. Nationally, sawlog harvest levels were 17% below the calculated sustainable yield for the period 2006–11, and were 6–18% below the calculated sustainable yield in each of the four SOFR (State of Forests Report) five-yearly reporting periods. In the period 2006–07 to 2010–11, the average annual sawlog volume harvested from multiple-use public native forest was 1.40 million cubic metres, a decline from 1.96 million cubic metres in the period 2001–02 to 2005–06 (ABARES, 2013).

As the supply of high-quality logs from public multiple-use native forests declines as a consequence of increasing forest reservation and other factors, the importance of private native forests for the supply of hardwood logs will increase. The management of private native forests will increasingly determine the long-term national supply of high-quality native hardwood logs. However, a national assessment found that there is insufficient information to determine whether the rate of wood harvest from private native forests is sustainable (ABARES, 2013).

Figure 3.13 reveals the major changes in Australia's forest resource supply since 1971–72. Key trends are the growth in both softwood and hardwood plantation log volumes and the substantial decline in native forest hardwood log supply.

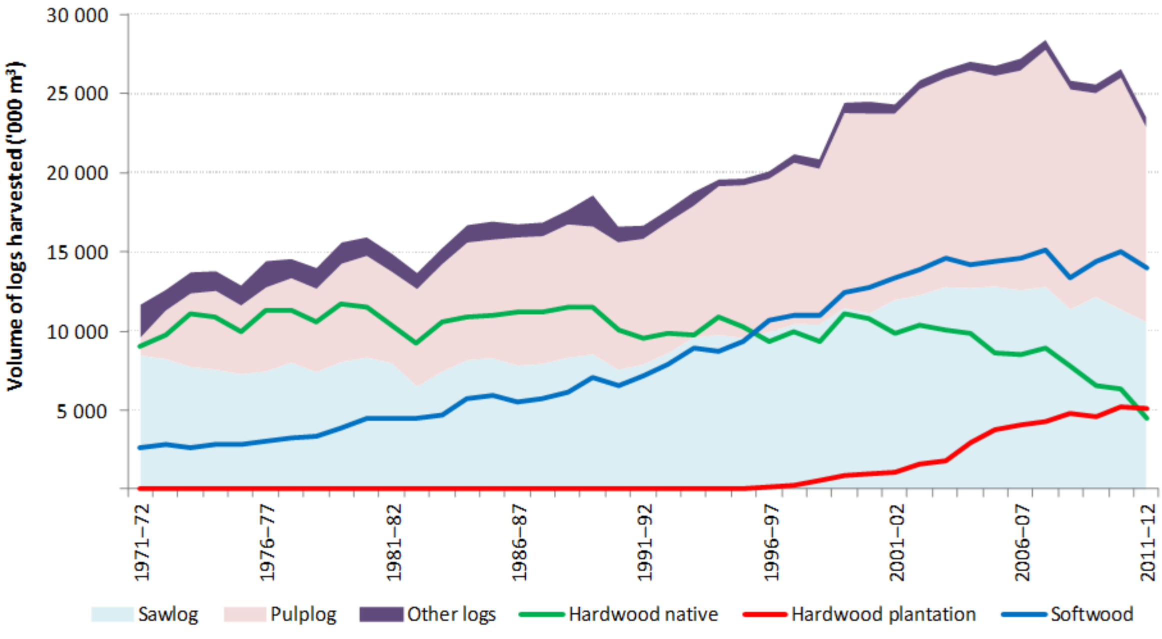

Figure 3.13. Historical logs harvested, by log type, 1971–72 to 2011–12 (Burns *et al*., 2015)
Note: Other logs include poles, piles, fencing and logs not elsewhere included. Excludes fuel logs.

A forecast of potential future wood supply from multiple-use public, leasehold and private native forest to 2050 is presented in Figure 3.14 (ABARES, 2013). The forecast is a compilation of projected wood supply from native forests in six forest regions covering the majority of Australia's production forests; impacts of climate change, market forces or changing markets are not considered (ABARES, 2013). High-quality sawlogs are logs graded to standards used by state agencies; native pine sawlog is cypress pine; low-quality sawlog is sawlog not included in the high-quality category; and other hardwood product includes poles, piles, girders and other solid logs. Miscellaneous wood products such as firewood, industrial fuelwood, sleeper logs and fencing material are not included in the forecast projections (ABARES, 2013).

The overall pulpwood supply from native forests is predicted to decrease from approximately 4.5 million cubic metres annually in 2010–14 to approximately 3.5 million cubic metres annually from 2020–24 onwards (Figure 3.14). This is a consequence of the predicted decrease in sustainable yield from public forests. As the supply of high-quality native sawlogs decreases from multiple-use public forests, the demand for supply of high-quality native sawlogs from private and leasehold forests will increase. Supplies from private and leasehold forests will depend on markets, and the objectives and goals of private and public owners (ABARES, 2013).

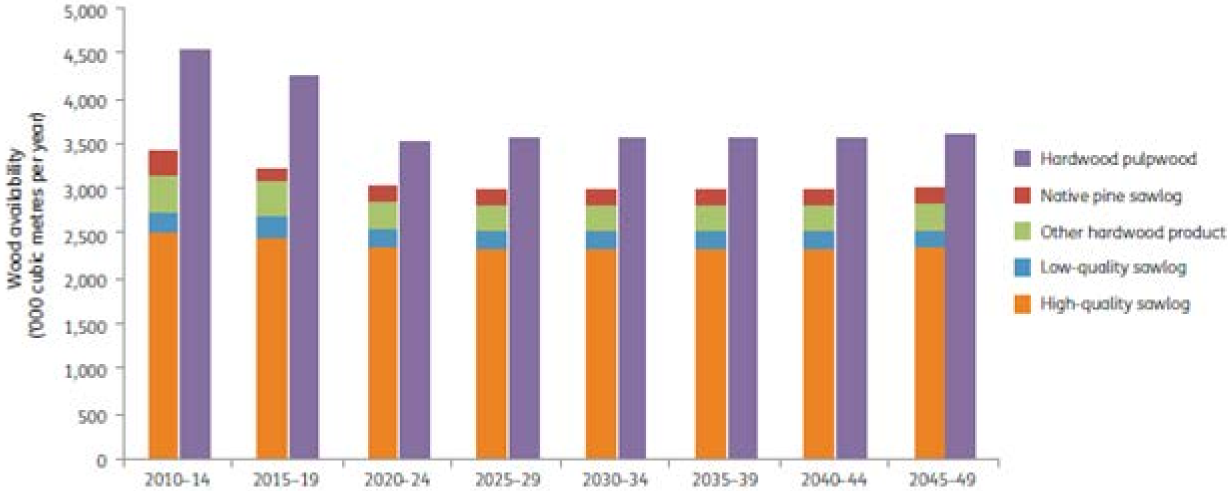

Figure 3.14: Forecast availability of wood from native production forest in Australia (public plus private), 2010–14 to 2045–49 (ABARES, 2013).

Current uses of native forest logs

The main wood products currently harvested from Australia's native forests are high-quality sawlogs for solid wood products, and pulp logs for paper, cardboard, fibreboard and related products. Increasingly, logs are also used to produce veneer for wood-based panel products (ABARES, 2013). Other products include logs for speciality timbers, low-quality sawlogs, round and split posts, poles, piles and girders, timber sawn and hewn in the forest, sleepers and firewood for residential use, and fuelwood for industrial use. Some of these are obtained as ancillary products during a sawlog harvest (ABARES, 2013). Table 3.3 summarises the volumes of different types of native forest logs harvested from Australia’s native forests from 2000–01 to 2010–11.

Table 3.3. Volume of logs harvested by the Australian native forest sector, 2000–01 to 2010–11 (ABARES, 2013).

	Volume ('000 m³)										
Sector	**2000–01**	**2001-02**	**2002–03**	**2003–04**	**2004–05**	**2005–06**	**2006–07**	**2007–08**	**2008-09**	**2009–10**	**2010–11**
Hardwood sawlog	3,583	3,639	3,543	3,444	3,320	3,204	2,939	2,966	2,640	2,495	2,251
Other hardwood product	221	167	167	184	192	191	252	201	155	150	179
Native pine sawlog (cypress)	296	293	297	316	291	279	224	210	211	198	182
Hardwood pulp log	6,998	6,022	6,605	6,462	6,354	5,180	5,360	5,773	4,944	3,944	3,898
Native forest total	11,098	10,121	10,611	10,406	10,158	8,855	8,774	9,150	7,950	6,787	6,509

Notes: Native hardwood sawlog includes logs for railway sleeper production, but excludes logs collected for firewood.
Sawlogs include logs for plywood and veneer.
'Other product' categories include poles, piles, fencing and other logs not included elsewhere.
Totals may not tally due to rounding.
Source: Australian Bureau of Agricultural and Resource Economics and Sciences (figures are supplied by growers and producers), Australian Forest and Wood Products Statistics database, ABARES (2013c).

The supply of other wood products, such as low-quality sawlogs, girders, poles, piles, non-pulpwood logs (logs that are not sawlogs or pulp logs), timber for mining, split and round posts, bush sawn/hewn timber and sleepers, varies by jurisdiction and is often opportunistic (ABARES, 2013). These products are generally harvested in association with high-quality sawlogs and pulp logs, and are a major resource in New South Wales, Tasmania and Victoria (ABARES, 2013). Figure 3.15 shows average annual harvest volumes for these products from multiple-use public native forests, by jurisdiction. Limited data are available on harvest rates for these products from private forests.

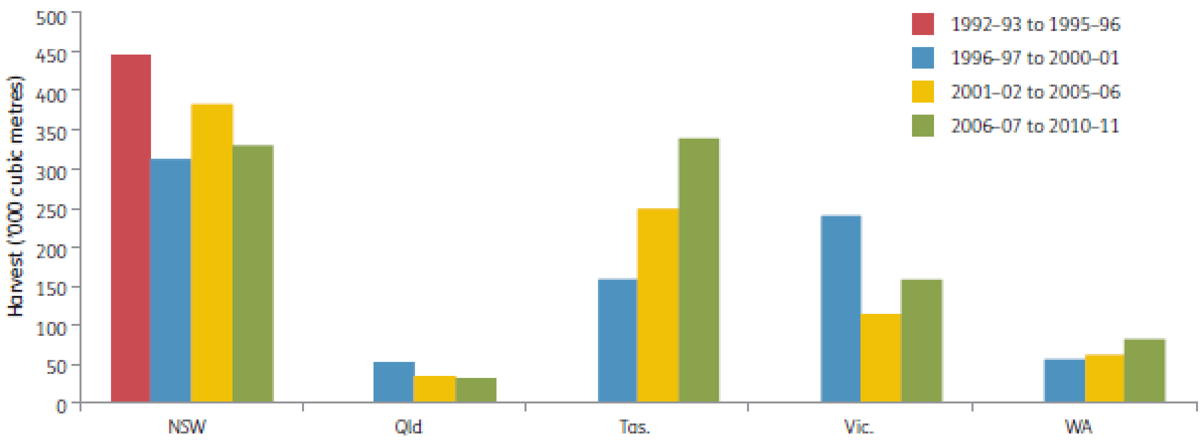

Figure 3.15: Average annual harvest of 'other wood products' from native multiple-use public forests, by SOFR reporting period (ABARES, 2013)

Notes: Data are unavailable for the 1992–93 to 1995–96 reporting period for all states other than New South Wales.
'Other wood products' are products that are not included in data for high-quality sawlogs and veneer logs, special-species timbers or pulpwood; they do not include firewood and fuelwood.

As revealed in Figures 3.16 and 3.17, most of Australia's native forest wood products are provided by multiple-use public native forests.

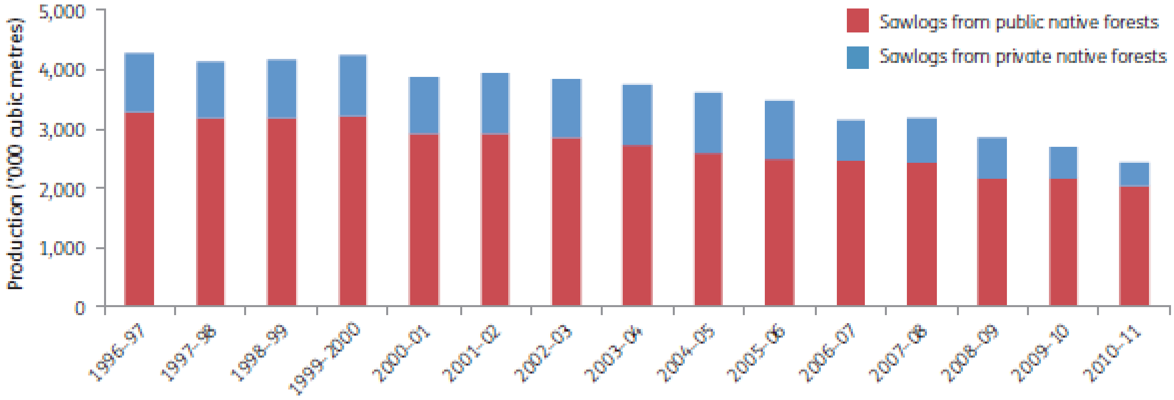

Figure 3.16: Production of sawlogs from Australia's native forests, 1996–97 to 2010–11 (ABARES, 2013)

Note: Sawlogs include native hardwood and cypress pine species.
Source: Australian Bureau of Agricultural and Resource Economics and Sciences, Australian Forest and Wood Products Statistics database.

Figure 3.17: Production of pulp logs from Australia's native forests, 1996–97 to 2010–11 (ABARES, 2013)

Note: Pulp logs are sourced from native hardwoods.
Source: Australian Bureau of Agricultural and Resource Economics and Sciences, Australian Forest and Wood Products Statistics database.

During the past decade, the proportion of total wood supply and pulp log derived from native forest has decreased, although native forests have remained the main source of hardwood sawlogs. Plantation hardwoods made up 35% of the total pulp log supply and 5% of Australia's hardwood sawlog supply, which is 1% of Australia's sawlog supply (ABARES, 2013).

Australia's hardwood plantations

General overview of Australia's hardwood plantations

Plantation land area and tenure

Australia's total commercial plantation area was around 1,974,770 ha in 2015–16, an increase of 1,331 ha (0.1%) from 1,973,439 ha in 2014–15 (Figure 3.18) (Downham and Gavran, 2017).

In 2015–16 the total area of hardwood plantations remained relatively unchanged at around 928,300 ha, a decrease of 66 ha since 2014–15, and accounted for 47% of total commercial plantation area (Downham and Gavran, 2017). Total softwood plantation area was 1,036,800 ha, an increase of around 1,400 ha from 2014–15, and accounted for almost 53% of total commercial plantation area (Downham and Gavran, 2017).

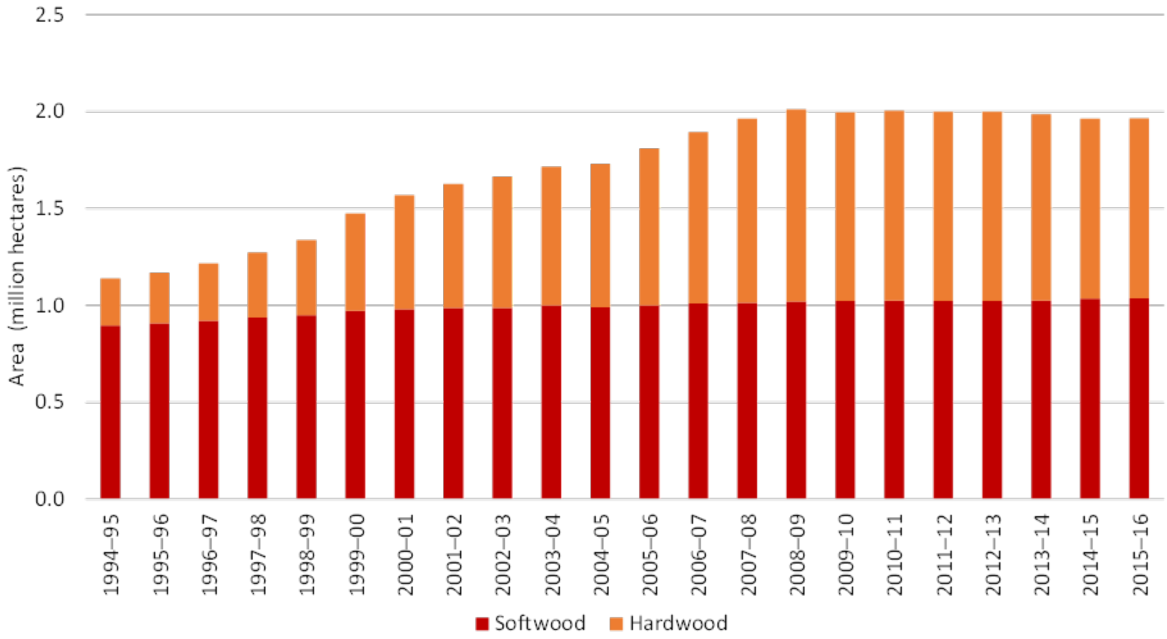

Figure 3.18. Total Australian plantation area, by type, 1994–95 to 2015–16 (Downham and Gavran, 2017)

Note: Data for 1994–95 to 2004–05 are for calendar years representing 1994 to 2005; data for 2005–06 to 2015–16 are for financial years. 'Other' category plantations are not included.

Source: ABARES

Western Australia accounted for the largest proportion of hardwood plantations (30%).

The hardwood plantation estate is dominated by southern blue gum (*Eucalyptus globulus*) (52.7%) and shining gum (*Eucalyptus nitens*) (25.2%), both of which are managed primarily for pulp log production (Downham and Gavran, 2017). Most Australia's southern blue gum plantations are located in West Australia and in the Green Triangle (South Australia/Victoria) National Plantation Inventory (NPI) regions. Most shining gum plantations are in the Tasmania NPI region (Downham and Gavran, 2017). Most blackbutt (*Eucalyptus pilularis*), flooded gum (*Eucalyptus grandis*) and spotted gum (*Corymbia* spp.) plantations are in the North Coast (New South Wales) National Plantation Inventory (NPI) region and are managed primarily for sawlog production (Downham and Gavran, 2017).

Table 3.4 details the plantation area by State/Territory in 2015–16.

Table 3.4 Plantation area, by State/Territory, 2015–16 (Downham and Gavran, 2017)

Plantation area ('000 ha)				
State/territory	Hardwood	Softwood	Other	Total
New South Wales	87.1	307.1	0.1	394.4
Victoria	199.0	223.3	0.8	423.0
Queensland	34.8	195.5	0.1	230.4
South Australia	51.4	127.2	0.2	178.8
Western Australia	276.4	98.4	8.5	383.4
Tasmania	233.9	75.9	0.0	309.8
Northern Territory	45.7	1.9	0.0	47.6
Australian Capital Territory	0.0	7.4	0.0	7.4
Total	928.3	1,036.8	9.7	1,974.8

Note: All columns and rows have been rounded, so totals may not tally.

Figure 3.19 shows the main National Plantation Inventory (NPI) regions across Australia.

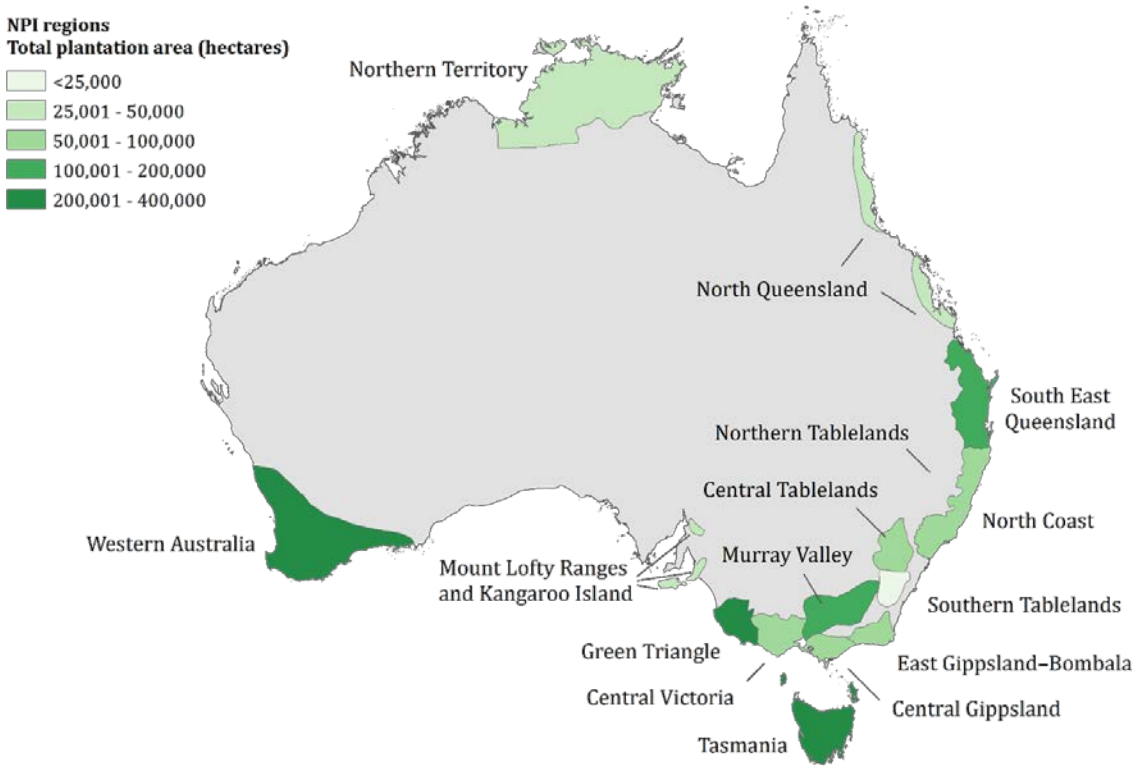

Figure 3.19. National Plantation Inventory regions (Downham and Gavran, 2017)

Compared with 2004–05, annual establishment of new hardwood plantations in Australia progressively declined from 65,600 ha to zero in 2015–16 and annual establishment of new softwood plantations decreased from 6,500 ha to 1,400 ha in 2015–16 (Downham and Gavran, 2017).

Plantation hardwood log production

The proportion of Australian hardwood plantations managed primarily to produce pulp logs for products such as woodchips and paper remained constant in 2015–16 at 82.4% (Figure 3.20) (Downham and Gavran, 2017). In 2015–16 around 17.5% of hardwood plantations were managed to produce sawlogs for sawn wood, mainly from the public plantation estate to supplement native forest sawlog production (Downham and Gavran, 2017).

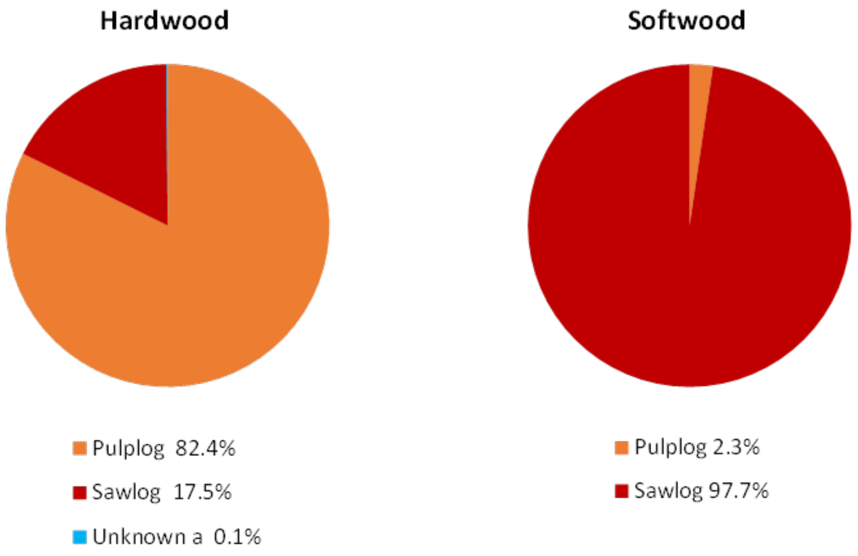

Figure 3.20. Proportion of plantations managed for sawlogs and pulp logs, 2015–16 (Downham and Gavran, 2017)

Note: Information on plantation management was insufficient, so it was not always possible to ascertain the main products.

The vast majority of Australian plantation hardwood log production is currently used for pulpwood. In 2014–15, 97% of the total plantation hardwood log production was used for pulpwood and 3% was sawlogs (ABARES, 2016a). Included in the 3% sawlogs (269,000 m^3) was an 'unpublished' volume of plantation hardwood logs that were peeled for veneer products in Australia. An 'unpublished' volume of plantation hardwood logs is also being exported to countries such as China for plywood and other EWP production.

Hardwood plantation log availability in the 2015–19 period is forecast to average around 12.9 million cubic metres annually, around 4.4 million cubic metres more than the actual volume of around 8.5 million cubic metres harvested in 2014–15 (ABARES, 2016b).

Hardwood plantation pulp log production was around 8.2 million cubic metres in 2014–15. Average annual pulp log availability is forecast to fluctuate between 12.5 million cubic metres a year in the 2015–19 period to 7.7 million cubic metres in the 2045–49 period (ABARES, 2016b).

Hardwood plantation sawlog production was around 269,000 m^3 in 2014–15. Hardwood sawlog availability is forecast to increase to 408,000 m^3/yr for the 2015–19 period, peaking at around 994,000 m^3/yr in the 2055–59 period (ABARES, 2016b).

For the 2015–19 period, the Tasmania, North Coast and Green Triangle regions are forecast to be the main areas of hardwood plantation sawlog availability, with annual averages of around 111,000, 58,000 and 120,000 m^3 respectively available for log harvest. Sawlog estimates include peeler logs, high-grade and low-grade sawlogs and posts and poles (ABARES, 2016b).

Figures 3.21 and 3.22 show forecasted plantation pulp log and sawlog availability by region.

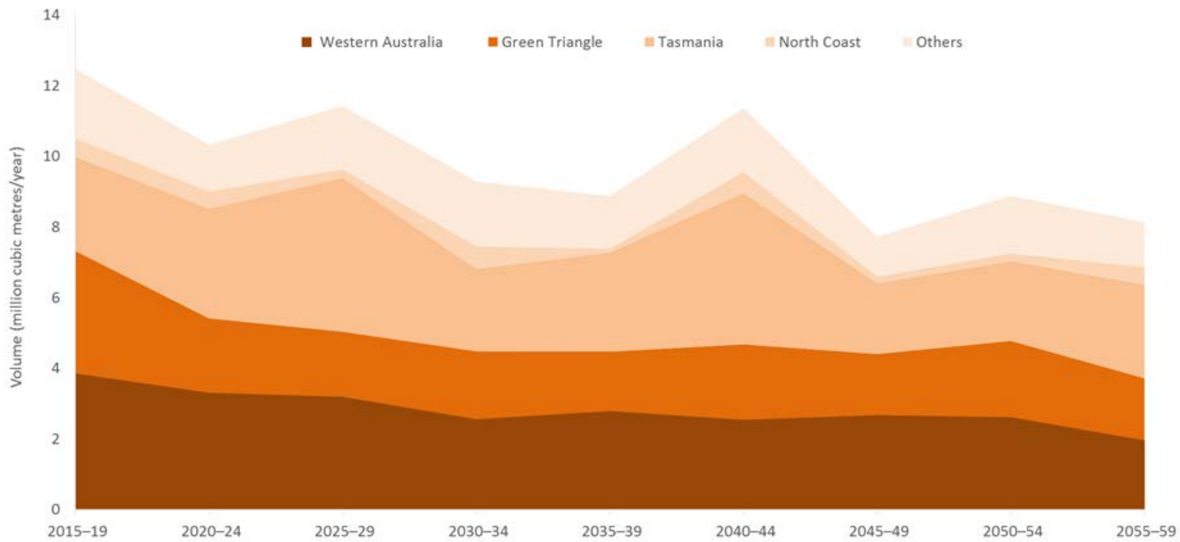

Figure 3.21. Forecast plantation hardwood pulp log availability, by region (ABARES, 2016b).

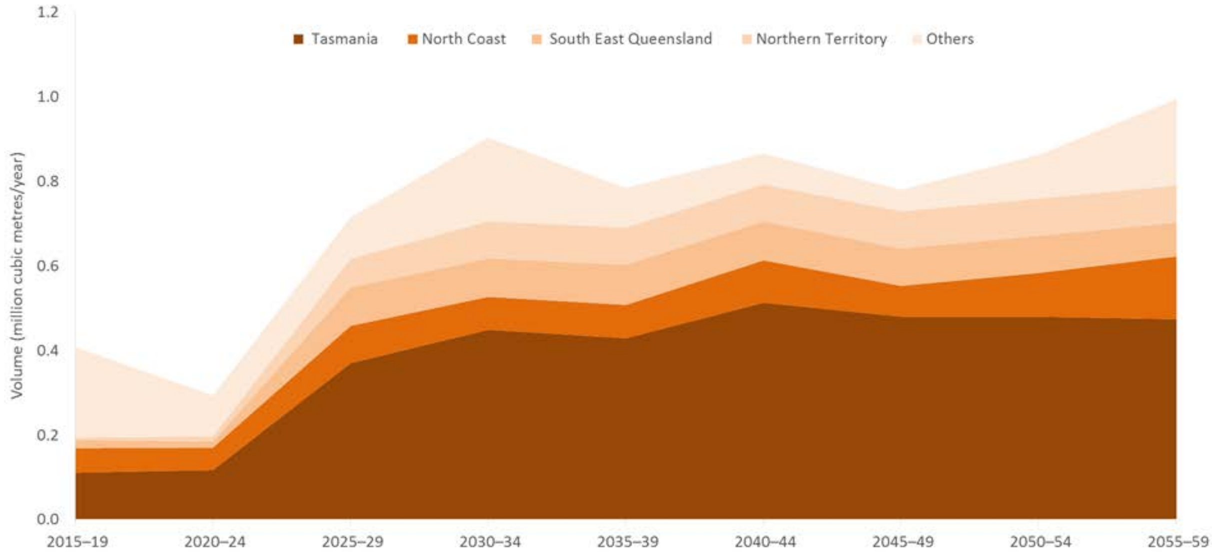

Figure 3.22. Forecast plantation hardwood sawlog availability, by region (ABARES, 2016b)

No detailed assessments have yet been undertaken to determine how much of the pulp log and sawlog production from hardwood plantations might be available and suitable for spindleless lathe processing.

Current utilisation of Australian native forest and plantation hardwood resources for engineered wood products and new opportunities

Review of current utilisation of Australian native forest and plantation hardwood resources for engineered wood products

The wood processing industry in Australia is predominantly based on traditional sawing production systems. Additionally, apart from a relatively small quantity of predominantly plywood, glulam and hardboard, the existing engineered wood products (EWP) industry in Australia is primarily based on softwood resources.

No wood processing companies in Australia are currently using any great quantities of plantation-grown or residual native forest hardwoods to produce EWPs—such as glulam, strand/flake based EWPs, fibreboard, particleboard or veneer-based EWPs (Hague, 2013). Lignor in Western Australia are reported to have developed technology to produce engineered strand lumber (ESL) from plantation southern blue-gum; however, production has not yet commenced.

Major existing hardwood (natural forest resource-based) EWP producers include Ta Ann from Tasmania and Big River Timbers and Weathertex from New South Wales.

- Ta Ann predominantly peels a mixture of regrowth eucalypt species and exports the resulting veneer, mainly to Malaysia for the manufacture of laminated veneer lumber (LVL), plywood and flooring (Freischmidt & Blakemore, 2009). However, Ta Ann has also started hardwood plywood production from their plant in Smithton, Tasmania.
- Big River Timbers produces hardwood plywood from a range of hardwood species sourced from natural forest and some from plantations. Big River Timbers are the only commercial operation in Australia using spindleless lathes.
- Weathertex is the only remaining plant producing wet-formed fibreboard in Australia. The product is produced from eucalypt thinnings and sawmill residues derived from natural forest logging operations and is sold as cladding for buildings (Hague, 2013).

Sustainable Timber Tasmania (previously Forestry Tasmania) and other industry partners are exploring the potential for using local Tasmanian hardwood species for Hardlam production (LVL) for both appearance and structural products. This product aims to use smaller-diameter, low-grade logs that would otherwise be converted to woodchips (Forestry Tasmania, 2015).

In addition, hardwood regrowth timber veneers are being used by Wesbeam to improve the strength and stiffness of LVL. This initiative continues to show promising results that will complement the utilisation of softwood species in the manufacture of LVL (Forest Products Commission WA, 2016).

The Victorian industry has undertaken some limited research directed at understanding the processing and performance of engineered products made from their hardwood species (McCombe *et al*., 1996, 1997, CSIRO, 1998). The 1998 CSIRO study funded by the FWPRDC (now FWPA) investigated the potential to produce reconstituted hardwood products from residual hardwood. Some key conclusions of this work were:

- An engineering grade of LVL was produced in commercial manufacturing trials with mixed hardwood species residue logs. The LVL products performed well in strength tests, however the most significant adverse finding was a low yield of LVL product from the logs.
- High-density Australian hardwood species can be successfully flaked to produce oriented strand board panels but further research needs to go into studying optimisation of the flaking operation. The dominant problem exists with the internal bond strength which emphasizes the priority that must be given to the study of new adhesive systems.
- The Australian hardwood resource can be used to make a fibreboard, but at densities which are higher than those normally associated with MDF. However, further work is required in pressing regimes, resin systems and preparation of hardwood fibres.

Research and development trials in peeling Western Australian hardwoods have been undertaken by the Inglewood Products Group with the aim of producing veneer blocks which can then be re-sawn into large dimension boards (Forest Products Commission WA, 2016). The Forest Products Commission of Western Australia assisted by providing timber resource to the required log specifications (Forest Products Commission WA, 2016). This product has proven to be of high quality and suitable for a range of high-value uses. The new product is currently being tested in furniture manufacture, joinery, and flooring products, as well as new products such as cross-arms on power poles. In Western Australia peeling is considered desirable for small regrowth logs, which are more difficult to efficiently process with most sawmill technology (Forest Products Commission WA, 2016).

Many processing studies have been completed to convert plantation hardwood trees into a traditional suite of sawn products, mainly using conventional production systems both in Australia (Leggate *et al*,2000; Washusen *et al*.,2008; Washusen *et al*.,2009; Blakemore *et al*.,2010a,b; Washusen, 2011; Washusen and Harwood, 2011) and outside Australia. The results of these studies have consistently shown that complications are encountered with persistent problems arising in recovery, drying, stability, and durability and appearance qualities. As summarised by McGavin *et al.* (2014a) despite the various approaches, mainly based on alternative technologies targeting sawn timber products, many challenges remain, resulting in excessively low recovery of marketable products and unprofitable processes.

However, DAF in Queensland are leading research using Australian plantation hardwood species for veneer-based EWPs and they have completed several research studies on this theme (McGavin *et al*.; 2006, Hopewell *et al.;*2008, Zbonak *et al*.;2012, McGavin *et al*.;2014, 2015). The main conclusions from this work are:

- Veneer processing was found to be an efficient method of conversion for fast-grown hardwood plantation trees compared to other approaches such as sawing.
- The use of spindleless lathe veneer processing methods demonstrated many advantages compared to more traditional veneer processing methods. One major advantage was the demonstration that relatively inexpensive, compact and simple equipment can be used to successfully produce usable and marketable veneer.
- The research has successfully demonstrated that the Australian plantation hardwood resources can be processed into rotary veneer using spindleless lathe methods with the achievement of recovery rates up to six times higher than those reported for more traditional processing techniques such as sawing. The resulting veneer has visual qualities and mechanical properties that are suitable for the manufacture of structural products.
- Veneer defect assessments revealed that the veneers were likely to be more suited to structural products rather than appearance applications (McGavin *et al*, 2014b). Research has shown that the mechanical properties of the veneers and veneer-based products from plantation hardwoods in many cases have been shown to be similar or superior to those of plantation exotic pine (McGavin *et al.* 2006; Hopewell *et al*.2008;Thomas *et a.*. 2009;Farrell *et al.*2011).
- Further research is required particularly in the areas of improving manufacturing protocols, gluing, market and economic analysis.

Currently, spindleless lathe processing has not been sufficiently researched as a production option for native forest logs in Australia with previous DAF efforts focused mainly on young plantation-grown hardwoods. However, this project includes spindleless lathe processing trials with native forest hardwoods and cypress pine.

FWPA commissioned a review (Hague, 2013) on the utilisation of plantation-grown eucalypts in EWPs. This review comprehensively examined the literature from Australian and international research and summarised information on using plantation eucalypts for EWPs such as laminated veneer lumber (LVL) and plywood, glulam, flake/strand-based products, fibreboard and particleboard. Emphasis was on gluing systems, the properties and performance of EWPs and any inherent limitations on the uses of particular eucalypt species. Key conclusions from this review were:

- The available information on the suitability of Australian-grown plantation eucalypts for EWPs is scarce. Furthermore, that which does exist is typically based on limited replication within given studies.
- Currently in South America and Iberia significant quantities of veneer-based engineered wood products (EWP) are produced from plantation eucalypts; however, no Australian wood processing companies use any significant quantities of plantation-grown eucalypts to produce either veneer or veneer-based EWPs.
- Fast-grown, low-density eucalypts generally present no major difficulties with respect to adhesion; any of the adhesive systems conventionally used by the EWP industry could in all likelihood be used by Australian EWP manufacturers to produce fit-for-purpose products from plantation eucalypt resources with air-dry densities less than 650 kg/m^3.
- Based on available published research data and current practices in the global EWP industry, it is thought that much of the current Australian plantation eucalypt resource including that originally established for woodchip and pulp would be suitable for select EWPs.

The FWPA report mentioned above does highlight the considerable research and commercial activities occurring overseas using plantation hardwoods for a variety of EWPs including laminated veneer lumber (LVL) and plywood, glulam, flake/strand-based products, fibreboard and particleboard (Hague, 2013).

In their recent detailed analysis of options for utilisation of Tasmanian forest industry residues, Indufor (2016) comprehensively analysed the case for plywood as a possible viable product option. In their report they highlighted the phenomenal growth in plywood production in China and more recently in Vietnam, based on peeling plantation hardwood logs. As the supply of tropical hardwood logs has declined, and low cost labour has become increasingly accessible in China and more recently Vietnam, a plywood industry based on small-diameter hardwood plantation logs has emerged (Indufor, 2016). Logs as small as 8 cm SEDUB are being processed (Indufor, 2016). China has built a plywood industry of enormous proportions around thousands of small businesses operated mostly by individuals or families (Indufor, 2016). The equipment for veneer production uses mini rotary and small spindleless lathes, manual veneer handling, air drying or static press drying, single glue spreaders and small scale multi-opening presses. It is very labour intensive, but requires far less capital investment than a conventional large scale plywood mill (Indufor, 2016).

Chinese and Vietnamese plywood manufacturers use both domestically grown hardwood plantation logs and imported supplies. The Chinese plywood sector utilises large volumes of plantation eucalypt logs, including plantation-grown shining gum logs from Tasmania (Indufor, 2016). Low production costs allow this supply chain to be competitive despite the cost of importing logs from countries such as Australia. The competitiveness of this supply chain can be demonstrated through the export log price for hardwood logs that are currently comparable to prices paid for logs delivered to an Australian export chip mill (Indufor, 2016).

Forest residue minimisation and opportunities for use as veneer-based EWPs

The most important forest resources used by the wood products industry in Australia include plantation exotic pine and hoop pine, plantation hardwoods, natural forest hardwoods and cypress pine. Substantial processing knowledge and experience exists for common processing techniques (sawmilling and veneer processing) for plantation softwood (exotic and hoop pine), plantation hardwoods and larger dimension native forest hardwoods; however, a significant knowledge gap exists on the suitability and performance of smaller dimension native forest hardwood logs and cypress logs for rotary veneer production.

Opportunities for EWPs have not yet been fully explored for all Australian resource types and forest qualities. Advantages of EWPs compared to traditional sawn products include increased value-adding, efficient resource utilisation, ability to use low-grade wood and small piece sizes, greater selection of product dimensions, as well as compatibility with modern day building systems. EWPs exhibit uniform and predictable mechanical properties that are analogous to steel and concrete, particularly in non-residential construction markets; however, they also have far superior and increasingly well-recognised sustainability credentials.

Increasing levels of conservation Australia-wide, have led to a reduction in the area of native forest available for commercial timber production. This in turn has led to a decrease in the availability of large-diameter, high-quality sawlogs used for traditional solid wood products. As a result, there is a growing interest in EWPs as a practical alternative (Forestry Tasmania, 2014).

The Australian forest industry also produces substantial volumes of wood (log and processed) that does not meet target product requirements and therefore could be suited to alternative EWPs. For example, in the native forest sector in Australia, most sawmills recover less than 40% of the input log volume as saleable product, and in all native forests there are significant proportions of non-sawlog trees (residual or pulp wood) whose traditional markets, particularly woodchip, are in many cases in decline. In addition, there are the large quantities of wood that are unsuitable for conventional products and remain unprocessed or are sold in marginal recovery outlets. Limited viable markets currently exist for these native forest residues in some Australian states in comparison with the plantation softwood sector which relies mainly on bio-energy, wood panels and woodchip as options. Elsewhere, in those Australian states that are more traditionally dependent on hardwood wood chip, recent market uncertainty has generated an accelerated interest by forest growers and asset managers in exploring potential new bio-economy opportunities such as EWPs.

Finding suitable processing systems, products and market outlets to minimise the generation of residues and/or better utilise residues is critical for ensuring the profitability of forest growing and processing operations. In a recent review of R&D priorities, residue solution strategies were identified as a major priority for the Queensland timber industry. Other states such as Victoria and Tasmania have also highlighted this area as critical.

Whilst hardwood Glulam and plywood is accepted and available in relatively small quantities in the market, there are currently no local (and very limited international) manufacturers of other hardwood EWPs. A key impediment to take-up is the lack of fundamental hardwood ‘resource based’ technical information regarding appropriate species, efficient processing methods, grade inclusion opportunities, potential construction strategies, manufacturing requirements and product performances.

The cypress pine industry focus is on sawn timber processing. Very limited research exists describing research into EWP opportunities from this resource. However, cypress pine industry representatives have expressed considerable interest into research exploring the potential to produce EWPs in particular from rotary peeling of cypress pine using spindleless lathes.

The vast majority of the native forest hardwood and cypress pine log resource in Australia is currently converted using conventional sawing systems. Rotary peeled veneer produced using this relatively new spindleless lathe technology could assist industry in maximizing the economic and market potential of the Australian native hardwood and cypress sector as well as plantation resources, by allowing greater and more profitable utilisation of available resources.

Figure 3.23. Examples of veneer-based engineered wood products (McGavin, DAF, Qld)

Hybrid engineered wood products

Hybrid engineered wood products can be manufactured from mixed species and different materials. This could help to assist manufacturing plants achieve adequate scale and also capitalise on the advantages of different forest resources and other feedstocks. One of the benefits of engineered products is that different components can be utilised to maximise their physical and engineering strength properties. The Forest Products Innovation team (FPI) within DAF has previously undertaken some limited research to demonstrate the concept of such hybrid products through small-scale limited investigations involving EWP development using combinations of sawn and veneer feedstocks from exotic softwood, cypress pine, plantation hardwood, bamboo and coconut. Figure 3.24 demonstrates that it is possible to improve the stiffness of pine plywood by using hardwood face veneers. In this trial, core veneers are matched between both construction strategies, therefore the increase in panel modulus of elasticity (approximately 40% gain) can be attributed to the replacement of high quality softwood face veneers with high quality hardwood veneers. In this trial, early-age plantation Gympie messmate (*Eucalyptus cloeziana* – GMS) was used.

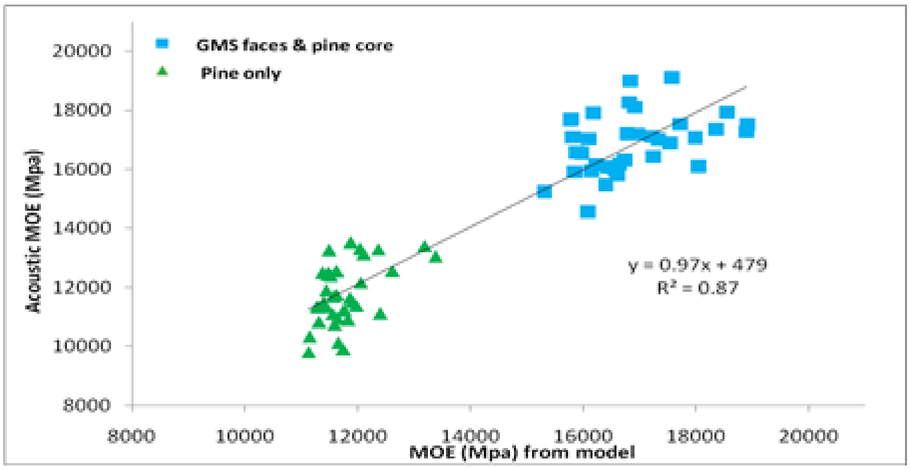

Figure 3.24. Superior stiffness of mixed species plywood (DAF) (note that GMS is plantation grown Gympie messmate -*E. cloeziana*)

However, opportunities are not only limited to veneer-based products. There is also the potential to develop products based on various combinations of sawn timber, veneers, round wood and fibre-based products. Mixed species combinations in such products could include native hardwood, cypress pine, hoop pine, exotic softwood and plantation hardwoods (Figure 3.25). Also, advanced engineered wood products could include combinations of wood and other materials such as carbon/epoxies, glass/polyesters and metals.

Although there are some international examples of the use of EWPs being made from mixed species the only local research has been a few small-scale investigations by DAF. This works needs to be expanded to include a larger range of species and other sources of fibre.

Figure 3.25. Hardwood veneer faced softwood cross laminated timber (CLT) manufactured by DAF at the Salisbury Research Facility

Estimates of small peeler log availability from Australian native forest and plantation hardwood resources: assessments for each state and territory

It is difficult to estimate what volume of Australian native forest and plantation hardwood resources might be available and suitable for processing in spindleless lathes.

Apart from New South Wales, no other state or territory has developed log specifications specifically for spindleless lathes. There is only one spindleless lathe commercial operation in Australia which is located in New South Wales and the log specifications adopted may not be applicable to other species and other states. Most hardwood peeler logs in Australia are sold using specifications designed for more traditional lathe types. Spindleless lathes can use a smaller and lower log quality specification compared to most other lathe types.

Most forest inventory data for Australia is based on assessments for traditional products such as sawlogs, poles, girders and pulp logs. There is inadequate or zero inventory data on log volumes for logs grades that fall outside these product groups such as specifically suited for spindleless lathe processing. It is difficult for forest authorities in each state and territory to estimate log volumes potentially available and suitable for spindleless lathe processing without reliable log specifications, established markets and adequate inventory data.

There are many competing product choices for Australian forest resources and availability of logs for spindleless lathe processing will depend on market and economic factors. There are also existing supply agreements which could restrict supply for alternative uses. However, if the conversion of logs using spindleless lathes is shown to be more profitable compared to other options then customers might choose to divert log supply under existing supply agreements.

Government policies concerning native forest log supply can have a major influence on volumes available. In most Australia states there have been significant reductions over time in the volumes of logs being made available from native forests. The main reason has been increased conservation of forests for non-wood values. This trend is expected to continue. It is likely that private native forest log supply will become more important and could represent the best source of small peeler log supply from native forests over the long term.

However, a significant limitation in log supply from private native forests in Australia for traditional markets is the lack of adequate forest management and silviculture for wood production. Many of Australia’s private native forests are over-stocked. One of the main reasons that they are not being thinned is lack of viable markets for small-diameter thinnings. Spindleless lathe processing could present a solution to this problem by creating a new market for small diameter logs.

The vast majority of hardwood plantations in Australia are being managed to produce pulpwood. However, this does not preclude utilisation of a certain component of this resource as peeler logs. Future peeling operations do not just need to be limited to sawlog qualities. In China and other countries in Asia, very small logs similar in quality to pulp logs from Australian hardwood plantations are being successfully converted into veneer products using spindleless lathes. As mentioned above, research studies have highlighted the competitive mechanical properties of young Australian plantation hardwoods

The following sections discuss the situation in each state and territory relevant to log production from native forests (where applicable) and hardwood plantations. Data is provided on existing (and forecasted where possible) log production by category and commentary is provided on potential availability of small peeler logs for spindleless lathe processing.

Further inventory, resource and market assessment is required in Australia in order to more reliably estimate the quantities of logs potentially suitable and available for conversion using spindleless lathes.

Queensland

General findings

For this study, the availability of small peeler logs suited to spindleless lathe processing was studied in detail in Queensland (see Chapter 2). The main conclusions summarised in the report were:

Many factors influence the potential quantities of peeler logs available from native forests in Queensland. These include but are not limited to:

- specifications adopted regarding grade quality and size requirements

- government log supply agreements, policies and regulations, including codes of practice requirements restricting supply
- alternative current or future uses of logs of the same quality
- economic and market conditions e.g. increased or decreased harvesting of private forests during economic downturns or upturns in agricultural industry (as log timber harvesting helps provides cash flow).

Substantial volumes of logs meeting the small peeler specifications adopted for this study are potentially available from native forests in Queensland. However, in the case of hardwood, most of this volume is currently left standing in the forest for the following reasons:

- part of the future growing stock for the next and subsequent selective harvesting events
- current lack of ‘demonstrated’ viable markets for this log size and quality
- current tree marking, harvesting and sale practices focusing on mainstream larger log size products such as compulsory sawlogs, poles and girders
- Code of Practice and other regulations.

Current native hardwood forest sales currently favour products such as sawlog, poles and girders because of existing market demand. It is possible that if demand for small peeler logs commenced, then there may be a shift in tree marking and harvesting procedures to facilitate supply and sales of the smaller peeler logs. This would need to consider economic viability for processors and forest managers.

The long-term supply of peeler logs from crown forests in Queensland will depend on Government policies and decisions around access to forests for timber harvesting and any continuation of supply agreements beyond current contracted timeframes. There is no certainty of crown log supply beyond these agreements.

Cypress pine resource

The future potential supply of cypress pine peeler logs will come mainly from crown forests (estimated at least 95% of total supply). The vast majority of cypress pine peeler logs would also have to be derived from diversion of cypress pine sawlogs to peelers because very minimal quantities of suitable logs are available from cypress pine forests after sawlog harvesting. Assessments undertaken during this project indicated that around 60% of cypress sawlogs would meet the specifications for peeler logs adopted in this study. There are no existing peeler log specifications for cypress pine logs so a modified hardwood peeler log standard was used. Resource availability will vary depending on the specifications adopted. Based on the assumptions made and the assessments undertaken, an estimated 80,000 m^3 of cypress pine sawlog per year could be available for peeling; however, this would mean reductions in annual cypress pine sawlog supplies by 60%. Larger diameter cypress pine logs could also be considered for peeling; however, this was outside the scope of this analysis. Cypress pine peeler logs would also come almost exclusively from the South-West Hardwood region of Queensland assuming current harvesting rates by region applied.

Private native hardwood resource

It is likely that private native hardwood forest in Queensland would be a more important long-term source of potential peeler log supply compared to crown forest. Currently, private native forests in Queensland supply an estimated 60% of Queensland’s domestically produced hardwood logs (DAF, 2016). This equates to around 155,000 m^3/yr based on 2014–2015 year figures from ABARES. Inventories undertaken by MBAC Consulting in 2003 concluded that the net available forest area for harvesting from private native forests in Queensland (South-

East Queensland and Western Hardwood Regions) was around 2,137,717 ha (MBAC, 2003 a,b). MBAC (2003a,b) also estimated that the total net recoverable volume from this area was 26 million cubic metres. A substantial proportion of this is likely to meet the small peeler specifications adopted for this study. Further inventory work is required to produce better estimates of peeler quantities.

Spotted gum is the dominant species and spotted gum and ironbark account for around 80% of the private native forest log removals in the South-West Hardwood Region of Queensland. The limited case studies undertaken in private native hardwood forests revealed that significant volumes of peeler logs were available (on average close to 14 m^3/ha). Further inventory work is required to extrapolate this to the rest of the state and establish overall small peeler log volumes available. Again, resource estimates were based on the ultra-small and conservative log size specifications adopted for this study. If larger logs were considered then peeler volume availability would increase substantially. However, net peeler log recovery would reduce after application of relevant regulations and consideration of other product types.

Selective harvesting practices are universally applied in private native forests in Queensland; however, a history of crop tree harvesting without follow up silvicultural treatment has tended to leave the majority of these forests in a relatively low commercial productivity state (DAF, 2016). Excessive regrowth has caused huge competition between trees causing many stands to become essentially dormant. One reason that these forests are not being silviculturally treated is that the cost of removing the small stems is unable to be offset due to a lack of demonstrated markets for the small thinned stems. Harvesting these logs to supply spindleless lathe peeling operations could offer a viable solution to this problem.

Crown native hardwood resource:

In 2016, 142,365 m^3 of hardwood logs were harvested from crown forests in Queensland. Around 65% of this was hardwood sawlogs with the balance being poles, girders, piles, landscaping, fencing, other round timber and other products. Spotted gum accounted for 75% of all crown hardwood log removals in 2016.

According to ABARES (2013), the net harvestable area of public native forest in Queensland is around two million hectares. The net harvestable area represents the net area of available and suitable forest on multiple-use public native forest land after allowing for local and/or operational constraints on harvesting (ABARES, 2013). ABARES (2013) also advises that in 2010–2011, the forest area harvested annually from multiple-use public native forest in Queensland was 28,200 ha and the five-year mean, 2006–07 to 2010–011 was 36,220 ha.

The South-West Hardwood Region would provide the greatest quantities of crown peeler logs (at least in accordance with the project adopted small-diameter peeler specification), followed by South-East Hardwood region at least until the end of current supply agreements.

Based on the limited case studies undertaken for this project in the Gurulmundi and Allies Creek State Forests, very minimal residual hardwood logs remain (on-ground) post-harvesting that would be suitable for small log peelers (less than 1 m^3/ha). This was the result assuming that current tree marking, harvesting and sale practices were adopted and it is also based on the peeler specifications adopted for this project that focused only on smaller logs not well suited to compulsory sawlogs or girders. If larger log sizes were considered for peeling, then peeler availability would be substantially increased. This volume is minimal because current practices predominantly target the harvesting of larger trees suitable for compulsory sawlogs, poles and girders. Smaller stems which would be suitable for peeler logs are left standing because of various reasons including lack of current suitable viable markets, Code of Practice requirements and provisions for future growth and subsequent selective harvesting events.

However, if smaller stems that are more compatible with the log specifications used in this project were included in harvesting in preference to more traditional products, then the case studies undertaken indicated that much larger volumes (up to 10.5 m^3/ha) of small hardwood peeler logs are potentially available from crown forests. Further inventory work is required to extrapolate this to the rest of the State and establish overall peeler volumes available. For current harvesting and sale practices, DAF Forest Products usually consider an area viable for harvesting if there is at least 3 m^3/ha of hardwood sawlogs available.

If future supplies of small peeler logs from crown hardwood forests had to be sourced only from diverting hardwood logs from other current uses (such as sawlogs, poles, girders, fencing etc.), then the analysis undertaken revealed that around 5000 m^3 per year would meet log size and quality specifications for peeler logs adopted for this project[2]. Furthermore, this assumes that all hardwood species harvested are suitable for peeling. If spotted gum only was considered then this figure would be reduced by at least 25%. The dominant reason for such minimal quantities is the available logs have diameter in excess of that considered by the project followed by log quality. The vast majority of logs removed from crown hardwood forests in Queensland under current practices are too big to meet the target peeler specifications adopted for this project (18–30 cm SEDUB).

Current tree marking, harvesting and sale practices in crown forests in Queensland do not prioritise the smaller log dimensions that correspond with the peeler log specifications adopted for this project. The current focus is on larger sawlogs, poles and girders. For more commercially viable small peeler log volumes to be produced from crown hardwood forests adjustments would need to be made to tree marking, harvesting and sale practices.

Queensland hardwood plantations

It was outside of the scope of this project to analyse in detail the potential supply of peeler logs from Queensland’s hardwood plantations. This resource has the potential to add useful volumes of peeler logs to those supplied from native forests and increase the overall viability of spindleless lathe operations in Queensland. As discussed, recent research by Queensland Department of Agriculture and Fisheries (DAF) has demonstrated the potential to use emerging spindleless veneering technologies to process hardwood plantation logs with sizes and qualities previously considered unable to be efficiently processed (McGavin *et al.* 2014a and b; McGavin *et al.* 2015a and b).

A recent hardwood plantation review commissioned by DAF and undertaken by GHD (2015) concluded that:

- A projected hardwood plantation estate of around 19,400 hectares could make a contribution to a future processing industry over the period 2025–2049.
- Of the 19,400 ha it is estimated that 84% is in the Inland region, 9% in the coastal region and 7% in the northern region. It is also estimated that around 70% of the expected plantation estate could fall within 100 km radii centered on either Wondai or Yarraman with around 50% estimated to fall within a 100 km radius centered on Gympie. Around 65% of the plantation estate will be on either HQ Plantations Pty. Ltd. owned or other freehold land and the remainder established on state-owned land.
- Only around 27,000 m^3/yr of standard and utility grade butt logs combined is available from these plantations over a 25-year average supply/investment timeframe starting in 2025, with 60% available in the first 10 years. There was also more than 33,000 m^3/yr of residual grade log available over the same timeframe; however, the review report

[2] This study deliberately focused on the availability of logs that were smaller than those currently typically used for sawlogs.

did not discuss this as a suitable log grade for peeling. Most of the residual grade log volume is in small tops.

- The review did not consider the plantation log supply as being of sufficient scale to support investment in a dry veneer mill (required minimum log input 50,000 m³/yr) or in a plywood mill (minimum log input 100,000 m³/yr). However, the review did not consider potentially more realistic, smaller scale and still viable operations based on throughput volumes less than 30,000 m³/yr.
- The future hardwood plantation resource will be dominated by spotted gum (62%), western white gum (*Eucalyptus argophloia*) (26%), Gympie messmate) (6%), Dunn's white gum (*Eucalyptus dunni*) (4%), blackbutt and other hardwood species (2%).

ABARES forecasts for plantation hardwood log availability for South-East and North Queensland are shown in Figures 3.26 and 3.27.

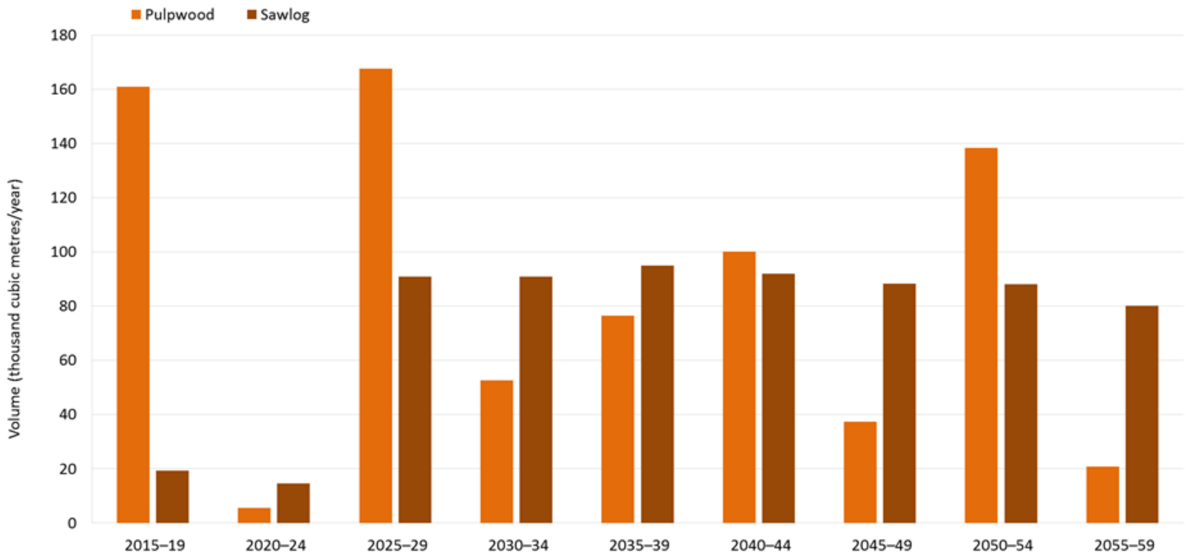

Figure 3.26. Forecast hardwood plantation log availability, South East Queensland (ABARES, 2016b)

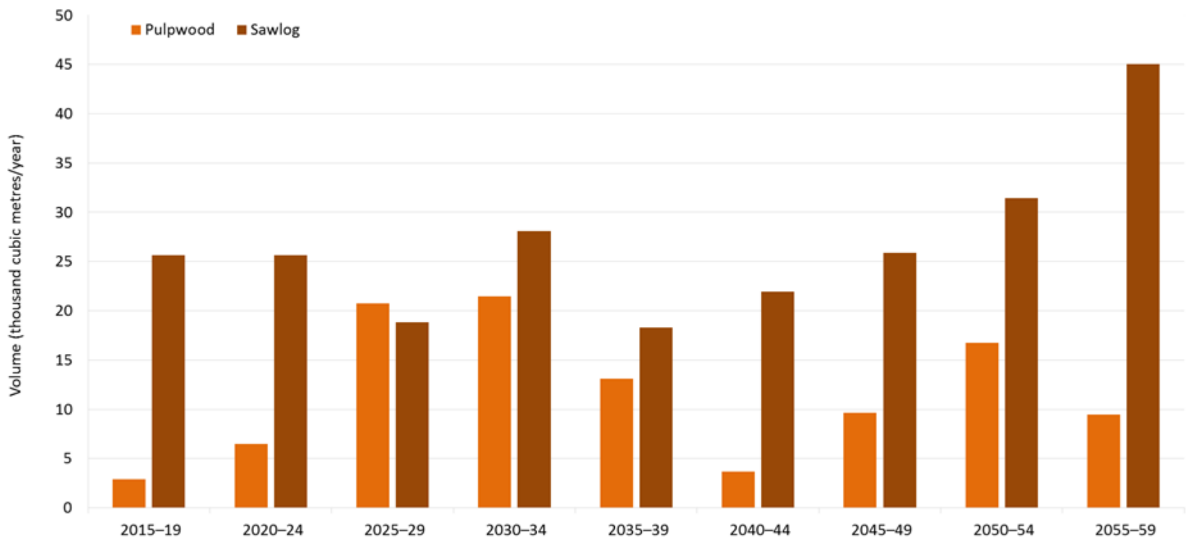

Figure 3.27. Forecast hardwood plantation log availability, North Queensland (ABARES, 2016b)

Other forest resources
This study focused on native forest hardwood and cypress pine log supplies. However, spindleless lathe operations could potentially draw from a number of forest resources including plantation pine and also produce potentially mixed species products. This could help to improve the overall viability of such operations.

Further research
This study discussed the results of a preliminary resource assessment based on limited case studies. Further inventory work and analysis is recommended to determine how transferrable the findings are to the wider crown and private native forest estate in Queensland. Additionally, the work was undertaken using a small diameter log specification for spindleless lathe processing. Further processing, product and market research could result in a new set of log specifications being developed that could positively change the resource availability estimates.

Other states and territories
Many of the issues described for Queensland will apply to the other states and territories in Australia.

Based on a review of existing information and in consultation with industry representatives the following are key comments and estimates on availability and suitability of native forest and plantation hardwood logs for spindleless lathe processing.

Victoria

Native forest
VicForests supply the majority of native forest logs in Victoria. Detailed data on private native forest log supply from Victoria is not available. Between 2006 and 2012 the area of forest available for timber production in Victoria decreased by 7%, from 2.6 million hectares in 2006, to 2.4 million hectares in 2012 (DEPI Victoria, 2014). This reduction in public forest available for timber production is primarily associated with major land use decisions to re-classify approximately 196,000 ha of State Forest to Parks and conservation reserves in the East Gippsland, Mid-Murray, Mildura, Otway and Portland FMAs4 (Forest Management Areas) (DEPI Victoria, 2014). The area of State Forest harvested between 2006–07 and 2011–12 ranged from 7,900 to 11,600 ha/yr (DEPI Victoria, 2014). The area harvested represents (on average) less than 1% of the total area available for harvesting (DEPI Victoria, 2014). The majority of this log volume (97%) is extracted from Eastern Victoria (DEPI Victoria, 2014).

The main wood products harvested in Victoria's public forests are sawlogs and pulpwood. Sawlogs are processed into structural grade and appearance grade timber products. Pulpwood comprises logs used for paper and wood-based panel products and is usually a residual product of sawlog harvesting. Other wood products harvested in native forests include low-quality sawlogs, posts and poles, bush sawn/hewn timber, firewood, speciality timber and sleepers. These are also usually a residual product of sawlog harvesting (DEPI Victoria, 2014).

Table 3.5 below summarises Vic Forests production figures by log grade from 2009–10 to 2014–15. In 2014-15 around 40% of the total production was sawlogs and the rest mainly residual logs for pulpwood. The figures in the table reveal the gradual decline in log production—approximately 31% reduction in native forest log production since 2009–10. This is mostly due to increasing conservation of native forests.

Table 3.5. Vic Forests production figures by log grade

	Volume of production by grade (m³)					
Product	2014–15	2013–14	2012–13	2011–12	2010-11	2009–10
ASH B grade	90,448	93,663	102,265	83,688	102,063	118,552
ASH C grade	97,184	101,026	97,459	92,987	95,628	151,436
ASH D grade	16,901	13,797	7,839	8,773	24,513	30,595
ASH E grade	191,596	163,001	179,786	147,972	129,808	135,717
ASH U ungraded salvage sawlog	911	953	1,056	1,423	53,342	22,735
ASH Total	397,041	372,440	388,405	334,842	405,353	459,035
MXS B grade	8,602	8,226	10,461	11,682	12,528	15,463
MXS C grade	63,278	65,228	67,308	77,759	73,538	92,287
MXS D grade	17,102	16,753	16,996	19,032	18,053	28,883
MXS E grade	23,734	16,506	9,806	19,399	16,690	8,668
MXS Other sawlogs*	–	–	–	34	2	–
MXS Ungraded salvage sawlog	192	183	4,929	2,041	1,000	1,848
MXS total	112,908	106,896	109,499	129,946	121,810	147,150
TOTAL Sawlog	509,949	479,336	497,904	464,788	527,163	606,185
Residual log	765,425	719,650	743,352	961,838	1,167,916	1,250,167
Firewood†	11,781	14,918	17,986	4,787	–	–
TOTAL All products	1,287,155	1,213,904	1,259,719	1,431,413	1,695,077	1,856,352

*Additional sawlog recovered from thinning operations or as poles/piles/posts †Prior to 2011–12 firewood sold as residual log. Only very small amounts were sold.

Table 3.6. Vic Forests Standing log volumes by log grade forecasted to 2019-20

	Log volume by grade (m³)					
Product	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20
ASH B grade	116,520	116,520	116,520	116,520	116,520	113,547
ASH C grade	101,614	101,614	101,614	101,614	101,614	98,379
ASH D grade	24,087	24,087	24,087	24,087	24,087	24,980
ASH E grade	113,939	113,939	113,939	113,939	113,939	103,805
TOTAL Sawlog	356,160	356,160	356,160	356,160	356,160	340,711
Residual log	482,183	482,183	482,183	482,183	482,183	482,064
TOTAL All products	838,343	838,343	838,343	838,343	838,343	822,775
MXS B grade	10,192	10,192	10,192	10,192	10,192	10,192
MXS C grade	83,237	83,237	83,237	83,237	83,237	83,237
MXS D grade	26,571	26,571	26,571	26,571	26,571	26,571
MXS E grade	36,742	36,742	36,742	36,742	36,742	36,742
TOTAL Sawlog	156,742	156,742	156,742	156,742	156,742	156,742
Residual log	522,015	522,015	522,015	522,015	522,015	522,015
TOTAL All products	678,757	678,757	678,757	678,757	678,757	678,757

The main commercial native forest timber species in Victoria are the ash species—mountain ash *(Eucalyptus regnans*) and alpine ash (*Eucalyptus delegatensis).* Other important timber species vary depending on the region: the Central Forest Management Area (CFMA) resource is predominantly messmate (*Eucalyptus obliqua*) with lesser quantities of mountain grey gum (*Eucalyptus cypellocarpa*) and manna gum (*Eucalyptus viminalis*). The East Gippsland resource is more variable but consists predominantly of messmate, silver top (*Eucalyptus sieberi*), cuttail (*Eucalyptus fastigata*), mountain grey gum (*Eucalyptus cypellocarpa*), errinundra shining gum (*Eucalyptus denticulata*), manna gum, white stringybark (*Eucalyptus globoidea*) and range of other *Eucalyptus* species.

The Victorian native forest resource is under a lot of pressure at the moment on various policy, economic and conservation fronts (McTavish pers. comm. 2017). This, on top of significant fires in the 2000s, has led to a sizeable reduction in forecast harvest levels (McTavish pers. comm. 2017). Whilst, there is a large volume of ash log that would likely meet the small peeler log specifications, it is all currently required to meet VicForests commitments to existing buyers, including the paper mill at Maryvale (McTavish pers. comm. 2017). Hence, availability of ash log for a new rotary peeling facility will be limited to a direct diversion from an existing process (McTavish pers. comm. 2017). This will be driven, by two factors; 1) market demand for the existing product declines and/or 2) peeling offers an improved financial return (McTavish pers. comm. 2017). In summary while there is no ash peeler log currently available, there could be upwards of 40,000 m^3/yr if there were to be a transition from an existing process to peeling (McTavish pers. comm. 2017).

The mixed species resource in Victoria is somewhat different in its structure (McTavish pers. comm. 2017). The paper mill absorbs all of the low grade mixed species within its economic catchment; however, in East Gippsland (Orbost) and CFMA (Alexandra) areas the low grade mixed species relies on export woodchip markets. These can be somewhat fickle but the exchange rate is currently favourable (McTavish pers. comm. 2017). The East Gippsland resource is contiguous with the south-east New South Wales resource and could be considered jointly. The CFMA resource is more discrete and possibly another 30–40,000 m^3/yr may be available as small peeler logs, assuming that logs larger than 30cm SEDUB can be included (McTavish pers. comm. 2017).

VicForests produces a range of log grades: B and C are expected to produce appearance grade products, whereas grades D and E are aligned to structural products and pallets. Ungraded sawlogs are not produced routinely but if so would be akin to B and C grade. In Victoria the term salvage log is used mainly to refer to logs produced from post fire salvage operations. Another source of peeler logs in the future could be fire salvage operations. Below E grade are the woodchip/pulp grades and firewood.

The residual log grades are used as pulpwood with the exclusion of relatively low quantities of firewood. The pulpwood as described earlier is processed at Australian Paper's mill at Maryvale or is exported in chip form from either Geelong or Eden.

Further research and inventory work would be required to determine how much of the residual log grades could meet the specifications of peeler logs for spindleless lathe processing.

Plantations

Victoria has the largest area of plantations of any state or territory in Australia with 423,000 ha in 2015–16 (Downham and Gavran, 2017). The majority is softwood plantations 223,300 ha and 199,000 ha of hardwood plantations. Plantation forests are almost all (99%) privately owned (DEPI Victoria, 2014). Victoria has developed the third largest state-wide industrial hardwood plantation resource in Australia (Downham and Gavran, 2017).Victorian hardwood plantations are comprised mostly of southern blue gum and a small amount of shinning gum. There is uncertainty as to how much of Victoria's existing plantation area will be retained for subsequent rotations. Victoria's total plantation estate may decrease slightly in the next few years (DEPI Victoria, 2014).

The hardwood plantations in Victoria are managed primarily for pulpwood production.

In 2014–15 Victoria produced 2.834 million cubic metres of hardwood plantation logs (ABARES 2016a). Of this 98 % or 2.775 million cubic meters was pulp logs and 2% or 59,000 m^3 was sawlogs (ABARES, 2016a).

ABARES estimates for plantation hardwood log availability in the main plantation regions of Victoria are shown in Figures 3.28, 3.29 and 3.30. Further research and inventory work is required to determine how much would be suitable and available for peeling using spindleless lathes.

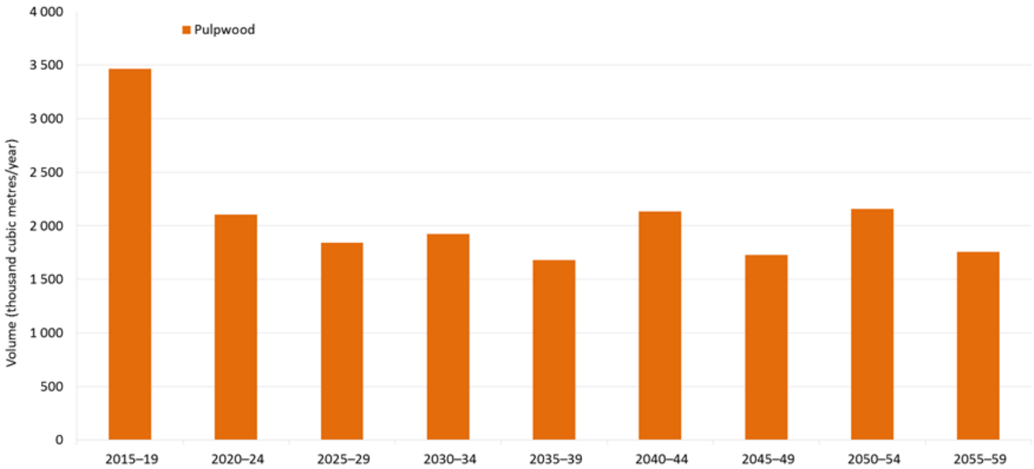

Figure 3.28. Forecast hardwood plantation log availability, Green Triangle (ABARES, 2016b)
Note: this region includes south-east South Australia.

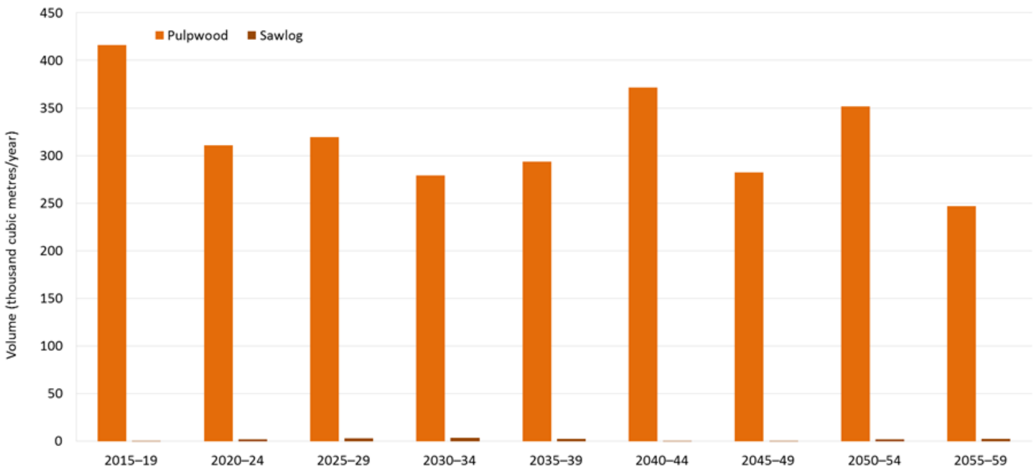

Figure 3.29. Forecast hardwood plantation log availability, Central Victoria (ABARES, 2016b)

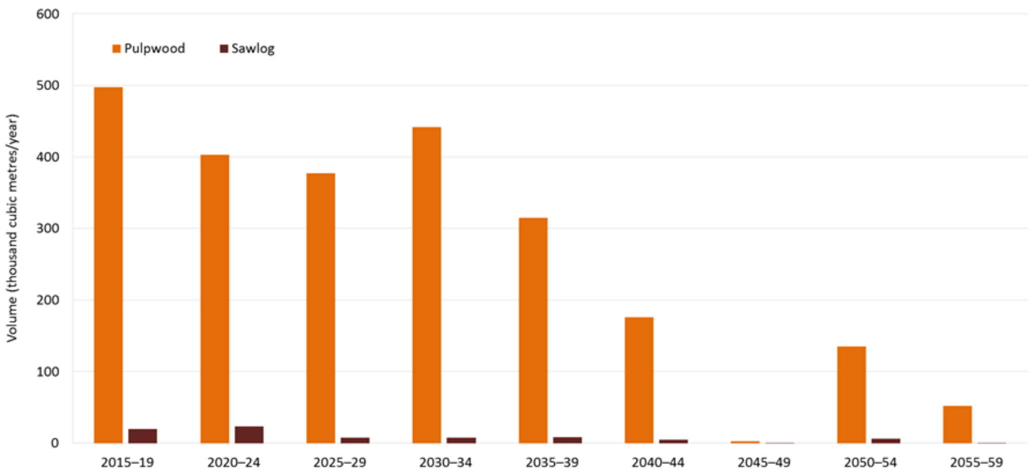

Figure 3.30. Forecast hardwood plantation log availability, Central Gippsland (ABARES, 2016b)

Tasmania

Native Forest

Native forest logs in Tasmania are supplied by Sustainable Timber Tasmania (formerly Forestry Tasmania) and also by private native forest growers.

Sustainable Timber Tasmania is a Tasmanian Government Business Enterprise responsible under State legislation for:

- sustainably managing approximately 800,000 ha of public production forest (Permanent Timber Production Zone land)
- undertaking forest operations for the production and sale of forest products from these forests (including making available at least 137,000 m³ of high quality eucalypt sawlogs and veneer logs per annum) (Forestry Tasmania, 2017)

About 60% or 485,000 ha of the land managed by Sustainable Timber Tasmania is available for actual wood production, with the remainder set aside in informal reserves or other non-production areas. In 2015–16 Sustainable Timber Tasmania harvested 5000 ha of native forest (clear-fell, selective harvest and thinning) (Forestry Tasmania, 2016).

Privately owned native forest in Tasmania occupies 858,000 ha, approximately 26% of the State’s reported native forest area (Private Forests Tasmania, 2016). Privately owned native forest is dominated by eucalypt forest (both low and tall) that occupies 809,000 ha, leaving 49,000 ha supporting rainforest and other native forest (Private Forests Tasmania, 2016).

The dominant native forest hardwoods harvested in Tasmania are the Tasmanian oak species—*E. delegatensis*, *E. obliqua* and *E. regnans*.

In 2015–16, 1.47 million tonnes of wood products were produced from Sustainable Timber Tasmania’s Permanent Timber Production Zone land. This total production figure includes 127,000 m³ of high-quality eucalypt sawlog, sourced entirely from native forests (Sustainable Timber Tasmania, 2016).

The high-quality sawlog comprised 1,092 m³ of logs suitable for sliced veneer production, 114,939 m³ appearance- grade sawlogs and 11,026 m³ construction-grade logs (Sustainable Timber Tasmania, 2016). In addition, Sustainable Timber Tasmania also sourced 77,467 tonnes of timber from the private sector (Sustainable Timber Tasmania, 2016).

Sustainable Timber Tasmania native forest operations also produced the following products:

- 4,698 m³ of posts and poles, the majority of which were destined for use as electricity poles
- 35,721 m³ of lower-quality sawlog that was suitable for uses similar to those of high-quality sawlogs, but which were expected to have lower product recoveries and primarily produce structural timber
- 164,302 tonnes of peeler logs, suitable for domestic rotary peeling into veneer
- 725,138 tonnes of pulp logs that were suitable for local processing into export woodchips
- 10,504 m³ of fuel/firewood.

(Sustainable Timber Tasmania, 2016).

Table 3.7 summarises the annual log production figures (in tonnes) from private native forest growers in Tasmania from 2011–12 to 2015–16 (Private Forests Tasmania, 2016).

Table 3.7. Annual log production from private native forest in Tasmania (PFT, 2016)

Native hardwood	Log production (tonnes)				
	2011–12	2012–13	2013–14	2014–15	2015–16
Native sawlog, veneer and ply	28,894	21,110	12,355	10,694	61,801
Hardwood pulpwood	105,064	57,202	76,632	76,661	106,665
Minor log products	84	36	55	278	247
Fuel wood	4,812	1,325	1,486	863	6,487
Total native forest including fuel wood	138,854	79,674	90,529	91,496	175,200
Total native forest excluding fuel wood	134,042	78,349	89,043	90,633	168,713

A significant quantity (approximately 180,000 tonnes/yr) of hardwood peeler logs are also exported mainly to China from Tasmania, by Sustainable Timber Tasmania (Williams pers. comm. 2017). Although these logs are notionally 'peeler logs' it is not known how they are used overseas.

There is no large-scale commercial native forest thinning carried out on the Sustainable Timber Tasmania's estate as it generally does not deliver economic outcomes (cost and also value degradation of remaining stand) (Williams pers. comm. 2017). It is used sparingly in some situations for environmental/conservation reasons and only where economically practical (Williams pers. comm. 2017). Partial harvest systems are used in some native forest types where sawlogs are extracted and small trees and seed trees are retained. Small peeler log may represent a viable option for thinnings; however, the concern would still be the damage to the residual trees caused by thinning (Williams pers. comm. 2017).

One problem with using lower grade logs for peeling versus for wood chip in Tasmania is the merchandising that is required can in some cases make the use of logs for peeling less economically viable compared to chipping (Williams pers. comm. 2017).

Plantations

In 2015–16 Tasmania had 309,800 ha of plantations of which 233,900 ha were hardwood and 75,900 ha were softwood (Downham and Gavran, 2017). After Western Australia, Tasmania has the second largest area of hardwood plantations in Australia (Downham and Gavran, 2017). Approximately 83% of Tasmania's plantations are privately owned. Close to 90% of the hardwood plantations in Tasmania are shining gum followed by southern blue gum 8% and then the rest is other species (Downham and Gavran, 2017).

The hardwood plantations in Tasmania are managed primarily for pulpwood production.

In 2014–15 Tasmania produced 1.290 million cubic metres of hardwood plantation logs (ABARES 2016a). Of this 97% or 1.253 million cubic metres was pulp logs and 3% or 37,000 m³ was sawlogs (ABARES, 2016a).

In 2014 the National Centre for Future Forest Industries (NCFFI) undertook a study investigating the feasibility of regional rotary veneer peeling in Tasmania (Blackburn and Nolan, 2014). Included in this study was an analysis of potential peeler log supply. The feasibility study focused on smaller-scale peeling operations with equipment that has a specific log size limitation of approximately 150–300 mm small end-diameter (SED) (Blackburn and Nolan, 2014). Log size limitations for spindleless lathe rotary peeled veneer (RVP) were presented to resources planning staff at Sustainable Timber Tasmania and staff at Sustainable Forest Management to enable them to provide annual log availability estimates for the next 30 years (Blackburn and Nolan, 2014). Estimates based on logs harvested from mainly pulpwood estates were provided with the assumption of a 0–60 km cartage distance and a 20% recovery of peeler logs from clear-felled coupes. Table 3.8 summarises these estimates for the two case study regions in the study – the Scottsdale and Tasman Peninsula region.

Table 3.8. Annual small peeler log availability (Blackburn and Nolan, 2014)

Region	Estimated log volume available
Scottsdale region processing capacity	100,000 m³ /yr
Tasman Peninsular region processing capacity	10,000 m³/yr
Log factor	**Peeler log specifications**
Log small end diameter	180–350 mm
Log length	5.6 m (provides billet length multiples of 2.6 or 1.35 m)

Forecasted plantation hardwood log availability from ABARES for Tasmania is shown in Figure 3.31. Further research and inventory work is required to determine how much would be suitable and available for peeling using spindleless lathes.

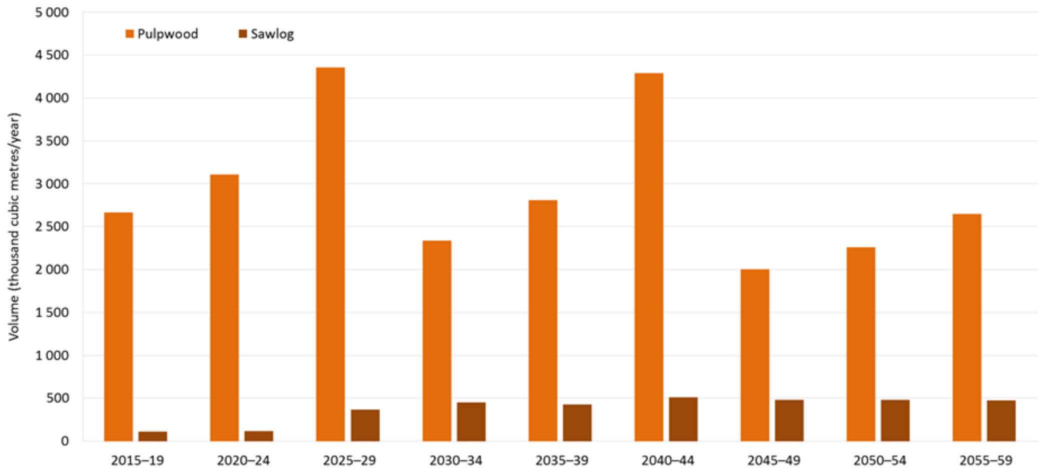

Figure 3.31. Forecast hardwood plantation log availability, Tasmania (ABARES, 2016b)

Western Australia

Native Forest
Native forest log supply in Western Australia is mainly provided by the Forest Products Commission. Private native forest supply is minimal. The vast majority of native forest logs are produced in the South-West of Western Australia.

The 2014–2023 Forest Management Plan (FMP) covers approximately 2.25 million hectares of native forest within the geographic areas of the Swan, South West and Warren regions. Of this area approximately 850,000 ha of mixed regrowth forest is available for harvesting (Forest Products Commission WA, 2017).

The main native forest species harvested for wood production in Western Australia are jarrah (*Eucalyptus marginata*), karri (*Eucalyptus diversicolor*), marri (*Corymbia colophylla*), West Australia blackbutt (*Eucalyptus patens*) and she oak (*Allocasuarina decussata*).

Native forest harvesting levels are based on an annual allowable cut which is determined by the FMP, which accounts for all resource as either sawlog or other bole volume.

The quantities of sawlog harvested must be consistent with the allowable cut in the FMP.

The allowable annual cut of first and second grade sawlogs for jarrah and karri between 2014 and 2023 are 132,000 m^3 and 59,000 m^3 respectively (Forest Products Commission WA, 2016). Other bole volume logs are also supplied by the Forest Products Commission for jarrah, karri and marri. The FMP 2014–23 now has an upper and lower limit for the annual harvest of other bole volume logs which are detailed in Table 3.9 (Forest Products Commission WA, 2016).

Table 3.9. Allowable annual cuts for other bole volume logs (Forest Products Commission WA, 2016)

	Jarrah	Karri	Marri
Annual upper limit*	521,000 m^3	164,000 m^3	254,000 m^3
Annual lower limit*	292,000 m^3	164,000 m^3	140,000 m^3

*Excludes first and second grade sawlogs for jarrah and karri

Tables 3.10 to 3.13 detail the native forest log production in Western Australia from both crown and private land in 2015–2016 (Forest Products Commission WA, 2016).

Table 3.10. Log production from Crown land and private property in 2015–16 (Forest Products Commission WA, 2016)

Product type	Log production (m^3)		
	Crown land	Private property	Total
Native forest sawlog timber			
Jarrah	120,994	1,100	122,094
Karri	45,628	–	45,628
Marri	4,924	35	4,959
Blackbutt	580	-	580
Wandoo	67	18	85
Sheoak	537	–	537
Other	2	-	2
Total native forest sawlogs	172,732	1,153	173,885
Other native forest log material			
Chip logs	121,973	–	121,973
Firewood/charcoal logs	106,855	850	126,984
Sandalwood	1,859	–	1,859
Other	4,492	–	4,492
Total other native forest log material	235,179	850	236,029

Table 3.11. Native forest sawlog production in 2015-16 (Forest Products Commission WA, 2016)

Species	High quality sawlogs	1st and 2nd grade sawlogs	Bole sawlogs	Other sawlogs	Total
Jarrah	553	–	90,182	31,359	122,094
Karri	–	35,627	–	10,001	45,628
Marri	34	–	–	4,925	4,959
Other species	11	–	656	537	1,204
Total	**598**	**35,627**	**90,838**	**46,822**	**173,885**

Table 3.12. Native forest chip log production from crown lands (Forest Products Commission WA, 2016)

Species	Chip log production (m^3)		
	2013–14	2014–15	2015–16
Marri	5,836	9,375	7,734
Karri	104,998	80,060	114,239
Other species	10,412	1,501	–
Total	**121,246**	**90,936**	**121,973**

Table 3.13. Native fuelwood production (Forest Products Commission WA, 2016)

Product type	Fuelwood production (tonnes)		
	2013–14	2014–15	2015–16
Firewood logs	89,056	65,650	64,089
Charcoal logs	79,871	66,769	62,895
Total	**168,927**	**132,419**	**126,984**

There is currently only one facility peeling softwood and hardwood logs in Western Australia which is WESBEAM—the Forest Products Commission supplies approximately 10,000–15,000 tonnes/yr of karri (*E. diversicolor*) logs to WESBEAM for peeling (Charles pers. comm. 2017).

Native hardwood forests are thinned in Western Australia. This does represent an opportunity for peeler log processing; however, there is competition for this resource for biomass for energy production and for woodchip. It is considered potentially easier to use the residue for biomass uses compared to peelers because minimal sorting and merchandising is required (Charles pers. comm. 2017). Another big market for thinnings in Western Australia is fencing, however this could represent an opportunity for small diameter peeler logs if it was demonstrated to be more profitable and also subject to log size and grade suitability (Charles pers. comm. 2017).

Plantations

After Victoria and New South Wales, in 2015–16 Western Australia had the third largest total commercial plantation area with 383,400 ha (Downham and Gavran, 2017). However, Western Australia has the largest area of hardwood plantations with 276,400 ha in 2015–16 (Downham and Gavran, 2017). Approximately 92% of the hardwood plantations are blue gum.

The hardwood plantations in Western Australia are managed primarily for pulpwood production.

In 2014–15 Western Australia produced 3.376 million cubic metres of hardwood plantation logs (ABARES 2016a). Of this 99.98 % or 3.375 million cubic meters was pulp logs and 0.02% or 2,000 m^3 was sawlogs (ABARES, 2016a).

Forecasted plantation hardwood log availability from ABARES for Western Australia is shown in Figure 3.32. Further research and inventory work is required to determine how much would be suitable and available for peeling using spindleless lathes.

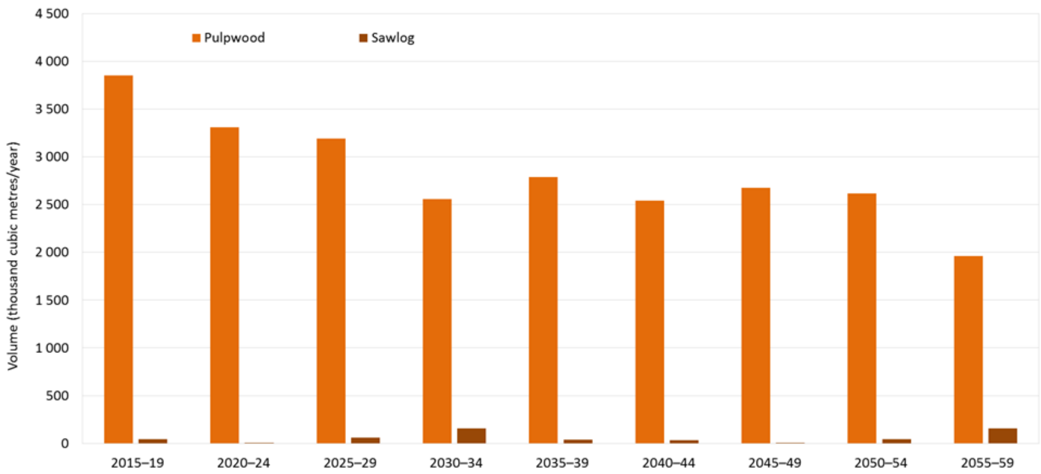

Figure 3.32. Forecast hardwood plantation log availability, Western Australia (ABARES, 2016b)

New South Wales

Native Forest

The Forestry Corporation of NSW is the largest manager of commercial native and plantation forests in New South Wales. There is also significant supply from private forests.

In New South Wales, the net harvestable area of public native forest declined from 2.35 million hectares in 1995–96 to 1.23 million hectares in 2010–11, a reduction of 48 % (ABARES, 2013.

In any given year, less than 2% of the state forest estate is harvested for timber (Forestry Corporation, NSW 2016a).

Almost all native forest timbers harvested in New South Wales are hardwood species, mainly eucalypts. In total there are over 50 commercial species, the most common being coastal blackbutt, spotted gum (*Corymbia maculata*), Sydney blue gum (*E. saligna*), stringybark (various *Eucalyptus* species), silvertop ash (*E. sieberi*) and ironbark (various *Eucalyptus* species) (Timber NSW, 2017). Flooded gum is also an important native forest species.

In 2014–15, 924,000 m^3 of hardwood logs were harvested from New South Wales forests of which 643,000 m^3 were sawlogs and 281,000 m^3 were pulp logs (ABARES 2016a). ABARES data on sawlogs includes sawlogs, veneer and peeler logs, poles, piles, fencing and other logs not elsewhere included.

In 2015–16, the Forestry Corporation of NSW recorded that 15,150 m^3 veneer logs, 492,413 m^3 sawlogs, 32,312 m^3 of poles, piles and girders, 299,770 tonnes pulp logs and 37,723 m^3 of cypress pine sawlogs were produced (Forestry Corporation NSW, 2016). The report doesn't separate native forest hardwood from plantation grown hardwood; however, most of this log volume would be sourced from native forests (Forestry Corporation NSW, 2016a).

Big River Timbers is the only veneer operation in New South Wales that is supplied with logs by the Forestry Corporation of NSW. Currently, around 16,000 m^3 logs/yr is sold to Big River Timbers of which approximately 60% is blackbutt 15% spotted gum (*Corymbia* spp.) and the rest a mixture of species (Johnston pers. comm. 2017).

Forestry Corporation of NSW have a few export customers who export exclusively to China, taking what is referred to as an "industrial grade" sawlog that is not considered economically viable for the local sawmillers—usually small straight logs with a SED of 15–25 cm (Johnston pers. comm. 2017). These good logs with not a lot of external defect are containerised and sent to China (Johnston pers. comm. 2017). A mixture of species is exported. It is unknown how are they processed or used in China (Johnston pers. comm. 2017). This log grade may be suitable for peeling.

Thinnings from native forest and plantation operations also represent another source of potential peeler logs in New South Wales. Currently the thinnings are used for products such as poles, biomass for energy, woodchip and peelers.

According to the Forestry Corporation of NSW there are potentially considerable volumes of logs left standing after harvesting operations that could be suitable for peeling using spindleless lathe operations. However, accessing these logs would depend on regulatory, market and economic factors (Crowe, pers. comm. 2017).

Plantations

In 2015–16 after Victoria, New South Wales (394,400 ha) had the second largest area of commercial plantations (Downham and Gavran, 2017). Of this area 307,100 ha were softwood and 87,100 ha were hardwood (Downham and Gavran, 2017).

The most important plantation hardwood species in New South Wales are: flooded gum, spotted gum, shining gum and Dunns white gum *(Eucalyptus dunni*).

At least half of the hardwood plantations in New South Wales are managed to produce sawlogs to supplement sawlog supply from native forest. Most of the plantations managed for sawlog production are in the North Coast New South Wales region.

In 2014–15 New South Wales produced 72,000 m^3 of hardwood plantation logs (ABARES, 2016a). Of this 55.6% or 40,000 m^3 was sawlogs and 44.4% or 32,000 m^3 was pulp logs (ABARES, 2016a).

ABARES estimates for plantation hardwood log availability for the main plantation regions of New South Wales are shown in Figures 3.33, 3.34 and 3.35. Further research and inventory work is required to determine how much would be suitable and available for peeling using spindleless lathes.

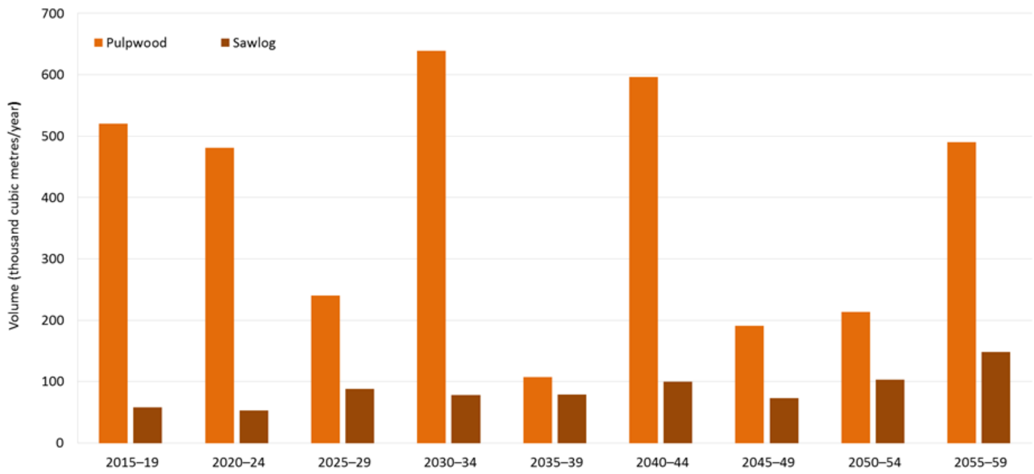

Figure 3.33. Forecast hardwood plantation log availability, North Coast (ABARES, 2016b)

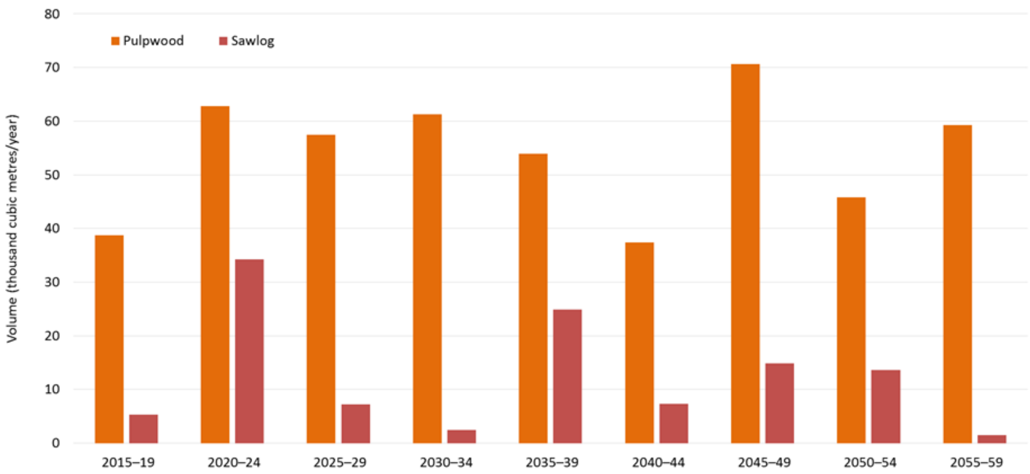

Figure 3.34. Forecast hardwood plantation log availability, Murray Valley (ABARES, 2016b)
Note: this region includes north-east Victoria.

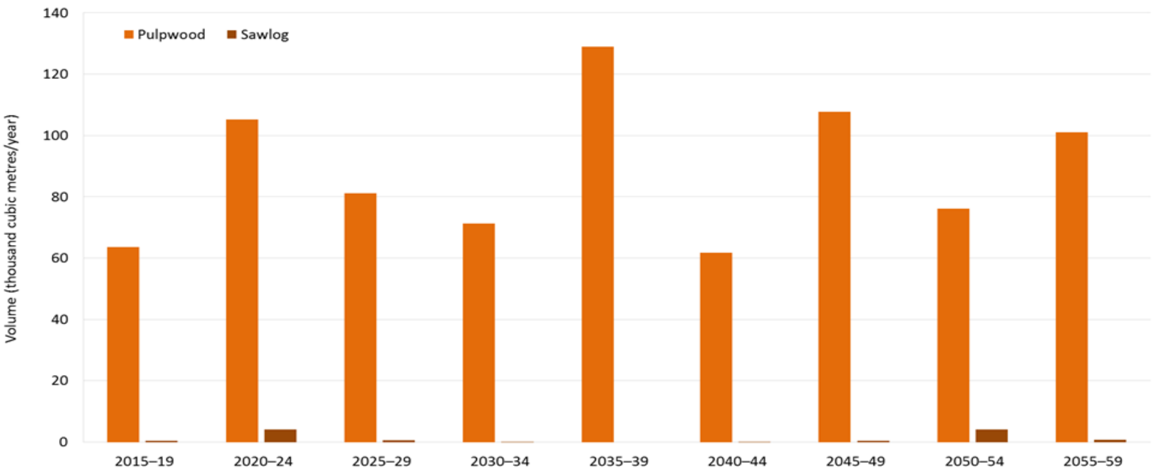

Figure 3.35. Forecast hardwood plantation log availability, East Gippsland–Bombala (ABARES, 2016b)
Note: this region includes Victoria's East Gippsland.

South Australia

Plantations
In 2015–16 the total area of commercial plantations in South Australia was 178,800 ha (Downham and Gavran, 2017). Of this, 127,200 ha was softwood and 51,400 ha was hardwood (Downham and Gavran, 2017).

The most important plantation hardwood species in South Australia is southern blue gum. The hardwood plantations in South Australia are managed primarily for pulpwood production.

In 2014–15 South Australia produced 862,000 m^3 of hardwood plantation logs (ABARES 2016a). Of this 84.9% or 732,000 m^3 was pulp logs and 15.1% or 131,000 m^3 was sawlogs (ABARES 2016a).

ABARES estimates for plantation hardwood log availability for the main plantation regions of South Australia are shown in Figure 3.36. Further research and inventory work is required to determine how much would be suitable and available for peeling using spindleless lathes.

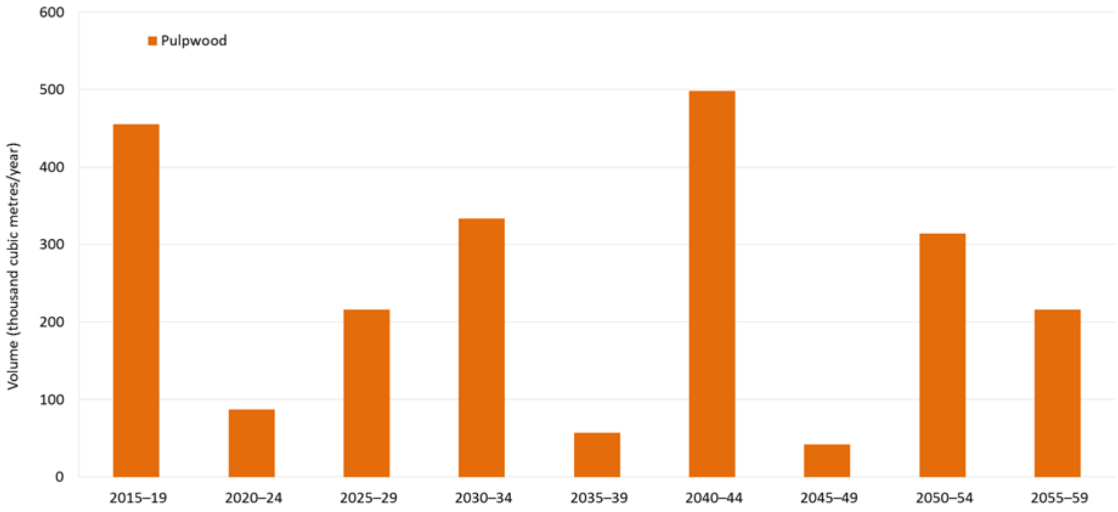

Figure 3.36. Forecast hardwood plantation log availability, Mount Lofty Ranges and Kangaroo Island (ABARES, 2016b)

Northern Territory

Plantations

In 2015–16 the total area of commercial plantations in Northern Territory was 47,600 hectares (Downham and Gavran, 2017). Of this 45,700 ha was hardwood and 1,900 ha was softwood (Downham and Gavran, 2017).

The majority of the hardwood plantations are black wattle (*Acacia mangium*) (31,200 ha) planted on Melville Island and African mahogany (*Khaya senegalensis*) (14,500 ha) planted on the mainland. Around 68% of the hardwood plantations are managed for pulp logs; the remaining 32% are managed for sawlogs (ABARES, 2016c).

ABARES (2016a) recorded zero log production currently from the hardwood plantations in the Northern Territory.

ABARES forecast for plantation hardwood log availability in the Northern Territory is shown in Figure 3.37. Further research and inventory work is required to determine how much would be suitable and available for peeling using spindleless lathes.

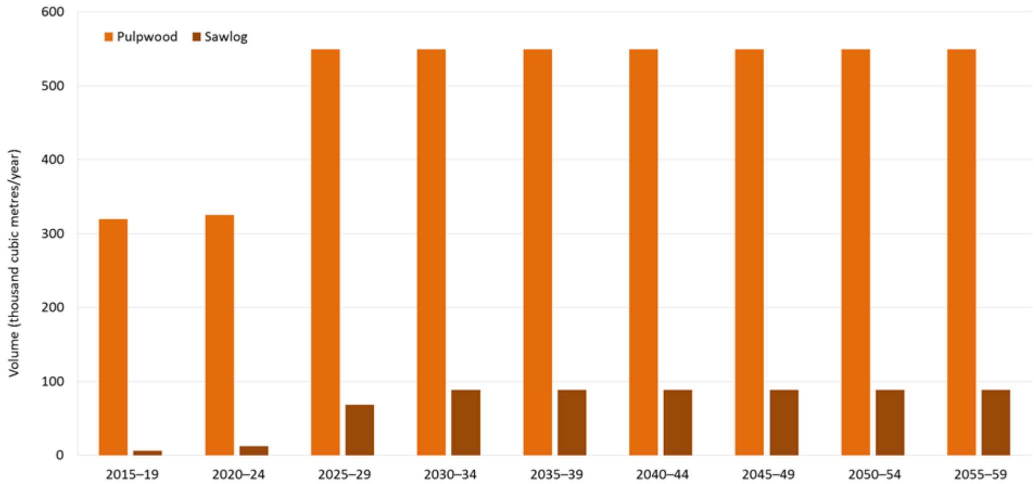

Figure 3.37. Forecast hardwood plantation log availability, Northern Territory (ABARES, 2016b)

Australian Capital Territory

Plantations
In 2015–16 the total area of commercial plantations in Australian Capital Territory was 7,400 ha (Downham and Gavran, 2017). All of this area is softwood plantations.

Conclusions

Limited data is currently available on the quantities of native forest and plantation hardwood logs in Australia that are potentially accessible and suitable for spindleless lathe processing. This is mainly because of the absence of appropriate log specifications and inventory data. However, the preliminary assessments completed suggest that substantial volumes of logs potentially suitable for spindleless lathe processing are present in Australia's native forest and hardwood plantations; however, access to/and conversion of these logs will depend on many factors including:

- demonstrated economic viability of spindleless lathe processing and veneer production compared to other resource utilisation options
- market demand
- accommodating government policies and regulations.
- private forest owner intent with respect to commercial wood production

This Chapter discussed the results of a preliminary resource assessment based on desktop analysis, industry consultation and limited field case studies. Further, more detailed inventory and analysis needs to be undertaken. Ideally, state and private forestry authorities should start to include assessments on peeler log volumes for potential spindleless lathe processing as part of their routine forest inventory work. However, in order to do this, appropriate specifications need to be developed which in turn will be influenced by processing, market and economic factors.

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Chapter 4: Comparison of processing methods for small-diameter logs: sawing *versus* rotary peeling

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Introduction

The forests in Australia are comprised of 123 million ha of native forests (98% of the total forest area), 2.02 million ha of industrial plantations, and 0.15 million ha of other forests (ABARES, 2013). Native forest resources have largely been limited to utilization by the timber industry as sawn timber. However, for more durable hardwood species, well established markets also exist for several round wood products, such as electrical distribution poles, bridge girders, *etc*. Sawing has for many years been a suitable method for converting relatively large-diameter native forest logs into a range of traditionally well-demanded sawn products, including large- and small-dimension structural posts and beams, bridge members, railway sleepers, flooring, decking, fencing, and landscaping timbers.

Traditionally, small-diameter hardwood logs (< 40 cm in diameter) have not been favoured for sawmilling, mainly because of unacceptable low recovery rates. However, some sawmills have recently begun accepting smaller diameter hardwood logs, usually at low log prices. Some limited low-value and low-volume markets (*e.g.*, fence posts and firewood) do exist for small-diameter native forest logs. However, this log resource is currently being underutilized, and it is often regarded as sub-optimal in quality and of low value. This is despite the wood properties potentially being favourable for a wide range of high-value products.

Engineered wood products (EWPs), particularly veneer-based EWPs, may provide a more efficient processing method and a new product market for small native forest logs. However, there is only limited knowledge and technical experience in Australia on the processing of relatively large-diameter native forest logs into veneer-based EWPs, such as plywood. For small native forest logs, the potential to produce EWPs using rotary-peeled veneers has been prevented because of processing equipment limitations. Traditional rotary peeling approaches have required large-diameter logs of high quality to overcome the limiting recovery rates that result from large peeler cores (peeler cores are the centre of the log that remains after the peeling process from which no veneer is recovered) and the propensity for logs to end split, especially in high density and regrowth hardwood logs, where the splits prevent adequate log holding capacities of the lathe spindles.

Recent research has demonstrated the potential to use emerging spindleless veneering technologies to process hardwood plantation logs with sizes and qualities previously considered unable to be efficiently processed (McGavin *et al.* 2014a; McGavin *et al.* 2014b; Peng *et al.* 2014; McGavin *et al.* 2015a; McGavin *et al.* 2015b; Leggate *et al.* 2017; Belleville *et al.* 2018). This research has shown that this new approach can process small-diameter logs and is able to yield recovery rates that are higher than what is achieved through other processes.

This study expanded on previous research that focused on plantation-grown resources to determine the suitability of this processing approach for small-diameter logs from native forest resources. Using small-diameter native forest logs, the recovery rates and product quality grade of wood products from traditional sawing approaches were compared with those of wood products produced using a spindleless veneer processing system.

Experimental

Log sampling

Two native forest tree species were included in this study: spotted gum (*Corymbia citriodora*) and white cypress pine (*Callitris glaucophylla*). These species were selected because they are the dominant hardwood and softwood species harvested from native forests for timber products in Queensland, Australia.

The spotted gum logs were selected during a commercial harvesting operation within the Gurulmundi State Forest, located in South West Queensland, Australia. This forest is representative of a typical mixed-age hardwood forest in this region. Commercial harvesting targets electrical distribution poles, bridge girders, and sawlogs, essentially all of which have diameters greater than 30 cm. For this study, 2.7-m long logs were chosen that contained small-end diameters under bark (SEDUB) within three target diameter groups (19 cm, 24 cm, and 28 cm). Because of physical restrictions with processing equipment at the commercial sawmill, the minimum SEDUB was 18 cm. Where possible, logs for the study were cut from trees harvested as part of a commercial harvest.

The white cypress pine logs were sourced from within full-length logs in the log yard of a commercial sawmill (original logs sourced from a mixed age forest within the Barakula State Forest). In Queensland, it is common practice for harvested white cypress pine trees to be docked to 16 cm SEDUB (unless defects necessitate cutting at a larger small-end diameter) and the full-length logs are delivered to a sawmill, where they are further cut to more desirable log lengths in preparation for sawmilling. Similar to the spotted gum logs, 2.7-m long logs were chosen that contained a SEDUB within three target diameter groups (16 cm, 22 cm, and 28 cm). The minimum SEDUB was set lower for the white cypress pine logs at 16 cm SEDUB to align with the current commercial sawlog criteria for this species. In addition to the SEDUB, other log grade criteria were used to evaluate the sweep, branching, and other log defects (Table 4.1).

Table 4.1. Log Grading Criteria

Grade Criteria	Spotted Gum	White Cypress Pine
Minimum Length	2.7 m	2.7 m
Minimum SEDUB	18 cm	16 cm
Maximum SEDUB	30 cm	30 cm
Core	Defective core should not exceed 6 cm in diameter	Defective core should not exceed 6 cm in diameter
External Defect	No green limbs > 6 cm in diameter; no dry limbs > 3 cm in diameter - No more than one bump (*i.e.*, occluded limbs) on visible half of the log within each 50-cm length; no more than one overgrowth (*i.e.*, insect or logging damage) on visible half of the log within each 50-cm length; fluting acceptable where the hollows do not extend into the centre log diameter	no green limbs > 9 cm in diameter - no dry limbs > 4.5 cm in diameter - No more than two bumps (*i.e.*, occluded limbs) on visible half of the log within each 50-cm length; no more than one overgrowth (*i.e.*, insect or logging damage) on visible half of the log within each 50-cm length; fluting acceptable where the hollows do not extend into the centre log diameter
Maximum Sweep	1/7 (14%) of the SEDUB	1/7 (14%) of the SEDUB
Ovality/Taper	maximum difference between the longest and shortest axis ranging from 2.2 cm (18 cm SEDUB) to 3.8 cm (30 cm SEDUB)	maximum difference between the longest and shortest axis ranging from 2.2 cm (16 cm SEDUB) to 3.8 cm (30 cm SEDUB)
Spiral Grain/Grain	No spiral grain, no excessive free grain	No spiral grain, no excessive free grain

Log assessment and allocation

The following parameters were measured on each log:

- Large-end diameter under bark (LEDUB) (m) – measured from the circumference with a diameter tape; and
- Small-end diameter under bark (SEDUB) (m) – measured from the circumference with a diameter tape.

Logs were then sorted into diameter groups to provide tree batches per species (three diameter groups). Logs within each batch were sorted by the SEDUB from smallest to largest before being alternately allocated to a processing method, at which point they underwent either sawing or veneer processing. Logs allocated for veneer processing were further docked in length to a standard length of 2.6 m. Each batch was color-coded by spray painting the log ends for easy tracking during processing.

From the measured data, the log volume was derived for each log and was calculated with the following equation:

$$V = \left(\frac{SEDUB + LEDUB}{4} \right)^2 \times \pi \times L$$

[eq. 4.1]

where V is the individual green log volume (m^3), π is 3.141593, and L is the nominal length of the log (2.7 m for sawlog and 2.6 m for veneer log).

Sawmill processing

Log conversion

The spotted gum logs were processed in a commercial hardwood sawmill equipped with modern equipment well-suited to processing high-density hardwood logs with diameters less than 45 cm SEDUB. The sawing approach adopted for the study mirrored the standard processing strategy used in sawmills that targets two different width flooring products. A chipper canter was used in conjunction with twin circular saws to target nominal 25-mm-thick (actually 27 mm to allow for shrinkage during drying) wing boards and either nominal 100-mm- or 150-mm-wide (actually 104 mm and 154 mm, respectively) centre cants. The wing boards and centre cants were then processed through a multi-saw board edger to recover either 100-mm- or 150-mm-wide (nominal), or 25-mm-thick (nominal) boards. As is performed during standard production, all of the boards were then passed through a scanning and docking station where only major defects were removed.

The white cypress pine logs were processed within a commercial cypress sawmill. The sawing approach adopted for the study mirrored the standard sawmill processing strategy that targets a wide variety of board sizes, which suit either structural, appearance, or landscaping/fencing products. The sawing approach and board size were chosen by the saw operators on a piece by piece basis based on visually assessing the log or piece for shape and defects and aimed to maximize the product recovery. Twin circular saws were used to remove wing boards and a centre cant from the logs. These pieces were then passed over traditional breakdown bench saws to recover sawn boards. During normal production, defects considered unacceptable by the market are docked from sawn boards before the boards are stacked and on-sold. This defect docking process was also followed so that the study logs closely matched the standard sawmill production approach.

Sawn timber grading

The sawn timber resulting from processing remained separated in line with the original log batch segregation. Because the hardwood sawmill targets a dried and dressed final product and the study aimed to replicate the standard commercial sawmilling process, the recovered spotted gum boards were dried to a target moisture content of 12% before the quality grade was assessed. The dried boards were graded according to AS 2796.2:2006 (2006). This standard is well accepted by the Australian hardwood timber industry and separates flooring-type products into three quality grades: select grade (highest quality), medium feature grade, and high feature grade (lowest quality). Each board was visually graded according to all three grades individually to determine the grade recovery of each specific grade. The most influential defect type that caused the boards to be down-graded/rejected was also recorded. A minimum piece length was set at 900 mm in line with the sawmill procedures.

For the white cypress pine, no grading was conducted as the cypress sawmill does not undertake any further processing or value adding onsite. The rough sawn and unseasoned sawn boards are either sold directly to market or on-sold within the company to another facility where boards are then sold to market (with or without any further processing). To closely replicate the commercial sawmill process, the white cypress pine boards were measured to determine the marketable volumes immediately after sawing and docking (*i.e.*, green-off-saw). A minimum piece length was set at 1800 mm, which was in line with the sawmill procedures.

Sawn timber recovery

Two recovery calculation methods were used: sawn recovery (SR) and dried-dressed recovery (DDR). Sawn recovery provides a useful measure of the percentage of the log volume converted into boards from the sawing process (mainly influenced by the log size, log geometry, and processing equipment). The SR (%) was calculated for each log batch as follows:

$$SR = \left(\frac{\sum_{Board}(W \times T \times L)}{\sum_{Log} V}\right) \times 100 \qquad \text{[eq. 4.2]}$$

where W is the sawn board nominal dried width (m), T is the sawn board nominal dried thickness (m), and L is the sawn board length (m).

Dried-dressed recovery includes the losses accounted for in SR, but also includes additional losses from grading and dressing (or machining) to a final dimension, *e.g.*, tongue and groove flooring. The DDR (%) was calculated as follows:

$$DDR = \left(\frac{\sum_{Board}(DDW \times DDT \times L)}{\sum_{Log} V}\right) \times 100 \qquad \text{[eq. 4.3]}$$

where DDW is the board nominal width (m) after drying and dressing, and DDT is the board nominal thickness (m) after drying and dressing.

Given the commercial process that the study aimed to replicate, only the SR could be calculated for the white cypress pine boards.

Rotary veneer processing

Log conversion

The spotted gum and white cypress pine logs allocated for rotary veneer processing were processed using an industrial spindleless veneer lathe in an industrial setting. The lathe was capable of processing logs up to 2600 mm in length and 500 mm in diameter. The minimum peeler core size was 40 mm; however, the veneer processing facility normally processes to a core size of approximately 60 mm. The actual peeler core size was measured for each log at the completion of processing. For the study, a nominal dried veneer thickness of 3.2 mm was selected, which was in line with the thickness frequently peeled by the facility for various structural products. The spotted gum and white cypress pine logs were preheated prior to peeling using saturated steam until the billet core reached approximately 70 °C and 60 °C, respectively.

Veneer management

The veneer ribbon produced by the peeling process was consecutively clipped into veneer sheets with a maximum width of 1350 mm and each veneer sheet was labelled with a unique identifier. Veneer sheets were seasoned to a target moisture content of 8% with a conventional jet box veneer drying system using the standard practices of the factory (temperatures ranged from 160 °C to 190 °C during drying).

The following parameters were measured on the veneer sheets:

- Dried veneer thickness (DT) — the mean thickness of each dried veneer sheet was calculated from measurements recorded at two positions along the veneer sheet using a dial thickness gauge; and
- Dried veneer width (DW) — the width (perpendicular to the grain) of each dried veneer sheet.

Veneer grading

The veneer quality was assessed by visual grading in accordance with AS/NZS 2269.0:2012 (2012). This standard is widely used across the Australian veneer industry and follows the same principles as other international veneer visual grading classification systems. The standard separates structural veneers into four veneer surface qualities and a reject grade, according to the severity and concentration of imperfections and defects. The grading process was undertaken by a minimum of two experienced graders to minimize variation with defect definition and measurement and to ensure consistent assessment.

The veneer logs within each batch were sorted by SEDUB, from smallest to largest. The veneer from every alternate log was allocated to provide a subset of recovered veneer for the purposes of grading analysis, and represented approximately 50% of the total recovered veneer.

Veneer recovery

Four recovery calculation methods were used: dry veneer recovery (DR), gross veneer recovery (GSR), net veneer recovery (NR), and graded veneer recovery.

The DR provides a useful measure of the maximum recovery and takes into account the log geometry (sweep, taper, and circularity), lathe limitations (*e.g.*, peeler core size), and drying process (*e.g.*, veneer shrinkage, *etc*.). The DR disregards internal log quality and was calculated in percentage as follows:

$$DR = \left(\frac{L \times \sum_{veneer}(DT \times DW)}{\sum_{billet} V}\right) \times 100 \qquad \text{[eq. 4.4]}$$

where *DT* is the average dry veneer thickness of each veneer (m), and *DW* is the dry veneer width (m, perpendicular to the grain).

The GSR provides a useful measure of the maximum recovery of dried veneer that meets the quality specifications of AS/NZS 2269.0:2012 (2012) (A-grade to D-grade). This recovery includes the losses accounted for in dry veneer recovery, but also includes additional losses from visual grading (*i.e.*, veneers that failed to meet grade). The gross veneer recovery (*GSR*, %) was calculated as follows:

$$GSR = \frac{L \times \sum_{veneer}(DT \times GRW)}{\sum_{billet} V} \times 100 \qquad \text{[eq. 4.5]}$$

where *GRW* is the width (m, perpendicular to the grain) of the dried veneer that meets the A-, B-, C-, and D-grade requirements, in accordance with AS/NZS 2269.0:2012 (2012).

The NR enables analysis of the efficiency of the process, as it determines the proportion of saleable product recovered, and takes into consideration any limiting factors of the product manufacturing process. The NR includes the losses measured in the GSR, along with the further losses that result from trimming of the veneer within product manufacturing stages. The losses resulting from veneer sheets being reduced in width to the final product dimension is called the trimming factor. In this study, the trimming factor corresponded to reducing the veneer sheet width perpendicular to the grain from 1275 mm to 1200 mm and the veneer sheet length (parallel to the grain) from 2600 mm to 2400 mm. The NR (%) was calculated as follows:

$$NR = GSR \times \frac{1200}{1275} \times \frac{2400}{2600} \qquad \text{[eq. 4.6]}$$

Thus,

$$NR = GSR \times 0.869 \qquad \text{[eq. 4.7]}$$

The graded veneer recovery separates the net veneer recovery into each grade quality classification in accordance with AS/NZS 2269.0:2012 (2012) (*i.e.*, A-, B-, C-, or D-grade). Each grade quality classification was individually calculated and labelled NR_A, NR_B, NR_C, and NR_D.

Veneer density

The veneer logs within each batch were sorted by the SEDUB, from smallest to largest. The second smallest, second largest, and median logs were chosen from each batch to provide a subset of veneers for the purposes of determining the air-dry density (at a 12% moisture content) of the recovered veneer. From each veneer from the identified logs, a 200-mm wide strip was removed from the veneer width (perpendicular to the grain). This was reduced in length to approximately 1200 mm (perpendicular to the grain) to provide a sample strip. The sample strip dimensions (length, width, and thickness) and weight were measured so that the veneer air-dry density could be calculated.

Veneer dynamic modulus of elasticity

The sample strips prepared for the veneer density measurement were used to measure the veneer dynamic modulus of elasticity (MoE), following similar procedures as described by McGavin *et al.* (2015b). An acoustic natural-vibration method described by Brancheriau and Bailleres (2002) was used to perform the measurements.

The sample strips were positioned on elastic supports so that the longitudinal propagation of the vibration was as free as possible and could be induced by a simple percussion on one end of the sample, in the grain direction. At the other end, a Lavalier-type microphone (Model ME104, Sennheiser, Germany) recorded the vibrations before transmitting the signal *via* an anti-aliasing filter (low-pass) to an acquisition card that included an analog-to-digital converter to produce a digitized signal.

A fast Fourier transform algorithm processed the signal to convert the information from time to the frequency domain. The mathematical processing of selected frequencies was undertaken using beam identification by non-destructive grading (BING) software (Version 9.7.2, CIRAD, Montpellier, France), in combination with the geometric characteristics and weight of the specimen, to determine the dynamic MoE, as well as other specific mechanical characteristics (CIRAD 2009; PICO 2014).

Results and discussion

Two hundred and forty logs (29.6 m^3) from two different wood species were processed using two different processing methods. Tables 4.2 and 4.3 provide details of the log characteristics and processing allocations for the spotted gum and white cypress pine logs, respectively. The method of log allocation ensured that there was minimum variation in the log SEDUB between the two processing methods (sawing and rotary peeling). The variation in the average log volume between the two processing methods was explained by the shorter log length used for rotary peeling (2.6 m *versus* 2.7 m used for sawing). The narrow range of SEDUBs within each log batch (as evidenced by the low SEDUB standard deviations) ensured that the diameter groupings were well separated for analysis purposes. The different target SEDUBs between the two species for diameter groups 1 and 2 meant that caution needed to be applied when comparing the results.

Table 4.2. Characteristics of the Spotted Gum Logs

Diameter Group	Processing Method	Number of Logs	Average Log Small-end Diameter Under Bark (cm)	Average Log Volume (m^3)	Total Log Volume Processed (m^3)
1	Sawing	20	19.6 (1.3)	0.089	1.789
1	Peeling	20	19.6 (1.2)	0.086	1.714
2	Sawing	20	23.5 (1.0)	0.128	2.566
2	Peeling	20	23.7 (0.9)	0.123	2.469
3	Sawing	20	27.8 (1.5)	0.180	3.600
3	Peeling	20	27.8 (1.5)	0.172	3.435
Standard deviation is given in parentheses					

Table 4.3. Characteristics of the White Cypress Pine Logs

Diameter Group	Processing Method	Number of Logs	Average Log Small-end Diameter Under Bark (cm)	Average Log Volume (m^3)	Total Log Volume Processed (m^3)
1	Sawing	20	16.2 (0.8)	0.065	1.303
1	Peeling	20	16.3 (0.7)	0.063	1.257
2	Sawing	20	21.2 (0.9)	0.110	2.196
2	Peeling	20	21.4 (0.8)	0.104	2.080
3	Sawing	20	27.2 (1.7)	0.180	3.608
3	Peeling	20	27.7 (1.6)	0.174	3.471
Standard deviation given in in parentheses					

The sawn timber recoveries are presented in Table 4.4. For both species, there was a consistent increase in the SR as the log SEDUB increased. For the spotted gum logs, the SR remained in a narrow range (between 41% and 43%) that resulted from the minimum variation in the processing approach between the three log diameter groups. More variability in the SR was produced within the white cypress pine logs. This was attributed to the larger range of board dimensions produced and adjustment of the target board dimensions to those that best suited the individual log diameter, log shape, and internal defects. The SR values yielded from the white cypress pine logs (between 43% and 54%) were higher than the spotted gum SR values (between 41% and 43%). This was also a result of the variation in the target sawn board dimensions with the spotted gum logs all sawn into comparatively small board dimensions (either 100 mm × 25 mm or 150 mm × 25 mm), as is shown in Figure 4.1. In comparison, the target sawn board dimensions of the white cypress pine boards (Figure 4.2) favoured larger-dimension boards that resulted in less waste because of fewer saw cuts.

Only the spotted gum sawn boards were dried and graded. There was minimum variation in the DDR within the diameter groups between the three grade types. However, more variation existed between the diameter groups with diameter group 1 (containing the smallest SEDUB logs). Approximately 25% less wood was recovered than from the other log diameter groups.

Table 4.4. Sawn Timber Recoveries

Species	Diameter Group	SR (%)	DDR (% of log vol.*)		
			Select Grade	Medium Feature Grade	High Feature Grade
Spotted Gum	1	41	13.9	14.4	14.5
	2	41	19.2	19.5	20.3
	3	43	19.4	19.9	21.9
White Cypress Pine	1	43			
	2	48			
	3	54			
*Grade recoveries are independent of each other					

Figure 4.3 details the primary defect type that resulted in boards or portions of boards failing to meet the grade requirements of AS 2796.2:2006 (2006). In all three diameter groups, wane was the leading cause for board downgrade, followed by knots, end splits, and heart shake. These defect types, with the exception of end splits, illustrated the obvious challenges of recovering sawn boards from small-diameter hardwood logs. The negative impact of end splits was more obvious in the larger-diameter log group (diameter group 3).

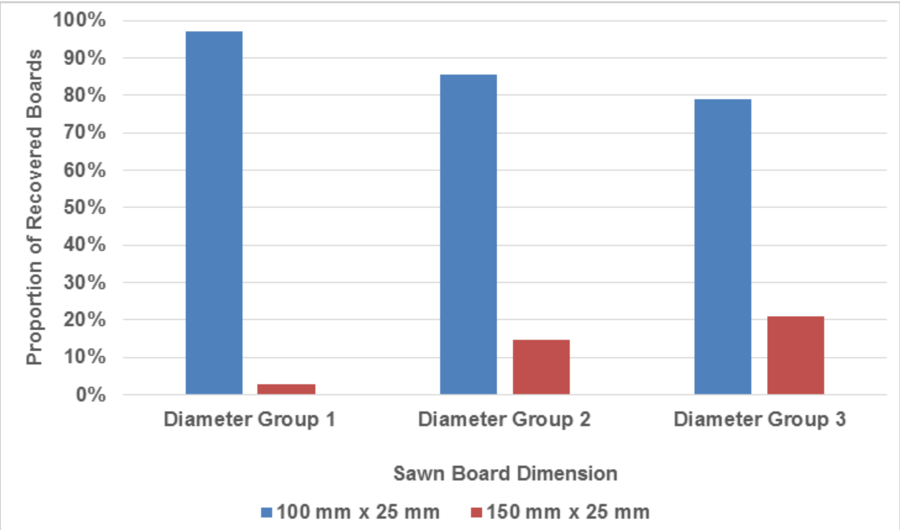

Figure 4.1. Distribution of spotted gum sawn board dimensions

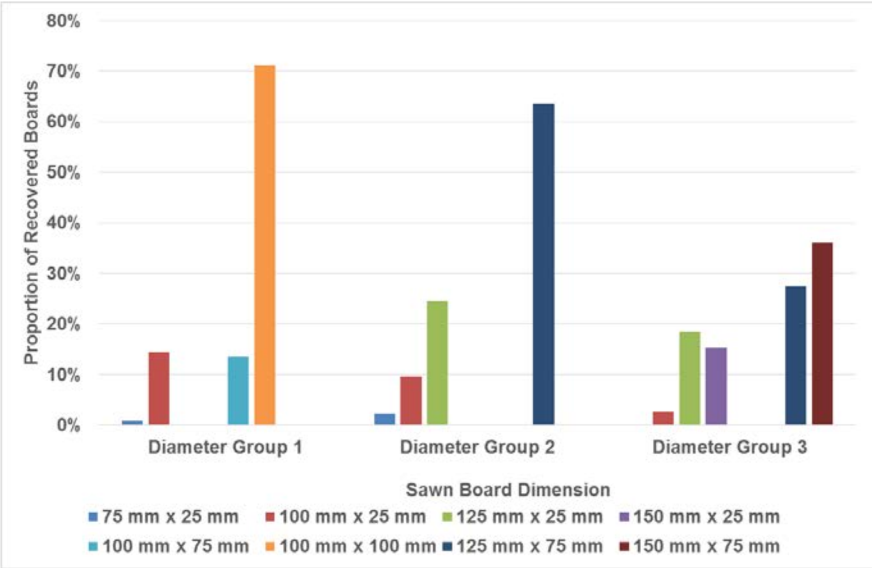

Figure 4.2. Distribution of white cypress pine sawn board dimensions

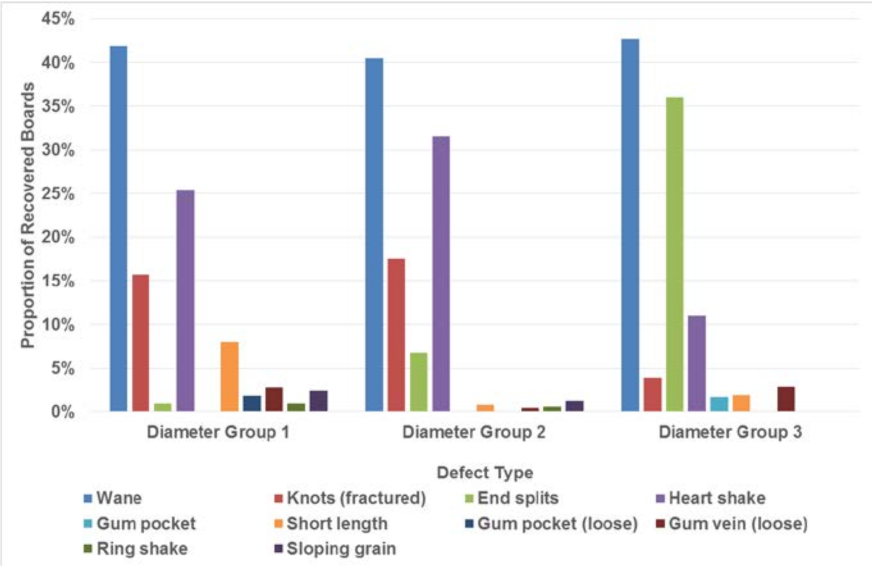

Figure 4.3. Primary reason for spotted gum sawn boards failing to meet a high feature grade

Table 4.5 details the veneer recoveries achieved for the spotted gum and white cypress pine logs. Regardless of the species, the veneer recoveries were higher than that achieved for the logs sawn into boards. This was mainly because the peeling process was based on a cutting technique (with no chip or sawdust) that produces less off-cuts because of the absence of losses resulting from cutting square sections from circular logs. The spindleless veneering approach adopted during this study ensured that the waste was restricted to the rounding stage where no usable veneer was recovered until the log was machined into a cylinder (with sweep, ovaility, and taper largely removed) and also the final stage, where no veneer was recovered from the peeler core. The average peeler core size was 58 mm and 66 mm for the spotted gum and white cypress pine logs, respectively.

The NR that represents the saleable volume of veneer (post-product manufacture) ranged between 38% and 46%, with the spotted gum logs yielding a higher recovery than the white cypress pine logs. For the spotted gum, this result was at least twice the equivalent recovery for the sawn boards, which ranged between 14% and 22%.

Table 4.5. Veneer Recoveries

Species	Diameter Group	DR (% of Log Volume)	GSR (% of Log Volume)	Gross Recovery Percentage of Dry Recovery (% of Dry Veneer Volume)	NR (% of Log Volume)
Spotted Gum	1	65	52	80	45
	2	66	53	81	46
	3	69	50	62	43
White Cypress Pine	1	55	43	78	38
	2	63	46	74	40
	3	67	46	72	40

Among both species and all of the log-diameter groups, the veneer grade recoveries were dominated by D-grade veneers (Table 4.6). Despite D-grade being the lowest visual grade quality for structural veneers, they are suitable for face veneers in non-appearance structural panels, and can be used as core veneers in the manufacture of most appearance and non-appearance structural panels. The low recovery of better grade veneers that are more acceptable for face veneers (C-grade and better), could make the production of a standard commercial mix of structural products challenging when only using a resource of this quality. However, the blending of veneers from small-diameter logs with a higher appearance grade veneer, potentially from larger-diameter logs from the same forest type, may produce a suitable mix for a range of solid wood end products.

Also, white cypress pine veneer has no commercial history and therefore, it has never been tested by the market to validate the acceptability of different quality grades or determine the suitability of the existing grading standard for this species. In the traditional markets for this species, unique features, such as colour variation and knots, can be a marketing advantage; however, these features contribute to lower veneer grades when the current industry standard is applied.

Table 4.6. Graded Veneer Recoveries

Species	Diameter Group	A-grade Recovery (% of Log Volume)	B-grade Recovery (% of Log Volume)	C-grade Recovery (% of Log Volume)	D-grade Recovery (% of Log Volume)
Spotted Gum	1	0	0	0	45 (100)
	2	0	4 (9)	2 (5)	40 (86)
	3	0	1 (1)	4 (11)	38 (88)
White Cypress Pine	1	0	0	0	38 (100)
	2	0	0	0	40 (100)
	3	0	0	0	40 (100)
Recovered grade veneer as a proportion of the net veneer volume is given in parentheses					

Similar defects prevented veneers from both species from achieving grades higher than a D-grade (Table 4.7). Between 54% and 91% of the spotted gum veneers were limited to a D-grade because of veneer surface roughness. Other defects that had a major influence included bark-encased knots, fractured knots, decay, and splits. Bark-encased knots prevented almost all of the white cypress pine graded veneers from achieving grades higher than a D-grade. Other contributing defects included the veneer surface roughness, fractured knots, and splits. More optimized processing settings (including log storage management) may be able to reduce the occurrence and severity of surface roughness in the recovered veneers.

The spotted gum logs produced veneers with an average air-dry density of 970 kg/m^3 and the majority of the veneers had a density between 850 kg/m^3 and 1100 kg/m^3 (Figure 4.4). The white cypress pine logs produced veneers with a lower average density of 620 kg/m^3 and the majority of the veneers had a density of 550 kg/m^3 to 700 kg/m^3 (Figure 4.5). These results were comparable to many studies reporting mature wood densities for these species (Bootle 2010).

Table 4.7. Top Five Ranked Defects that Prevented Graded Veneers from Attaining Grades Higher than D

Species	Diameter Group	Rank				
		1	2	3	4	5
Spotted Gum	1	Roughness (91%)	Bark-encased Knots (54%)	Fractured Knots (52%)	Decay (42%)	Cumulative Defects (24%)
	2	Roughness (54%)	Decay (37%)	Fractured Knots (27%)	Bark-encased Knots (22%)	Splits (22%)
	3	Roughness (76%)	Fractured Knots (39%)	Bark-encased Knots (33%)	Decay (30%)	Splits (28%)
White Cypress Pine	1	Bark-encased Knots (100%)	Roughness (91%)	Fractured Knots (79%)	Splits (58%)	Compression (21%)
	2	Bark-encased Knots (100%)	Roughness (85%)	Fractured Knots (57%)	Splits (52%)	Resin Pockets (20%)
	3	Bark-encased Knots (96%)	Roughness (84%)	Fractured Knots (70%)	Splits (48%)	Resin Pockets (25%)
Proportion of veneer impacted by each defect is given in parentheses						

Figures 4.6 and 4.7 show the variation in the veneer density as measured along the veneer ribbon for spotted gum and white cypress pine veneers, respectively. Both species recorded

minimal variation from the veneer recovered near the log centre (left side of the X-axis) and those recovered closer to the log periphery (right side of the X-axis). This relative consistency should be regarded as a valuable asset that does not exist in many other forest resources, such as fast-grown plantations, for which wide variations from the log centre to the periphery have been reported (McGavin *et al.* 2015b).

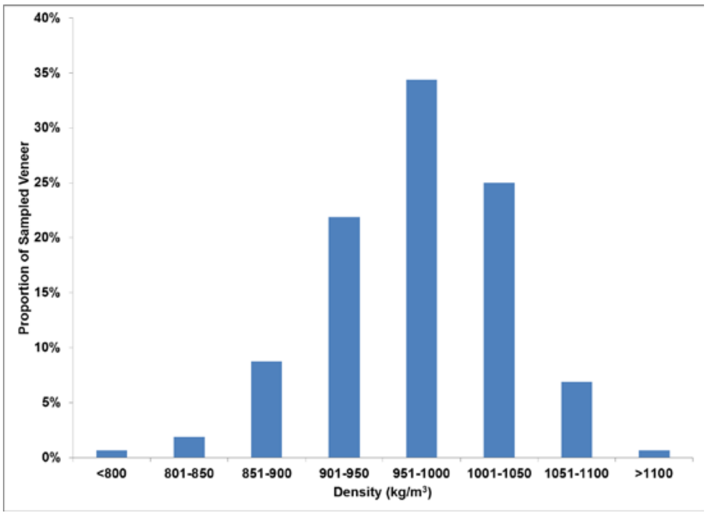

Figure 4.4. Spotted gum veneer density distribution

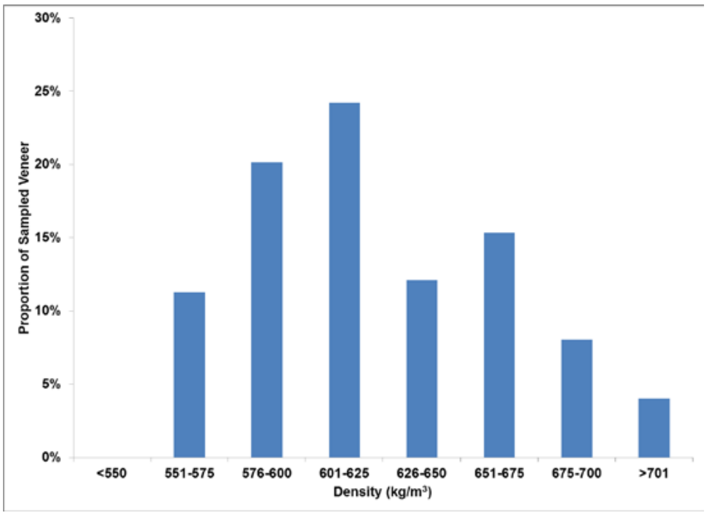

Figure 4.5. White cypress pine veneer density distribution

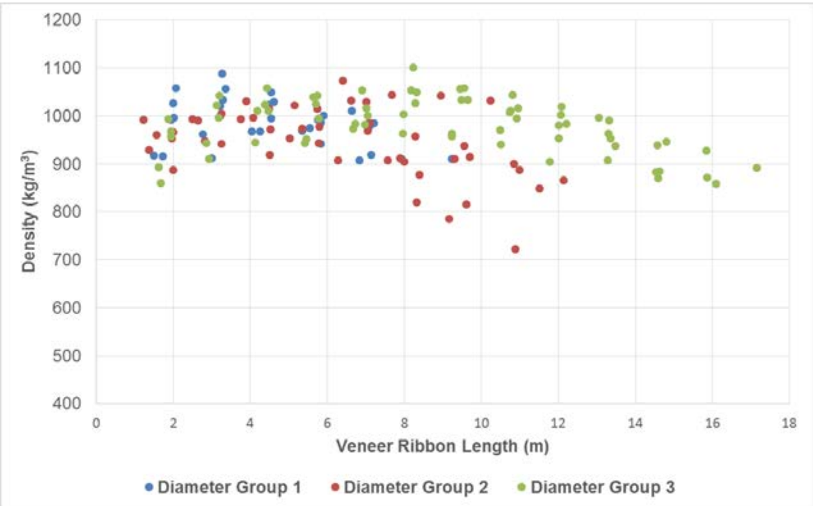

Figure 4.6. Spotted gum veneer density distribution along the veneer ribbon

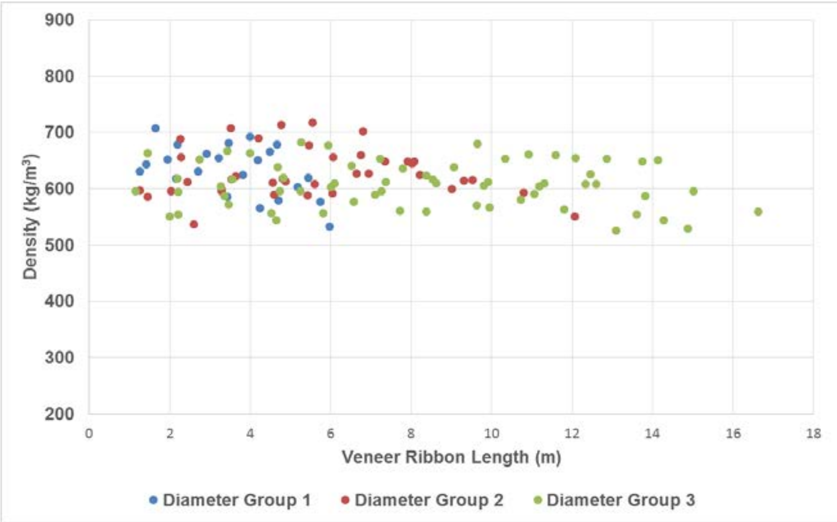

Figure 4.7. White cypress pine veneer density distribution along the veneer ribbon

The spotted gum logs produced veneers with an average MoE of 22236 MPa and the majority of veneers had a MoE of 15000 MPa to 29000 MPa (Figure 4.8). Compared with many commercial wood species, these results confirmed the international reputation of this species as having superior mechanical properties.

The white cypress pine logs produced veneers with a lower average MoE of 9011 MPa and the majority of the veneers had a MoE of 6500 MPa to 12000 MPa (Figure 4.9). These values were similar to those of many commercial wood species, including the plantation *Pinus* species grown in Australia.

While the variation in the MoE was greater when compared with the density results, the variation was not as large as for plantation-grown spotted gum reported by McGavin *et al.* (2015a). The wider variation when compared with the density results was attributed to the samples being systematically selected without bias and included any stiffness-reducing defects that were present.

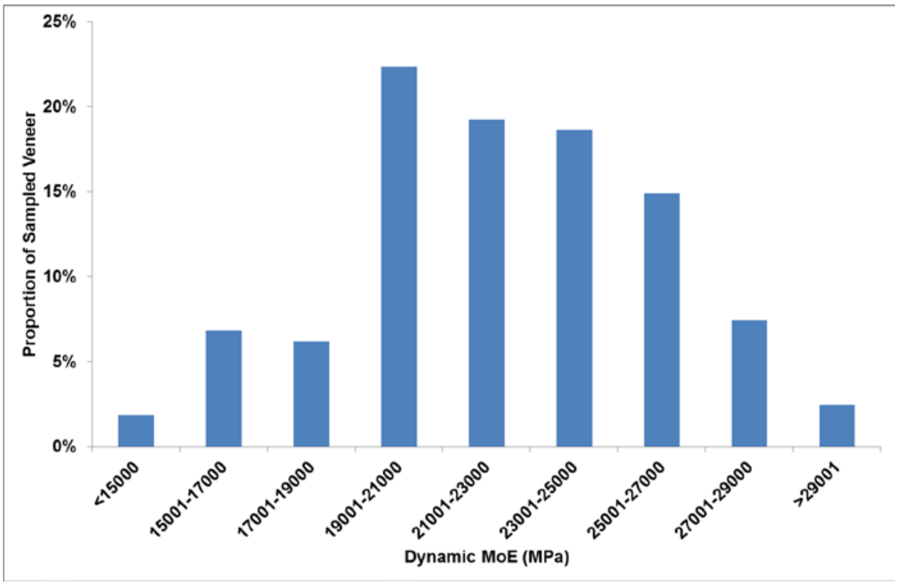

Figure 4.8. Distribution of the dynamic MoE for the spotted gum veneers

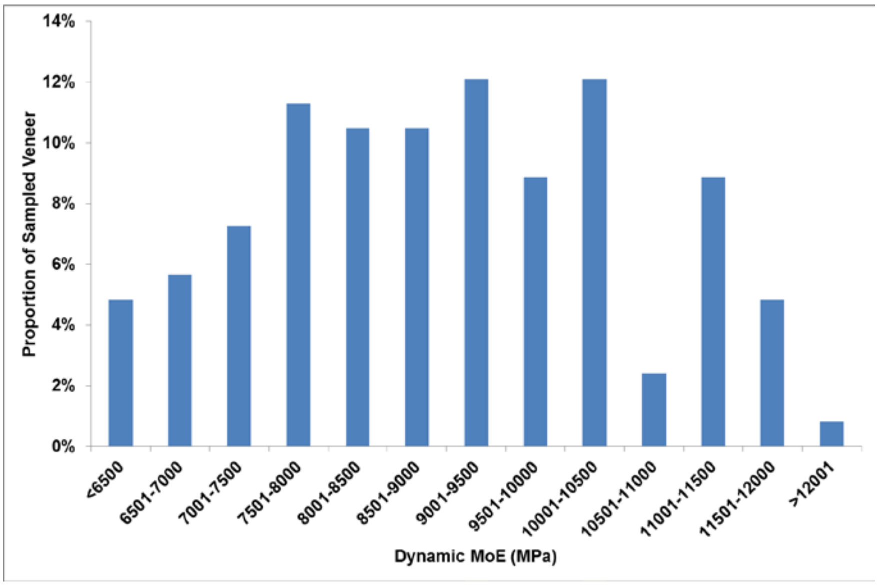

Figure 4.9. Distribution of the dynamic MoE for the white cypress pine veneers

Figures 4.10 and 4.11 show the variation in the veneer MoE as measured along the veneer ribbon for the spotted gum and white cypress pine veneers, respectively. The variation that existed was consistent along the veneer ribbon, which suggested that even when these mature native forest logs, regardless of diameter, are processed down to a relatively small peeler core size, consistent and mature wood properties can be obtained. In contrast, McGavin *et al.* (2015a) reported a wide variation in the veneer MoE measured along the veneer ribbon of 10-year- to 12-year-old plantation spotted gum. While the log diameter was smaller (mean of 15.6 cm), the results of this study clearly showed the negative impact of the juvenile core that contained lower MoE wood, which given the fast growth rate in plantations, occupied a greater proportion of the stem volume. The slow growth of the native forest logs ensured that the lower-quality juvenile core was small and probably contained within the waste peeler core. This was a clear advantage for native forest logs.

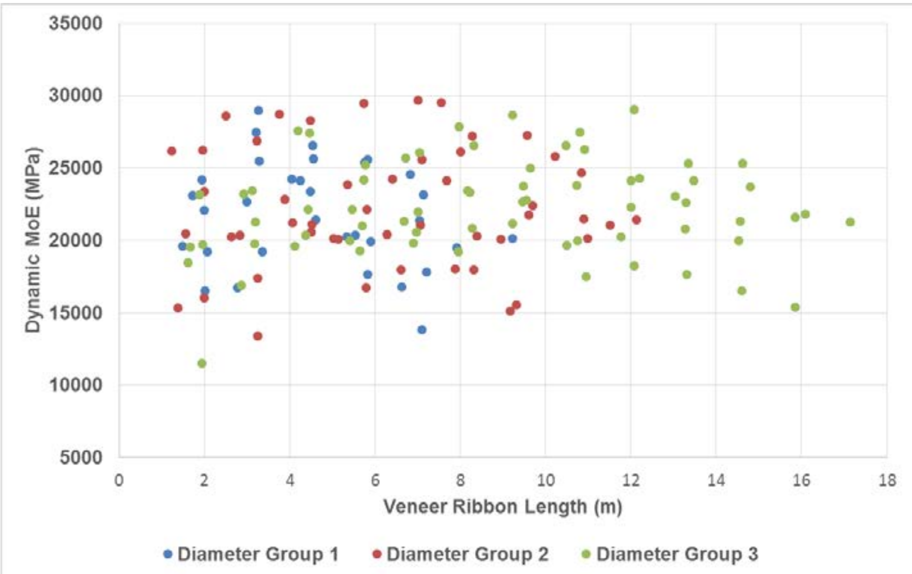

Figure 4.10. Distribution of the dynamic MoE of the spotted gum veneers along the veneer ribbon

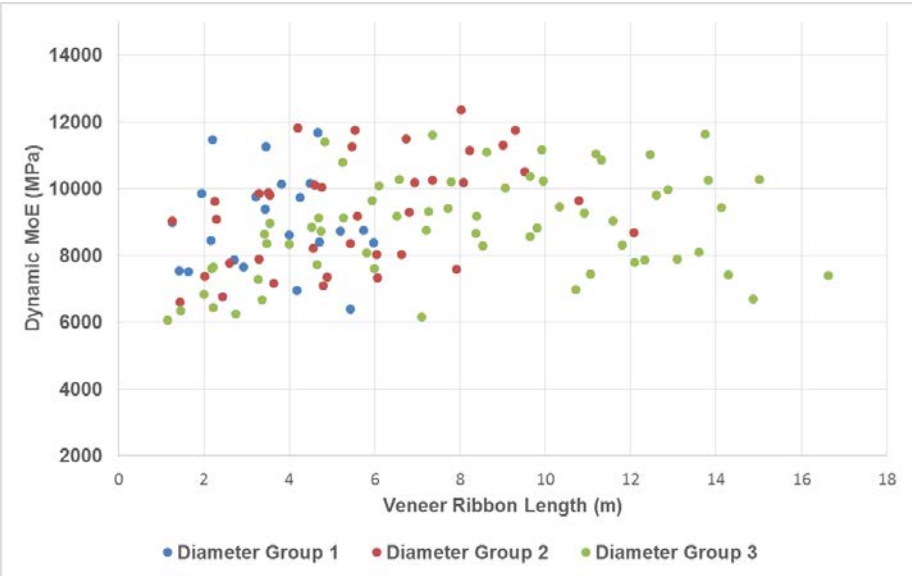

Figure 4.11. Distribution of the dynamic MoE of the white cypress pine veneers along the veneer ribbon

Conclusions

1. This study demonstrated that processing small-diameter logs from native forests into rotary veneers using spindleless lathe technology can yield higher recoveries compared with using traditional solid wood processing techniques. This processing method also produced a more consistent recovery result across the range of log sizes included in the study. For the spotted gum, processing small-diameter logs into dried and graded rotary veneer recovered twice the volume of saleable product compared with the same log quality sawn into flooring-type products (43% to 46% *versus* 15% to 22%). The recovery benefits were not as great for white cypress pine because the larger-dimension sawn boards aided in achieving a higher recovery compared with the spotted gum, and product grading was limited. Comparable dried and finished product grading was not undertaken as part of the study for the white cypress pine; however, this would be expected to further improve the comparative performance of veneer processing.
2. For both species, the graded veneer recovery was dominated by D-grade veneer. While D-grade is the lowest visual quality grade for structural veneer, the veneers were suitable for face veneers in non-appearance structural panels, as well as core veneers for the vast majority of appearance and non-appearance structural panels. The low recovery of higher-grade veneers (C-grade and better) may make the commercial production of structural panel products challenging (because of insufficient quantities of face veneer) if a processor solely relied on this resource grade. However, the blending of veneers from small-diameter logs with higher appearance grade veneers, potentially from larger-diameter logs from the same forest type, may produce a suitable mix for a range of solid wood end-products. Also, white cypress pine veneer has no commercial history and therefore, the willingness for the market to accept the range of defects present in this species has not been tested. The presence of some defects may indeed provide a marketing advantage for this species.
3. There was a relatively narrow variation in the veneer properties within the species. This is an advantage for the industry because sorting and segregation systems can be simplified compared with the management of more varied resources. The spotted gum logs produced veneers with high stiffness properties. Approximately 85% of the sampled veneers had MoE values above 19000 MPa and 25% of the veneers had MoE values above 25000

MPa. The stiffness properties in this range could be a key asset for this resource and would support its use in high performance structural products. The white cypress pine veneer had inferior mechanical properties compared with the spotted gum; however, the properties were suitable for structural applications.

4. While this study demonstrated that rotary veneer processing is a more efficient processing system to convert small-diameter native forest logs compared with sawing, the identification of veneer-based EWPs with a connected market demand is critical to further encourage the industry to consider adopting this approach.

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Chapter 5: Structural engineered wood product types and potential markets for high performance engineered wood products (EWPs)

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Introduction

Structural wood products are extensively used in Australia in the Class 1 residential markets for:

- roof framing (trusses, rafters, hanging beams, strutting beams, etc.),
- wall framing (studs, plates, lintels, bracing, etc.), and
- floor framing (joists, bearers, floor beams, floor trusses, flooring, etc.).

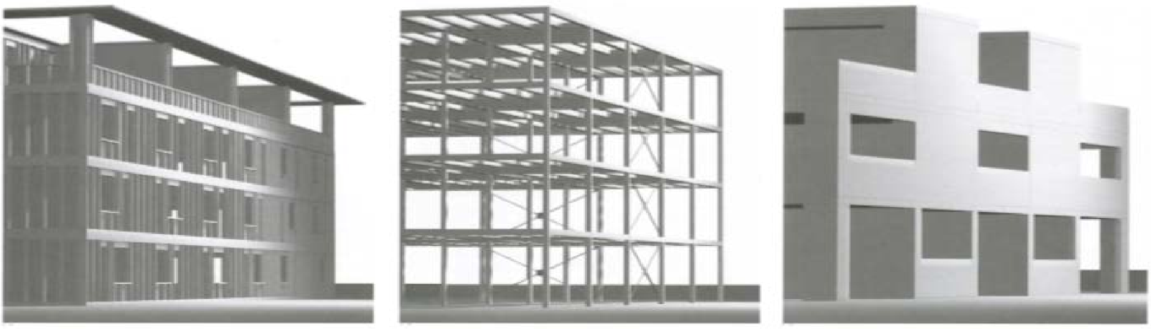
For many residential structural construction applications, graded sawn softwood and hardwood products provide adequate performance. However, there are also many opportunities in the Class 1 market for the increasing range of structural engineered wood products (EWPs) such as:

- glued laminated timber (Glulam),
- plywood,
- laminated veneer lumber (LVL), and
- the range of imported structural composite lumber (SCL) products such as,
  - laminated strand lumber (LSL),
  - parallel strand lumber (PSL),
  - oriented strand lumber (OSL),
  - oriented strand board (OSB), and more recently
  - cross laminated timber (CLT) and nail laminated timber (NLT).

The Class 1 market has been the mainstay for structural wood products. It is a mature market well serviced by the forest products industry and with minimal new opportunities for further major product expansion. A major new opportunity however is the ‘mid-rise construction’ market which is now rapidly developing due to changes in the 2016 National Construction Code (NCC) which allows the use of general* timber frame systems and massive** timber construction for Class 2 (apartments), Class 3 (e.g. hotels), and Class 5 (office) buildings up to an ‘effective height’ of 25m (approx. eight stories) under the simple ‘Deemed-to-Satisfy’ provisions (DTS); a straight forward ‘cookbook’ approach to demonstrating compliance. Taller timber buildings are also possible under the NCC’s ‘Performance Solution’ if detailed fire, acoustic and other regulatory compliance requirements are undertaken.

*** General Timber-Framed Systems**: includes small dimension framing products similar to that used in the Class 1 market such as lightweight timber-framed wall systems, prefabricated floor trusses (often provided as floor cassettes) and roof trusses. It also includes heavier timber post & beam construction that might utilise larger glulam columns and beams.

**** Massive Timber**: is defined under the NCC as an element not less than 75mm thick as measured in each direction formed from chemically bonded laminated timber and includes:
(a) Cross laminated timber (CLT)
(b) Laminated veneer lumber (LVL)
(c) Glued laminated timber (Glulam)



Lightweight Timber-Frame Systems ***Post & Beam*** ***Massive Timber***

Figure 5.1. Typical Mid-rise Timber Building Construction Methods

There are three main timber construction methods currently used for mid-rise timber buildings, as illustrated in Figure 5.1, including: lightweight timber-framed systems (up to around six levels), post and beam, or massive timber construction.

Buildings may be constructed using one system, or a mix of timber systems to provide a more optimised and/or economic solution. All timber building systems are likely to utilise reinforced concrete for sub-ground basement structures, and often also ground level construction for 'mixed class' buildings; for instance, the building might incorporate 'retail' (Class 6) tenancies at the ground floor level and then residential 'apartments' (Class 2) above.

This new 'mid-rise timber' construction sector provides totally new market opportunities for a wide range of structural timber (and appearance) products, both sawn and engineered. Table 5.1 provides a summary of the different EWP types, by manufacturing process, and possible mid-rise structural market applications.

Table 5.1. Engineered Wood Products by Product Types and Manufacturing Process

	Solid Wood Products	Veneered Products	Strand Products	Particle Products	Wood Fibre Products
Framing, Beam & Column Type Products	Glued Laminated Timber (Glulam) Roof Trusses I - beams	Laminated Veneer Lumber (LVL) Cross-Banded Laminated Veneer Lumber (X-LVL)	Parallel Strand Lumber (PSL) Laminated Strand Lumber (LSL) Oriented Strand Lumber (OSL)		
Massive Floor & Wall Products (≥75mm thick)	Cross-Laminated Timber (CLT) Nail Laminated Timber (NLT)	Laminated Veneer Lumber (LVL) Mass Plywood Panels (MPP)			
Panel & Bracing Products		Plywood	Oriented Strand Board (OSB)	Particleboard	Hardboard Medium Density Fibreboard (MDF)

The emerging mid-rise construction market will create demand for higher strength structural engineered wood products, which may provide attractive opportunities for many of Australia's high strength hardwood species; due to the resulting higher structural loads with the increased building heights involved.

Summary of engineered wood products

Framing, beam & column type products

Glued laminated timber (Glulam)

Product Description

Glued laminated timber, or Glulam, is an engineered wood product manufactured by gluing together pieces of timber to produce larger dimensions and longer length straight or curved members (see Figure 5.2). Short laminate lengths are typically finger-jointed to make longer continuous lengths and these laminates can then be either face glued and/or edge glued to make larger member sections. Timber laminates used in glulam manufacture are available in a range of both softwood and hardwood species.

Figure 5.2. Glued laminated beams

Typical product usage

Structural Glulam is used in a range of residential and non-residential (commercial & industrial) structural applications including:

- high strength structural columns and posts,
- high strength structural beams, such as: exposed alfresco roof support beams, lintels over wall openings, in-plane floor bearing beams, garage door opening beams, roof beams, roof truss members, and
- portal frame and post & beam columns and rafters.

A major benefit of Glulam manufactured from hardwood and cypress is the opportunity in many applications to expose the product providing both a desired appearance and structural function.

Country of Production/Availability in Australia

Glulam is widely produced internationally and in Australia. The two largest local manufacturers of glued laminated timber in Australia are:

- Hyne Timber, with a manufacturing facility at Maryborough in Queensland (annual production approx. 5,000 – 10,000m^3); and
- Warrnambool Timber Industries (WTI), at Warrnambool in south western Victoria (annual production approx. 5,000m^3).

A number of other medium to small manufacturers exist throughout Australia including:

- Lambeam from Trussmaster at Meadowbrook Queensland;
- Vic Beam at Montrose Victoria (annual prod approx. 1,500m^3);
- Merriwa at Wangaratta, Victoria; and
- Australian Sustainable Hardwoods, at Heyfield, Victoria

Major Glulam importers include:

- Tilling Timber with their SmartLam products.

Local manufacturers and importers also distribute through a number of major wholesalers including:

- Dindas;
- Laminated Timber Supplies;
- Dale Glass Industries; and
- Austim.

The Glued Laminated Timber Association (GLTAA) is a representative organization that assists in setting industry standards, implementing and maintaining a code of practice, policing its policies, and providing credibility to the product, and therefore to those manufacturers who are approved as members.

Structural grades & properties

A range of GL graded beams and posts are produced or imported depending on the different species of timbers used in manufacture. A standard set of GL grades has been developed by the GLTAA defining the suite of structural properties for each grade. With Glulam products, Modulus of Elasticity (E) is usually the structural property that governs design and as such it has been chosen as the descriptor for the individual grades (so GL17 describes a Glulam member that has an E-value of 16,700MPa or approx. 17GPa).

Figure 5.3 summarises the characteristic strengths and elastic moduli assigned for horizontally laminated Glulam grades.

	CHARACTERISTIC STRENGTHS (Mpa)				ELASTIC MODULI (Mpa)	
Stress Grade	Bending (*f'b*)	Tension parallel to grain (*f't*)	Shear in beam (*f's*)	Compression parallel to grain (*f'c*)	Short duration average modulus of elasticity parallel to grain (*E*)	Short duration average modulus of rigidity for beams (*G*)
GL18	50	25	5.0	50	18500	1230
GL17	42	21	3.7	35	16700	1110
GL13	33	16	3.7	33	13300	900
GL12	25	12	3.7	29	11500	770
GL10	22	11	3.7	26	10000	670
GL8	19	10	3.7	24	8000	530

Figure 5.3. Structural properties of Glulam timber

For structural applications, Australian manufactured Glulam achieves the following GL grades using the species listed below in Table 5.2; their equivalent F-grade rating is also shown.

Table 5.2. Summary of major Australian Glulam producers and grades

	GL10	GL13	GL17	GL18	GL 21
E- value (MPA)	10,000	13,300	16,700	18,500	21,500
Typical Species	Cypress Yellow cedar	Oregon Radiata pine	Slash pine *Merbau*	Tas oak (Sel) Vic ash (Sel)	Spotted gum
Equiv. F-Grade	F11	F17	F27	F27	F34
Companies manufacturing or importing these grades					
Hyne			Hyne Beam 17	Hyne Beam 18	Hyne Beam 21
Warrnambool Timber Industries	WTI GL10 Cypress	WTI GL13 Radiata pine	WTI GL17 Slash Pine	WTI GL 18 Hwd	
VicBeam	GL10 Cypress	GL13 Radiata pine		GL18 Vic ash	GL21 Mixed species hwds
Tilling (imported)		Smartlam GL13 (from US)	Smartlam GL17 (from WTI)	Smartlam GL18 Hwd (from VicBeam)	

Note: the *Goodwood SUPALAM* product manufactured by Australian Sustainable Hardwoods is produced and marketed as an A17 product rather than a GL grade and is offered in widths of 35 and 45mm and depths: 90, 120, 140, 190, 240 and 290mm.

Manufacturing adhesives

Typically: Phenol-resorcinol, resorcinol, or poly-phenolic adhesives are used in the manufacture of Glulam.

Size availability

Whilst Glulam manufacturers have sought to adopt agreed structural grades and product section sizes and to try and rationalise the market offering around Australia, there are still a very wide variety of beam dimensions on offer.

Most Australian produced Glulam products use 35mm and 45mm thickness feedstock (dressed back to approx. 33 and 43mm) and 70 and 90mm width framing material, dressed accordingly to 65 and 85mm wide Glulam members (popular). 120 and 140mm framing material can also be used for 115 and 135mm dressed Glulam sizes if needed. Typical sizes for GL17 include: 195, 230, 260, 295 and 330mm depths and 65 and 85mm widths as stock products; whilst sizes outside of this range (425, 460, 495, 525, 560, 590, etc.) are generally produced to order with beams up to 1,000mm deep available.

Glulam product lengths range from –

- stock 12m lengths (for importing companies restricted by shipping containers),
- to up to 16.8 – 18.0m lengths for traditional manufacturers, and
- up to 27m for specialist manufacturers.

Comparative 'retail prices to the builder' of Glulam products are as follows[3].

[3] Note: timber pricing is often quoted at a range of different levels: at the mill, at the wholesaler or at retail (the rate also varies depending on the volume consumed by the customer). The inclusion of costing is simply to provide comparative analysis between product groups. Costs have been obtained from a large timber retailer, 'at the builder level' in Melbourne.

- GL10: Cypress \$5,025, Yellow Cedar \$6,075/m^3 – both naturally durable species;
- GL13: Treated Pine \$3,400/m^3; and
- GL17: Hardwood \$5,300/m^3.

Importance to Current Advanced EWP Project

LOW –

Table 5.3. Importance of Glue Laminated Timber to the Current Advanced EWP Project

Project Objective / Measure	Comment
Ability to use sub-optimal feedstock of interest to the project	For Glulam products, sawing small diameter sub-optimal quality logs into traditional rectangular element may not be the most cost-effective and efficient processing system due to the relatively low recoveries that potentially will be achieved.
Volume of feedstock required *(is there enough volume to achieve required scale)*	Feedstock qualities and dimensions are already commercially readily available for current softwood and hardwood Glulam products.
Technical suitability *(resource properties – match product needs)*	Higher grade Glulam products rely on structurally graded sawn laminate feedstocks with specific structural properties generally not achieved from lower grade or residual logs.
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	Glulam manufacture can be implemented into existing mill operations at relatively low cost (depending on level of automation and throughput) compared to other EWP product approaches. The process often provides a good value-adding opportunity for sawmilling operations, particularly finger jointing of shorts or docked material.
Market Factors - *likely demand* - *price/performance competitiveness*	Glulam is already a well-established and widely used product in both softwood and hardwood species. As Glulam is marketed as both a structural and appearance grade product, price points tend to be higher than other structural-grade equivalent products (almost twice the price of similar grade LVL products). Glulam will be an important product option in the new mid-rise building market sector opportunity in exposed product applications where appearance characteristics are desired and valued.
Threats / Constraints	Higher strength glulam may be constrained mainly by suitable adhesive systems.

Laminated veneer lumber (LVL)

Product Description

Laminated Veneer Lumber (LVL) is an engineered wood product which utilises wood veneers glued together with the grain of the veneers all oriented in the same direction (see Figure 5.4).

Typical Product Usage

LVL is generally used in:

- residential construction for structural beam-type applications (joists, rafters, lintels, etc.),
- for tension members in truss fabrication,

- in industrial shed construction for portal frame columns and rafters (either solid rafters or as top and bottom chords in box-beam rafters), and
- as top and bottom chords in engineered I-beam manufacture.

In mid-rise construction, in addition to beams, LVL will also be used for higher strength wall studs (or in thicker sections as massive wall panels or columns).

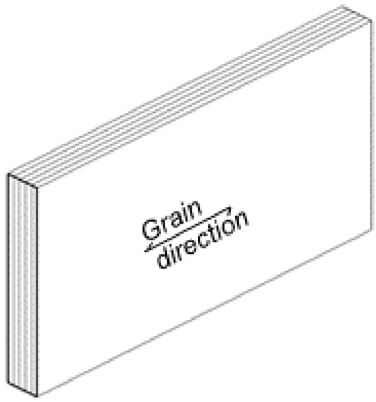


Figure 5.4. Laminated Veneer Lumber

Cross-Banded LVL (X-LVL)
Cross-banded LVL (bi-directional) is manufactured similarly to conventional LVL (unidirectional) but includes one, two or more, laminations in the cross section with the grain orientated perpendicular to the longitudinal axis of the sheet (see Figure 5.5 and 5.6). Cross-banded LVL has a different set of properties to conventional LVL where all plies run parallel to the longitudinal axis. Cross-banded veneers at 90° within the product construction increases the product's shear strength and the tensile strength perpendicular to the grain; however, there is also an associated slight reduction in the flexural strength and the Modulus of Elasticity parallel to grain; dependent on the number of cross-bands used and their position within the cross section. Cross-branded LVL is usually manufactured on order, as the process of re-orienting the sheets slows the manufacturing process and adds to the cost of production.

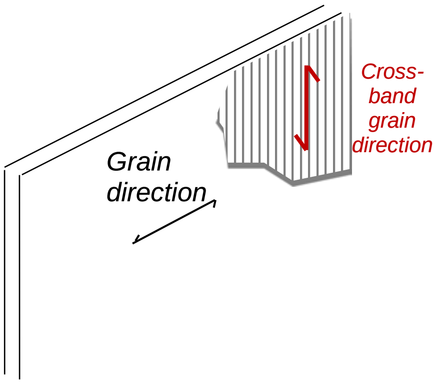


Figure 5.5. Cross-banded LVL

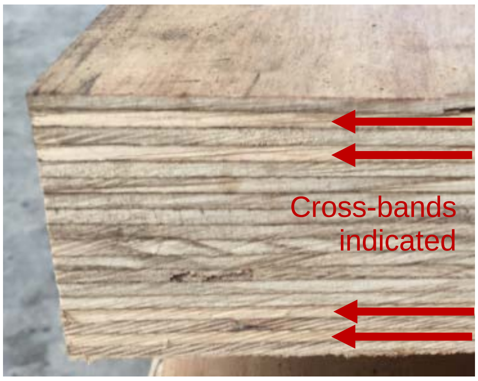


Figure 5.6. Cross-banded LVL lay-up detail

Typical product usage
Cross-banding can assist product stability when subjected to changing environmental conditions by reducing the product dimensional change and the product degradation that might result from these dimension changes such as cupping, splitting, increased glue line stresses and distortion.

Cross-banded LVL has advantages when used in specific applications:

- LVL products used in environments where additional product stability is necessary.
- Highly loaded short span deep beams produce very high internal shear stresses compared with the flexural stress. Cross-banding can assist with providing improved beam shear strength.
- Elements that are curved or taper cut from sheets have slope of grain that is at an angle to the flexural stresses. This would normally tend to cause splitting along the grain direction, but the cross-bands provide reinforcing fibre within the direction that assists in minimising these splits.
- As the mechanical properties of LVL are relatively low in tension perpendicular to the grain, this makes it susceptible to crack initiation and propagation around holes, notches and joints. Cross-banding can be used to assist in reinforcing the beam at points where large connection stresses might occur.

Country of production/availability in Australia

LVL is manufactured in many countries throughout the world and most of the LVL products commonly used in the Australian market are produced from a softwood feedstock material. There is currently only one Australian producer of LVL, Wesbeam in Western Australia – Wesbeam LVL predominately utilises Maritime pine (*Pinus pinaster*) and some Radiata pine in manufacture. Several major wholesaling companies import LVL into Australia. Table 5.4 provides a summary of LVL products found in the Australian market.

Table 5.4. Summary of LVL products found in the Australian market

Company	Country of Production	Products
Wesbeam	Australia	Wesbeam LVL products include: *e-beam, e-beam+[F17], e-joist, e-purlin, e-strut, e-batten, e-splay, e-stick, e-plate, e-plank, e-edge*
Carter Holt Harvey (CHH)	New Zealand	Marketed as Futurebuild LVL products include: *hySPAN and hySPAN+, hyJOIST (flanges), hyCHORD, hyPLANK, truFORM, and edgeFORM*
Meyer Timber	NZ - CHH	*CHH's hySPAN and hySPAN+*
Tilling	US – Pacific Woodtech Corp NZ- Nelson Pine Finland	Marketed as Smartframe LVL, products include: *SmartLVL 14/15, Smart LVL 19, SmartPlank, SmartForm, SmartEdge*
ITI Australia	US – Louisiana Pacific (LP)	Marketed as LP® SoldStart®LVL, *E14 (F17) LVL, E13LVL*

Hardwood LVL

Some Hardwood LVL (HLVL) is produced in limited quantities in Europe and Asia. A small volume of structural hardwood LVL has been imported into Australia by Tiling Timber (SmartLVL 19) from Sarawak utilising Keruing (FAO, 2003) timber (*Dipterocarpus spp*), a hardwood native to South-East Asia with a density between 800-950kg/m^3 (see Figure 5.8).

Forestry Tasmania has also been experimenting since 2013 with a Tasmanian Oak based hardwood LVL it originally marketed as Hardlam. The product utilises small diameter lower grade Tasmanian Oak logs, rotary peeled then structurally glued and hot pressed into 20mm thick HLVL panels approx. 2.4m long and 900mm wide. These panels are then glued, stacked and cold pressed using non-structural glues to form blocks from 200-300mm thick, and then re-sawn into a range of specific product sizes with the veneered surface featured.

Initial products targeted were interior non-structural appearance based, including: dressed boards, flooring (190 x 18mm T&G, prefinished), furniture stock, architectural trims, stair components, bowels, etc. (Figure 5.9 provides images of bowel and Figure 5.10 flooring products). Forestry Tasmania planned to also ultimately develop some structural products, so structural properties were tested but these at present have been kept commercial-in-confidence; though, public information on the internet advises that an average E-value of 16.3 GPa (14.8 – 18.4) was achieved with an average density of 825kg/m^3 (763 - 881).

Figure 5.8. Tilling Smart LVL19

Figure 5.9. Hardlam bowl products

Figure 5.10. Smart Oak flooring products

Forestry Tasmania were looking for a commercial partner to take the products forward but approximately 18 months ago sold the product rights on. The product has now been rebranded as SmartOak and is being manufactured in China. SmartOak purchase the logs, have them veneered in Tasmania, the veneers are then sent to China where the blocks are manufactured and resawn and then the final products are imported back into Australia and distributed through Blue Lagoon Timbers (Wood, 2017). Forestry Tasmania hope that at some time in the future full production might come back to Tasmania.

Blended LVL

Wesbeam is producing a blended LVL product utilising some karri hardwood laminates in addition to the base softwood veneers of maritime pine (see Figure 5.11). The major driver here is resource availability versus large mill capacity and the need to supplement the now more limited volumes of maritime pine. While the karri veneers assist in terms of their positive contribution to overall structural properties this is not the driving factor for their inclusion.

Figure 5.11. Wesbeam blended LVL product

The karri veneer resource is sourced from approx. 25-40-year-old plantation grown Western Australian karri which were originally planted for hardwood woodchip products. Veneer recovery from the logs is reported to be lower than the maritime pine feedstock and what is not usable for LVL veneer is used as a particleboard feedstock. Whilst the use of the karri veneers assist with expanding the resource supply options, it is reported that some manufacturing considerations include:

- the maximum hardwood thickness veneer limit of 3.8mm compared with the usual softwood veneer thickness of 4.8mm used with the Maritime Pine for glue line treated LVL (AS/NZS 1604.4) which varies and impacts the final product thicknesses; and
- the limit on hardwood veneers that might be blended; the experience being that "the gluing of hardwood veneers to softwood veneers works well, but the gluing of hardwood veneers to hardwood veneers poses some problems".

Size availability

LVL is manufactured as 'billets' in a variety of thicknesses depending on the manufacturer but typically 35, 36, 39, 45, 63 and 75mm. The pressed billets are generally 1.22 metres in width and a range of beam depths are cut from this: 90, 120, 130, 140, 150, 170, 190, 200, 240, 300, 360, 400, 450, 600 and 1200 mm. Lengths up to 12m, in 0.3m increments, are typically available but as LVL is produced in a continuous manufacturing process longer lengths are possible by order. Whilst 'off-the-shelf' LVL conforms to standard structural member sizes, special sizes can be ordered from the manufacturers. Large sheets of LVL can also be ripped or cross-cut into curves and angles, increasing its potential uses.

Comparative 'retail prices to the builder' of LVL products are provided below based on Modulus of Elasticity (E), or effective stiffness (resistance to bending deflection)[4].

- E13: \$1,500/m^3
- E14 (F17): \$1,400/m^3 (generally priced to compete with some F17 sections)
- E15: \$1,550 - \$1,600/m^3
- E19: \$2,500/m^3

[4] Note: timber pricing is often quoted at a range of different levels: at the mill, at the wholesaler or at retail (the rate also varies depending on the volume consumed by the customer). The inclusion of costing in this report is simply to provide comparative analysis between product groups. Costs have been obtained from a large timber retailer, 'at the builder level' in Melbourne.

Structural grades & properties

There are no generic grades for LVL, each manufactured product has its own grade and the properties and dimensions of each LVL product are specific to each manufacturer, Table 5.5 provides a summary of the range of structural design properties found in Australia.

Table 5.5. Structural design properties for typical LVL products found in Australia

LVL Structural Design Properties:			Softwood LVL Species - various	Hardwood LVL Keruing
Average Elastic Modulus (MoE)	E	MPa	13,200 – 15,300	19,500
Average Modulus of Rigidity	G	MPa	660 - 700	975
Bending	f'_b	MPa	50 – 62	72
Tension Parallel to grain	f'_t	MPa	25 - 35	47
Tension Perpendicular to grain	f'_{tp}	MPa	4.2	
Compression Parallel to grain	f'_c	MPa	39 - 47	45
Compression Perpendicular to grain	f'_p	MPa	12 - 16	19
Shear	f'_s	MPa	4.2 – 5.3	6
Average Density	□	kg/m^3	560 - 660	900

Manufacturing adhesives

As LVL is primarily used for permanent structural applications it is generally manufactured with a Type A bond, using a phenolic based resin adhesive (e.g. phenol formaldehyde) and is often recognisable by its dark gluelines. Generally, phenol formaldehyde Type A adhesives are used in manufacture of hardwood LVL.

Importance to Current Advanced EWP Project

HIGH –

Table 5.6. Importance of Laminated Veneer Lumber to the Current Advanced EWP Project

Project Objective / Measure	Comment
Ability to use sub-optimal feedstock of interest to the project	Market opportunities exist for new LVL products with mechanical properties that are equivalent to, or that can exceed, current commercially processed plantation softwood species. High mechanical quality veneers recovered from sub-optimal quality logs could be used either by themselves or in a combination with softwood species to manufacture speciality LVL sections with superior mechanical performance. New LVL products could be either: • single species, or • blended species, to provide improved structural properties, fire resistance performance or for mixed market usage i.e. providing appearance outer veneers on a structural beam, column or floor/ceiling panel.

Project Objective / Measure	Comment
Volume of feedstock required *(is there enough volume to achieve required scale)*	Volumes of possible feedstock are potentially high. A mix of grades of veneers are likely from feedstock logs with a proportion of veneers possibly being able to be used as an appearance product grade, a proportion of structural product grade, and a proportion of lower grade that might be more suitable for other EWP's such as oriented strand board (OSB) or particleboard.
Technical suitability *(resource properties – match product needs)*	Due to the mix of different grades of veneers likely available, and the ability for LVL manufacture to blend veneers to engineer a specific performance, there should be technical opportunities to investigate a range of improved LVL-type products to suit different market applications: structural, appearance/structural and improved fire performance. Some production feedback has indicated some issues: • for single species LVL, gluing hardwood veneers to hardwood veneers has been traditionally difficult although many new adhesive systems are becoming available, and • for appearance veneer faced products – the type, grade and cost of the face veneer – e.g. rotary veneer doesn't necessarily provide the 'real' solid timber appearance. Also, need to be able to deliver acceptably looking external joints and accordingly may need to utilise glues for the outer appearance laminates that provide a clear finish (not the traditional dark coloured structural glues).
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	LVL manufacture need not necessarily be high capital investment, depending on the level of automation and throughput desired. Specialised, niche (non-commodity) product/markets may suit lower levels of capital investment and machinery. The benefits of new, low cost, lean manufacturing approaches such as the spindleless veneer processing systems provide an example of the opportunity to revisit the manufacturing approach, including the capital investment required to profitably operate. Smaller niche operations also may provide more efficient approaches to niche LVL products such as appearance veneer faced LVL and cross-banded LVL; these can be difficult and uneconomic to produce in larger scale commodity driven LVL plants as the manual handling disrupts throughput.

<table>
<tr><th>Project Objective / Measure</th><th>Comment</th></tr>
<tr><td>Market Factors
- likely demand
- price/performance competitiveness</td><td>There are potentially a number of new market opportunities for advanced LVL products.
In the existing residential market,
• LVL products are used in commodity structural applications, and in the main compete on performance and price compared to alternative products (sawn timbers, glulam, LSL, etc.). The measure is the product’s strength (in bending, compression or tension, depending on application) and/or stiffness (Modulus of Elasticity – E) compared with how much the product costs to produce and supply. New advanced LVL products will need to be equivalent to, or better performing at a competitive price if they are to be specified and used. This is discussed in more detail on page 23.
• structural elements manufactured with outer laminates of:
  o appearance veneers to provide both an appearance and structural solution,
  o possible blending of cypress veneers with more traditionally used non-durable feedstocks to provide some increased natural termite resistance to the product (similar to an envelope treatment) but without chemicals.

The emerging mid-rise market sector with taller buildings and higher loading requirements should also offer new market opportunities for advanced LVL-type products, such as:
• higher strength structural support beams - may also utilise cross-banding depending on engineering requirements to reinforce for shear or connection requirements;
• high-strength studs for more highly loaded lower level storeys (LVL provides superior compression parallel to grain performance and a higher design capacity factor compared to sawn timber, may also be used as floor system Rim-boards);
• LVL rib-slab floor elements (where thicker LVL floor elements provide both improved acoustic performance and combined with LVL joists provide an effective structurally composite acting floor system);
• mass-panel walls or floors constructed using LVL elements with cross-bands (a less manufacturing dependant alternative to CLT);
• large dimension columns or beams;
• structural elements manufactured with outer laminates of:
  o higher density species to provide new fire-char design solutions; or appearance veneers to provide both an appearance and structural solution.</td></tr>
<tr><td>Threats / Constraints</td><td>• Cost of manufacture and supply compared to alternative products
• Willingness of industry to invest in new product/market opportunities
• Time for new mid-rise timber market opportunities to develop</td></tr>
</table>

Parallel strand lumber (PSL)

Product description

Parallel Strand Lumber is a structural composite wood product manufactured utilising long wood strands of pine or Douglas fir veneer clipped from veneer sheets into long narrow strands of wood up to 2.4m (8′) in length and about 13mm (1/2″) in width which is then bonded together using a structural adhesive, microwaved under high pressure to form a finished billet (typically 30 cm x 37.5 cm (12” x 15”) but larger is possible) that is then cut to custom sizes. The wood strands in PSL are aligned parallel to the beam length for maximum bending strength (see Figure 5.12). Very large beams can be made: up to 20 metres long; 30 cm wide; 50 cm deep.

Figure 5.12. Parallel Strand Lumber

Typical product usage

PSL is commonly used in the US for post and beam construction as well as beams and lintels (headers), see Figure 5.13.

Country of production/availability in Australia

PSL is manufactured and marketed by Weyerhaeuser as Parallam® PSL. LVL and PSL plants are often combined in the US to maximise the use of veneer recovered from peeling (Busta & Honesty, 2013). The veneer ribbon is evaluated for its moisture content and visual quality and is automatically cut into pieces that will be used for either LVL or PSL products. Pieces with inconsistencies such as knots, bark, wane and voids, usually found at the beginning and end of each log’s veneer sheet, are used for PSL.

PSL is not imported or used in any commercial volume in Australia, accordingly comparative pricing is not available.

Size availability

Typical sizes available in the US are as follows.

2.0E Parallam® PSL header and beam sizes:

Widths: 211⁄16" (68mm), 31⁄2" (89mm), 51⁄4" (133mm) and 7" (178mm)

Depths: 91⁄4" (241mm), 91⁄2" (241mm), 111⁄4" (285mm), 117⁄8" (301mm), 14" (356mm), 16" (406mm), and 18" (457mm)

1.8E Parallam® PSL column and post sizes:

3½" x 3½" (89x89mm), 3½" x 5¼" (89x133mm), 3½" x 7" (89x178mm), 5¼" x 5¼" (133x133mm), 5¼" x 7" (133x178mm),
7" x 7" (178x178mm)

Structural grades & properties
Weyerhaeuser manufactures two grades of Parallam: 2.0E (13,800 MPa) and 1.8E (approx. 12,400 MPa) and publishes specific design properties for these products
Manufacturing Adhesives
Phenol formaldehyde (PF) and urea formaldehyde (UF) adhesives are used in manufacture.

Figure 5.13. Parallam® PSL beams and columns

Importance to Current Advanced EWP Project
LOW –

Table 5.7. Importance of Parallel Strand Lumber to the Current Advanced EWP Project

Project Objective / Measure	Comment
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	The scale of operations for the Parallam® product produced by Weyerhaeuser in the US appears to be large. Manufacturing establishment costs and scale of operation are therefore likely to be the biggest inhibitor to possible Australian parallel strand lumber (PSL).
Ability to use sub-optimal feedstock of interest to the project	The manufacture of PSL appears to have the ability to utilise lower grade feedstock. With Parallam® manufacture in the US, pieces at the beginning and end of each log's veneer sheet with inconsistencies such as knots, bark, wane and voids are utilised whilst the better-quality veneers are utilised in LVL manufacture.
Volume of feedstock required *(is there enough volume to achieve required scale)*	As mentioned above, the manufacture of PSL is often undertaken in combination with LVL manufacture to allow as much of the veneer feedstock as possible to be used. It is anticipated that volume of feedstock will be less of a problem than initial set up cost.

Project Objective / Measure	Comment
Technical suitability *(resource properties – match product needs)*	It is expected that the potentially available hardwood resource feedstock would have resource properties suitable for a PSL type product though investigation and testing of suitable adhesives would need to be undertaken.
Market Factors - *likely demand* - *price/performance competitiveness*	From a market perspective, it is felt that PSL may be somewhat restricted in opportunity. The fact that no US products are currently imported to Australia tends to support this position. For the types of applications PSL is used for in the US, Australia has a choice of Glulam products of various (and higher) strength grades available (as no PSL product exists in Australia a more detailed performance/price analysis cannot be made).
Threats / Constraints	Scale of operations required. Cost of manufacture and supply compared to alternative products Some builders in the Australian market, may also view strand type products as an inferior alternative to solid wood or even veneer based products, this would potentially change over time is more strand structural products were available (LVL was once viewed as an inferior product to a solid hardwood beam, but most builders are now quite accepting of LVL).

Laminated strand lumber (LSL)

Product description

Laminated Strand Lumber (LSL) is a structural composite wood product manufactured utilising short strands of hardwood approx. 0.8 mm in thickness and 25 mm in width (see Figure 5.14). The least dimension of wood strands in LSL is 2.54mm and the average length is at least 150 times the least dimension, approx. 380mm). The manufacturing process of LSL involves steam injection and pressure, which allows heat to penetrate to the core providing a solid, consistent bond of the adhesive.

Lumber

LSL can be manufactured in two forms: one where all the strands are aligned in the direction of the major axis of the product; and secondly to produce boards where a portion of the strands are aligned in the direction of the minor axis of the product.

Typical product usage

LSL is promoted by its manufacturers to engineers and architects for use in most residential structural applications including framing joists, lintels, structural beams, studs, rim-boards etc.

Country of production/availability in Australia
Two major LSL brands manufactured in the US are:

- TimberStrand LSL by Weyerhaeuser made from Aspen and Yellow Poplar, and
- LP SolidStart® LSL made by Louisiana Pacific (LP) which is manufactured from a mix of Aspen (80%) and Maple (with Aspen, tree diameters tend to be small and the process by stranding allows the whole log to be used).

There is some limited importing of LSL into Australia from the US for framing application use.
An Australian company Lignor has also been researching and investigating an LSL type product: ESL® (Engineered Strand Lumber), see Figure 5.15, which could be manufactured utilising a range of Australian eucalypt species including:

- Karri - *E. diversicolor* (E: 19,900 MPa)
- Messmate - *E. obliqua* (E: 19,500 MPa)
- Jarrah - *E. marginata* (E: 16,500 MPa)
- Southern Blue Gum - *E. globulus* (E: 16,000 MPa)
- Manna Gum - *E. nitens* (E: 11,460 MPa)


Figure 5.14. Laminated Strand


Figure 5.15. Lignor ESL®

Lignor's website advises that whilst "products are not yet commercially available Lignor is open to collaboration on all commercialisation opportunities". A market feasibility study by Margules Groome (April 2016) for Lignor P/L and Norske Skog suggests a market potential for ESL® of 514,000m^3/yr in Australia and a further export market potential of 1.3M m^3/yr to countries including New Zealand, China, South Korea, US and Japan (Black, 2016).

Size availability
Sizes of LSL produced in the US have been set to match solid timber sizes (LSL can also be treated to H2-S if required).

1.55E TimberStrand® LSL sizes: Widths: 1¾" and 3½" Depths: 9½", 117⁄8", 14", and 16"

1.3E TimberStrand® LSL header sizes: Width: 3½" Depths: 5½" and 7¼"

1.3E TimberStrand® LSL column and post sizes: 3½" x 3½" 3½" x 43⁄8" 3½" x 5½" 31⁄2" x 7¼" 3½" x 85⁄8"

Structural grades & properties
There are currently no Australian product standard or design rules for LSL. However, manufacturers will have their own engineering data for the products they manufacture; SolidStart® LSL properties are shown in Figure 5.16 with the three products having Modulus of Elasticity (E) values of 9,000, 10,000 and 12,000MPa.

LP Brand Values for Australia				
Structural Properties required		E10 LSL/LVL	E9 LSL	E12 LSL
Bending (edge) (300mm)	f'b	33	25	36
Bending (edge) (95mm)	f'b	Calculated: (300/d)^0.143		
Bending (flat)	f'b	32	28	41
Tension parallel to grain (3.0m, 150mm)	f't	20	15	24
Compression parallel to grain	f'c	28	21	31
Compression perp to grain (edge)	f'p	12	12	12
Compression perp to grain (flat)	f'p	7.4	7.4	7.4
Shear in beams (edge)	f's	5.3	7.3	7.3
Shear in beams (flat)	f's	3.2	3.4	3.4
Shear at joints	f'sj	5.3	7.3	7.3
Modulus of Elasticity	E	10000	9000	12000
Modulus of Rigidity	G	500	450	600

Bending (edge) (95mm) has been adjusted based on LP's depth effect exponet of 0.143 (1/7).
Tension has been adjusted to AS/NZS 4357:2010. LP tension testing is based on 89mm depth

Figure 5.16. Structural design properties for SolidStart® LSL

In Australia, the imported LSL product was initially promoted as a superior stud framing material (90x35 LSL10 and 90x45 LSL10) due to the comparatively high compression strength compared to local pine products, see Table 5.8 comparison below.

Table 5.8. Comparison of compression parallel to grain – LSL and MGP grades

Property	LSL10	MGP10	LSL12	MGP12
Compression parallel to grain (f'_c)	**28**	18	**31**	24
MOE	**10,000**	10,000	**12,000**	12,000

Local importer representatives have advised that the take up of LSL use in Australia by builders has been low, suggesting that with E 9, 10 or 12 type products consumer choice tends to be heavily focussed on price, and alternative products are available that are more cost competitive –
LSL currently retails to the builder at around $1,100/m^3 which makes it somewhat expensive compared to local alternative products. Current importers have advised that they are likely to drop their US LSL import lines (E9, E10, E12) in the future.

Manufacturing adhesives
US LSL products are manufactured using Urea Formaldehyde adhesives.

Importance to Current Advanced EWP Project

LOW –

Table 5.9. Importance of Laminated Strand Lumber to the Current Advanced EWP Project

Project Objective /	Comment
Ability to use sub-optimal feedstock of interest to the project	As LSL utilises a comparatively short wood strand length it is anticipated that the volume of sub-optimal log feedstocks would be available for LSL production.
Volume of feedstock required	It is anticipated that volume of feedstock will be less of a problem than initial set up cost.
Technical suitability *(resource properties – match product needs)*	It is anticipated that the resource properties of the different sub-optimal log feedstocks would be appropriate for LSL production. The structural results from the Lignor testing program look quite promising with Australian eucalypt feedstocks: • Karri - *E. diversicolor* (E: 19,900 MPa) • Messmate - *E. obliqua* (E: 19,500 MPa) • Jarrah - *E. marginata* (E: 16,500 MPa) • Southern blue gum - *E. globulus* (E: 16,000 MPa) • Shining gum - *E. nitens* (E: 11,460 MPa) (Lignor, 2017).
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	Capital investment required for a commercially viable LSL facility appears to be an inhibitor; Lignor by example have been attempting for some years to secure commercial support. Advice from Lignor's 2016 AGM presentation is that a further full feasibility study will be undertaken to study the setting up of a commercial demonstration or full scale plant in Australia.

Project Objective /	Comment
Market Factors - *likely demand* - *price/performance competitiveness*	LSL's main market opportunity would be in commodity structural applications which, as mentioned previously, tend to compete on performance vs price. • At present, imported softwood LSL products do not appear to compete performance/pricewise compared to other alternative sawn or LVL type products which are readily available and have the necessary performances for the major applications. • Future hardwood LSL products would need to achieve an increased performance to the current softwood products offering and while Lignor's ESL® structural test results suggest this is the case, the question is how cost effectively they could be produced, especially compared to other EWPs such as hardwood or hardwood blended LVL. The latter could probably be more economically produced in Australia and industry (at least at this point in time) would be more accepting of a veneer-based product over a flake product, especially in structural applications. In terms of potential market opportunity, a market feasibility study by Margules Groome (April 2016) for Lignor P/L and Norske Skog suggests a market potential for ESL® of 514,000m^3/a in Australia and a further export market potential of 1.3Mill m^3/a to countries including New Zealand, China, South Korea, US and Japan (Black, 2016).
Threats / Constraints	• Cost of manufacture and supply compared to alternative products • Ability to secure funding for LSL plant establishment

Oriented strand lumber (OSL)

Product description

Oriented strand lumber (OSL) is made from flaked wood strands with a high length-to-thickness ratio (see Figure 5.17). Manufacture of OSL is similar to LSL, except that it uses shorter veneer strands (but still longer than OSB flakes, which are between 3" and 4"). OSL will generally have lower strength and stiffness properties than LVL or PSL.

Figure 5.17. Oriented strand lumber

Typical product usage
OSL may be used in beams and other framing applications. OSL and LSL tend to have a mottled appearance without the grain pattern for a 'timber look', which can limit the appearance applications in which these products can be used.

Country of production/availability in Australia
Weyerhauser and Louisiana Pacific (LP) were both very active in OSL some years ago. Now neither advertise OSL as an available product, however they do advertise Oriented Strand Board (OSB) products.

The issue for LSL and OSL products appears to be related to the low E values available compared to alternative materials of lower cost such as LVL. This was outlined in a recent US on-line article (The Merchant Magazine, 2013):

> *"Higher E-values are required for studs (about 1.3E to 1.5E), beams and headers (1.5E to 1.7E), glulam, and LVL (1.7E to 2.0E). Market price of the product is indexed to E-value and, of course, there is a correlation between E-value and manufacturing cost," Fouquet said. "The relationship between E-value and cost is such that in the higher range of E-values, a typical OSL/LSL product line becomes somewhat uncompetitive with LVL product lines from a usage perspective. With LVL being widely available from a variety of suppliers and in large quantities, it has become the preferred choice for use in mid-to-longer span headers and beams."*

OSL is not currently available in Australia.

Importance to Current Advanced EWP Project
LOW –

Table 5.10. Importance of Oriented Strand Lumber to the Current Advanced EWP Project

Project Objective / Measure	Comment
Ability to use sub-optimal feedstock of interest to the project	It is anticipated that the proposed sub-optimal log feedstocks would be appropriate for OSL production.
Volume of feedstock required *(is there enough volume to achieve required scale)*	It is anticipated that the volume of sub-optimal log feedstocks would be available for OSL production. The scale of operation necessary to be economically viable may require substantial volumes of feedstock which may be a constraint for Australia where the forests are somewhat dispersed.
Technical suitability *(resource properties – match product needs)*	It is anticipated that the resource properties of the different sub-optimal log feedstocks would be appropriate for OSL production.
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	Capital investment required for a commercially viable OSL facility may be an inhibitor. Commodity targeted products often need a massive scale in order to bring the unit price down low enough to be competitive. This therefore requires a substantial capital investment and requires a high-volume throughput and a large market for consumption.

Project Objective / Measure	Comment
Market Factors - *likely demand* - *price/performance competitiveness*	OSL's main market opportunity will be in commodity structural applications which as mentioned previously tend to compete on performance vs price. Information from the US markets indicates that the LSL with its lower E-value and higher cost makes it somewhat uncompetitive compared with available LVL product lines, production in the US of OSL has declined because of this.
Threats / Constraints	Cost of manufacture and supply compared to alternative products. Scale of operation needed. Low comparative performance and comparatively high price compared to alternative products.

Framing, beam & column type products – cost performance comparison
As has been mentioned several times in the previous discussion of different engineered wood product types, when it comes to commodity structural products, the general criteria for success is 'product structural performance versus cost'; unless the member is to be used in an exposed application where appearance is also a deciding factor, as it can be with Glulam products.

For beam applications, a useful structural measure is the Modulus of Elasticity value (MoE or sometimes just referred to as E) which is a measure of the beams stiffness or resistance to deflection. The higher the MoE value the stiffer the product.

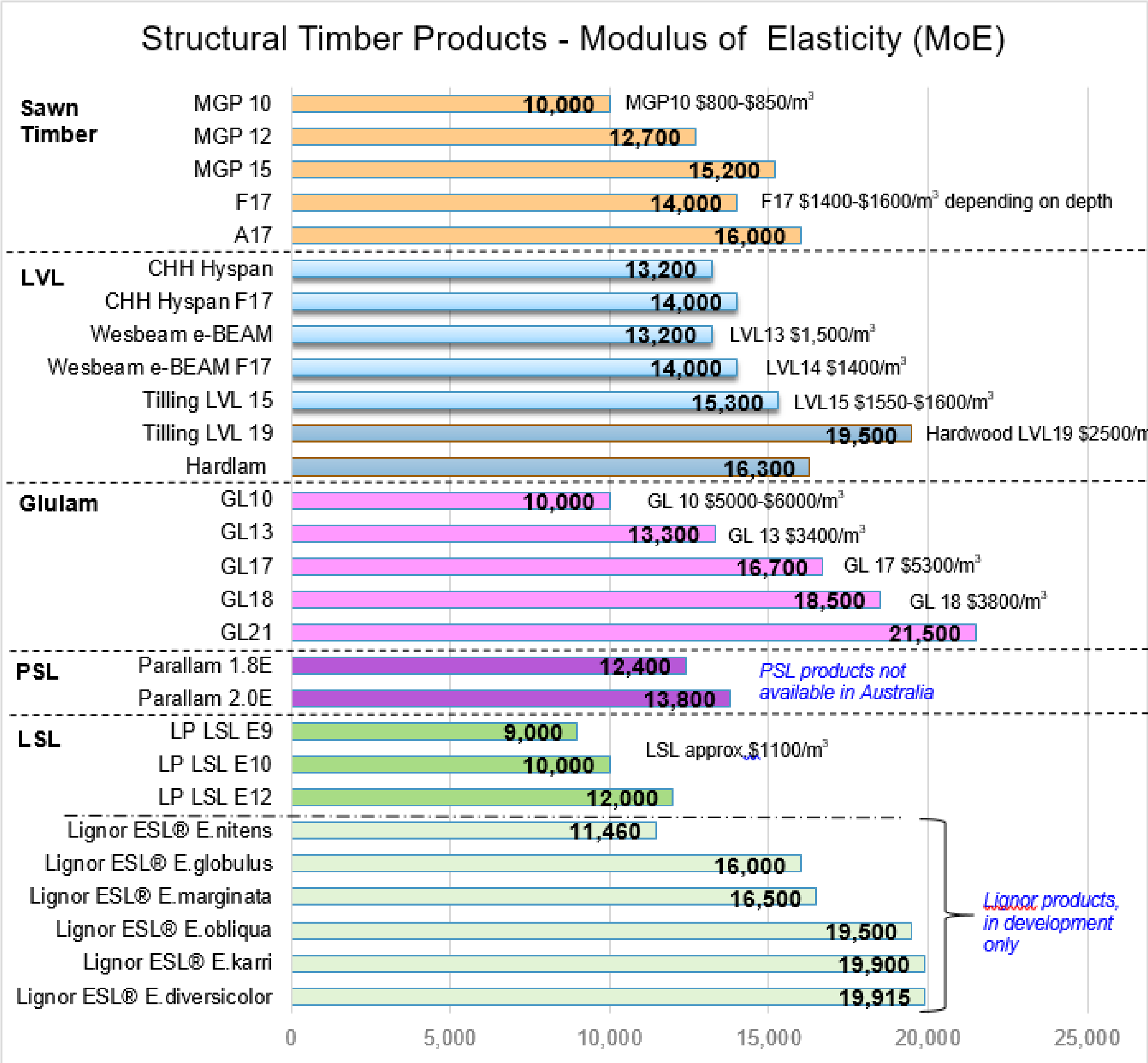


Figure 5.18. Summary of MoE values for Sawn and Engineered Wood Products and Comparative Cost

Figure 5.18 provides a summary of a range of sawn and engineered wood products and an approximate comparative retail cost where these products are available in the Australian market. Note: Costing is indicative and will obviously vary around Australia, at different levels of supply (manufacture, wholesale, retail), and based on size and volume. The inclusion of costing in this report is simply to provide a comparative analysis between product groups (so the actual number is of less importance than the difference between products). Costs quoted have been obtained from a large timber retailer, ‘at the builder level’ in Melbourne.

It can be seen that softwood LVL products (E13, E14 and E15) are priced between $1,400 - $1,600/m^3. It is noted that these prices are very similar to F17 sawn hardwood products due to the LVL sector reducing the price some years ago (following the home market crash in the US) to directly compete with F17 in the residential sector. The general feeling because of this is that LVL is currently under-priced in the market.

Glulam beams by comparison are almost twice the comparative cost/performance, for instance LVL13 at $1,500/m^3 compared with GL13 at $3,400/m^3. The Glulam products utilise a higher cost feedstock however due to their higher appearance value, as well a structural performance, allow for a greater price premium.

Imported LSL products, it can be seen, are at the lower end of E-performance measure (E9, E10) whilst their cost is quite high at $1,100/m^3 compared to available sawn MGP10 ($800-$850).

Hardwood LVL products such as the Tilling LVL 19 product (see Figure 5.19) have an improved E-performance measure (19,500MPa) compared to the range of softwood products available and its cost at $2,500/m^3 is higher, reflecting this improved performance. These darker hardwood products also have a more asthetically pleasing look than available softwood LVL products.

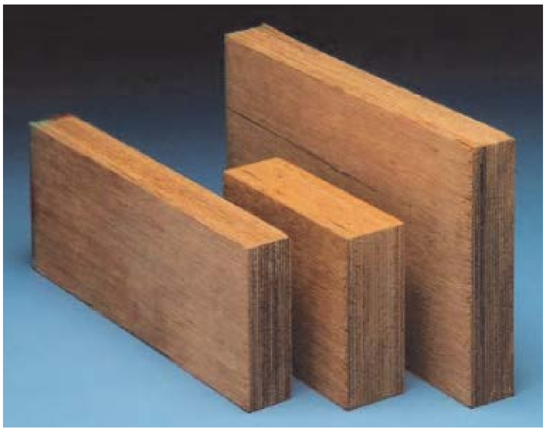


Figure 5.19. Tilling LVL19

For any new engineered wood products developed under this R&D project, if used specifically in structural applications, a close assessment will need to be undertaken of the new products' structural property performance compared with its cost of manufacture. If sub-optimal log feedstocks can be obtained at potentially reduced costs, this will influence the viability of any new product.

Massive floor & wall products

Cross-laminated timber (CLT)

Product description

Cross-laminated timber (CLT) is a solid engineered wood product manufactured from at least three orthogonally bonded layers of solid-sawn timber or structural composite lumber (See Figure 5.20). CLT utilises longitudinal and transverse rectangular plank feedstock, typically 12 to 45 mm thick and with a 40 to 300 mm wide face (to assist in reducing rolling shear issues it is recommended that the width should be a min 4 x thickness).

Figure 5.20. Cross-laminated timber

Typical product usage
CLT products are becoming more widely utilised globally in mid-rise construction applications such as massive wall panels, long-span floor elements, roofs and stair & lift shafts. In some colder countries, CLT is also used in residential construction due to its intrinsic thermal resistance (105mm CLT panel, R=0.875 (XLam, 2019)).

Country of production/availability in Australia
CLT is manufactured in Europe, North America and New Zealand, however increasing local interest has led to several imported products entering the Australian market from manufacturers including: Stora Enso, KLH, Binderholz, and XLam NZ.

CLT is not currently manufactured in Australia in commercial quantities, though XLam (now owned by Mayflower – Hyne Family) is at present constructing a new plant at Wodonga in Victoria, due to be operational in late 2017, that will have a capacity to produce around 60,000m^3 of CLT annually.

Size availability
CLT panels are available in a range of sizes depending on the manufacturer, with thicknesses from 57 mm – 500mm, comprised of 3, 5, 7, or 9 layers, depending on application; and overall panel dimensions typically: 2.2 to 3.5m in width and up to 18.5m in length. In Australia, as all product is currently imported by shipping container, the typical dimension available are 2.25m to 3.00m widths and up to 11.9m lengths. Larger panel dimensions will be more readily available once XLam Australia commences local production in late 2017.

Structural grades & properties
CLT also has no standardised stress grades and therefore design information and performance varies between manufacturers.

Whilst it is often touted that CLT can be made from low-grade resource, most of the products currently produced around the world come from structural grade timber feedstock.

- **Europe** – Common strength classes are C24 for a homogeneous layup and, if combined with C16 / C18, for the transverse layers. [C24, E=11GPa (C16 : 8GPa; C18 : 9GPa) *compared with MGP10 : E=10GPa; F5 : E=6.9GPa]*
- **Canada** – the visual quality requirements for lumber stock will be Structural Light Framing No.2 & Better grade for the major direction and No.3 & Better grade for the minor direction
- **US** – varies depending on species (see Section 3.2 CLT Handbook reproduced in Figure 5.21)

3.2 Stress Classes

As part of the standardization effort, seven CLT stress classes are stipulated in ANSI/APA PRG 320, while custom CLT products are also recognized, provided that the products are qualified by an approved agency in accordance with the qualification and mechanical test requirements specified in the standard. The stress classes are presented in the form of structural capacities, such as bending strength (F_bS), bending stiffness (EI), and shear rigidity (GA). This allows for the needed flexibility to CLT manufacturers in conformance with the product standard based on the available material resources and required design capacities.

The stress classes were developed based on the following prescriptive lumber species and grades available in North America:

- E1: 1950f-1.7E Spruce-Pine-Fir MSR lumber in all parallel layers and No. 3 Spruce-Pine-Fir lumber in all perpendicular layers
- E2: 1650f-1.5E Douglas fir-Larch MSR lumber in all parallel layers and No. 3 Douglas fir-Larch lumber in all perpendicular layers
- E3: 1200f-1.2E Eastern Softwoods, Northern Species, or Western Woods MSR lumber in all parallel layers and No. 3 Eastern Softwoods, Northern Species, or Western Woods lumber in all perpendicular layers

Figure 5.21. Stress class classification from US CLT Handbook

- **Australia** – It is understood that the CLT product to be produced at XLam Australia's new plant at Wodonga will utilise a softwood pine feedstock from Hyne Timber's Tumbarumba mill of a sub-MGP10 grade (possibly MGP8).

Manufacturing adhesives

There are a range of different types of adhesive used in the manufacture of CLT.

Europe - currently mainly Melamine-Urea Formaldehyde (MUF) and one-component Polyurethane adhesives (1K-PUR) are used.

- Both adhesives have an (nearly) uncoloured bond line, which in case of 1K-PUR is generally more flexible but also more vulnerable against higher temperatures (T > 60°C), if not modified adequately.
- The advantages of MUF can be seen in its higher resistance against high temperatures (e.g. in case of fire) and its penetrating properties. Furthermore, the curing process can be accelerated by increasing the temperature or by means of high-frequency technology. Its disadvantages are the emission of formaldehyde, its limited storage stability (1K-systems) and the strict mixing ratio of resin and hardener (2K-systems).
- In contrast, 1K-PUR are free of formaldehyde and can be easily adapted to the individual production requirements, in particular their reactivity and curing time.

Canada & US – generally Phenol-Resorcinol Formaldehyde (PRF), Emulsion Polymer Isocyanate (EPI), one component Polyurethane (PUR). Figure 5.22 provides a summary of some of the typical characteristics of adhesives for CLT manufacturing

Item	Units	Adhesive		
		PRF*	EPI**	PUR***
Cured adhesive colour		Dark	Light	Light
Component		Liquid, two components	Liquid, two components	Liquid, single component (isocyanate pre-polymer)
Solids content	(%)	50	43	100
Wood moisture content (MC)	(%)	6 - 15%	6 - 15%	> 8% optimal 12%
Target application rate (single spread)	(g/m^2)	375 - 400 (75 - 80 lb/msf)	275 - 325 (55 - 65 lb/msf)	100 - 180 (20 - 35 lb/msf)
Assembly time	(min)	40	20	45
Pressing time	(min)	420 - 540	60	120
Applied pressure	(psi)	120	120	120 - 200
Cost ****	($/lb)	2.0	3.5	4.8

† More information can be found in the adhesive manufacturer's technical bulletin.

Figure 5.22. Typical characteristics of adhesives for CLT manufacturing

Australia / New Zealand - Purbond clear Polyurethane (PUR) glue.

Hardwood cross laminated timber (HCLT)
Virtually all CLT produced globally at present utilises a softwood feedstock (Europe: spruce, larch, stone pine, white fir; North America: SPF (spruce, pine, fir mix), Douglas fir; NZ: Australian and NZ grown radiata pine).

An Australian company Lignor has been researching and investigating a hardwood CLT product Cross Laminated Strand Timber (CLST™) – a cross-laminated timber product made using their ESL® laminated strand lumber products. Whilst initial R&D has shown promise, no commercial production is yet underway.

In Europe, some solid hardwood CLT has been manufactured utilising Birch and Beech either as full hardwood CLT products or hybrid hardwood/softwood CLT products; however the commercial volumes are very limited. There does however appear to be an increasing interest in the use of hardwood in CLT based on several research papers at the most recent 2016 World Conference on Timber Engineering which in summary found the following.

Table 5.11. Summary of 2016 World Conference on Timber Engineering regarding CLT

Paper/*Author*	**Aim of work / Findings**
Hybrid Beech and Spruce Cross-Laminated Timber *Simon Aicher, Maren Hirsch, Zachary Christian*	This work examined the rolling shear properties of Beech used as cross-layers in hybrid cross-laminated timber; rolling shear modulus and strength of beech were determined by three different approaches. It found significantly better rolling shear properties obtained from tests of individual Beech boards as well as from the proof of concept Beech-Spruce hybrid CLT over those for softwoods representing a large improvement to the typically design-controlling properties of pure Spruce CLTs.
Mechanical Properties of Beech CLT *Steffen Franke,*	This work examined the production of CLT by producing it out of Beech or of Beech and Spruce in combination as hybrid product. The paper concluded that CLT elements out of Beech show a great potential. Particularly of interest were the improved mechanical values like the rolling shear and the compression strength perpendicular to the grain which provided the potential to open new applications of CLT in taller timber structures.
Composite Cross Laminated Timber (CCLT) Made with Engineered Wood Products (EWP) and Hardwood *Jean-Frédéric Grandmont, Brad Wang,*	This work investigated the potential of manufacturing CLT panels using various hardwood species and engineered wood products (EWP’s). Overall, the study showed a great potential for manufacturing future composite CLT (CCLT) products using EWP and low density hardwood species. The cost premium of using these alternative materials would need to be offset by improved properties or by a reduction of the manufacturing cost. The inclusion of hardwood lumber in CLT presented technical challenges, particularly in terms of bond line delamination. Higher wood shrinkage of hardwood, compared to softwood lumber, it was felt would likely lead to a greater amount of checking. Higher product density is another consideration when using hardwoods. An exception was Aspen, a lower density and lower shrinkage species that performed well. It was suggested that glue formulations specifically designed for hardwoods may improve bonding performance.
Mechanical properties of Glued Laminated Timber and Cross Laminated Timber produced with the wood species birch *Georg Jeitler, Manfred Augustin, Gerhard Schickhofer*	This work by Hasslacher Norica Timber, an Austrian wood processing company, investigated utilizing Birch *(Betula pendula)* to produce glued laminated and cross-laminated timber. The goal of the project was to set up a complete profile of the mechanical properties needed for the design, and by the means of a pilot project (detached house) erected with Birch CLT, demonstrate the effectiveness of this product for structural purposes. The results of the pilot illustrated in terms of the structural member design (walls, ceilings and roof) a decrease of the timber volume of about 10% to 15% if compared with common CLT made of spruce due to the higher mechanical properties, achievable by using Birch. Also, a special surface was tested termed “Excellent Lamella” – in which a visible lamella was built in to the CLT, with a 5 to 7 mm thick top-layer, a 5-mm cross layer and a filling layer of stress graded softwood. The thin top-layer and the cross layer prevented gaps between the boards, caused by the shrinkage of massive lamellas with the same total thickness.

As mentioned previously, in Europe, there has been some limited prototyping hardwood CLT production. Hasslacher Norica Timber manufactures a full Birch CLT product with an MUF adhesive system type 1. Structural properties of the product are shown in Figure 5.23.

Benefits of hardwood CLT are presented in the Technical Suitability section following.

MECHANICAL PROPERTIES FOR THE DESIGN OF CROSS LAMINATED TIMBER MADE OF BIRCH

Bending strength	$f_{m,CLT,k}$	38 N/mm²
Tensile strength	$f_{t,0,CLT,net,k}$	28.5 N/mm²
	$f_{t,90,CLT,k}$	0.6 N/mm²
Compressive strength	$f_{c,0,CLT,net,k}$	38 N/mm²
	$f_{c,90,CLT,k}$	5.0 N/mm²
Shear strength in plane	$f_{v,CLT,IP,k}$	15 N/mm²
	$f_{T,node,k}$	2.5 N/mm²
Shear strength out of plane	$f_{v,CLT,OP,k}$	4.5 N/mm²
Rolling shear strength	$f_{r,CLT,k}$	1.8 N/mm²
Modulus of elasticity	$E_{0,CLT,mean}$	15,000 N/mm²
	$E_{0,CLT,05}$	12,500 N/mm²
	$E_{90,CLT,mean}$	650 N/mm²
	$E_{c,90,CLT,05}$	540 N/mm²
	$E_{c,90,CLT,mean}$	650 N/mm²
	$E_{90,CLT,05}$	540 N/mm²
Shear modulus of elasticity	$G_{CLT,mean}$	850 N/mm²
	$G_{CLT,05}$	710 N/mm²
Rolling shear modulus of elasticity	$G_{r,CLT,mean}$	175 N/mm²
	$G_{r,CLT,05}$	145 N/mm²
Density	$\rho_{CLT,k}$	600 kg/m³
	$\rho_{CLT,mean}$	620 kg/m³

Figure 5.23. Mechanical properties for Birch CLT - Hasslacher Norica Timber

Importance to Current Advanced EWP Project

HIGH –

Table 5.12. Importance of Cross Laminated Timber to the Current Advanced EWP Project

Project Objective / Measure	Comment
Ability to use sub-optimal feedstock of interest to the project	Conventional CLT is typically manufactured using dried sawn softwood timber feedstock typically 12 to 45 mm thick and with a 40 to 300 mm wide face. Whether appropriately dimensioned solid rectangular boards can be cost-effectively recovered from the sub-optimal native forest logs will need to be determined from the project's resource processing recovery study, but it is considered unlikely. CLT could however potentially be manufactured using individual veneers mixed with softwood sawn boards, or using new EWP feedstocks such as LVL or LSL components manufactured from the sub-optimal resources. This approach would enable hardwood feedstock with higher performance properties to be included in CLT manufacture by overcoming several technical issues such as board stability and glue-ability that come from using solid sawn feedstock.

Project Objective / Measure	Comment
Volume of feedstock required *(is there enough volume to achieve required scale)*	If the CLT production process utilised new LVL or LSL components manufactured from the sub-optimal resources, then it is anticipated that appropriate volumes of possible feedstock would potentially be available depending on the species and product performance being targeted.
Technical suitability *(resource properties – match product needs)*	Due to the nature of CLT and its different product applications, technically there should be opportunities to utilise the available resource properties in a range of ways, depending on the species and its properties and the CLT application. CLT floor members require higher strength outer laminations, whilst wall elements require vertical laminates in compression to have a high strength parallel to grain. For both applications, the laminates perpendicular do not require this higher performance (tending to resist either shear force or simply assisting to hold the element together) and as such could be formed from a sub-optimal resource product. Recent research (WCTE 2016) has also shown that utilising hardwood as cross-layers in hybrid softwood/hardwood cross-laminated timber also assist in improving rolling shear resistance and overall product stiffness and strength. Higher density material products could also be utilised in the outer layers of CLT members to improve fire resistance performance or appearance grade products used to improve aesthetics and provide a distinctive look. The use of veneer for the manufacture of CLT type panels instead of or in combination with sawn boards offers some important advantages including further minimisation of the defects, reduced variations in properties, increased opportunities for feedstock utilisation and increased opportunities for higher performance products through optimised product construction strategies. This is an important consideration given the success with spindleless lathe processing approaches in recovery high volumes of high quality veneer from small diameter, sub-optimal quality logs. Gluing performance with hardwood or blended products may be an issue; this will need to be investigated in the prototype manufacturing phase of the project.

Project Objective / Measure	Comment
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	CLT manufacture need not necessarily be high capital investment, depending on the level of automation and throughput desired. For hardwood CLT feedstock the more expensive hydraulic press systems may be required to achieve adequate pressing pressures compared with the cheaper lower pressure vacuum press arrangements often used with smaller softwood CLT operations. CLT blank panel manufacture could quite effectively be integrated into existing sawmilling operations already manufacturing the potential feedstock. To provide a full CLT building systems supply service however would also require a design and CNC manufacturing capability.
Market Factors - *likely demand* - *price/performance competitiveness*	CLT provides a major emerging product opportunity for the mid-rise market sector particularly for buildings six storeys and above There are a range of new potential market opportunities for advanced CLT products including the following. • Conventional building structural elements: walls, floors, roofs, shafts, stairs, etc.; if stronger CLT panels can be manufactured using hardwood based resources or hardwood blended with softwood feedstocks, this will allow taller timber buildings to be constructed or smaller timber elements to be used (therefore less overall timber in structure or for walls, thinner wall sections which in-effect means larger lettable floor areas for the developer). • Structural elements manufactured with outer laminates of: o higher density species to provide new fire-char design solutions (this will assist in allowing timber elements to be designed to be exposed within a timber building rather than covered with fire-rated linings); or o appearance veneers to provide both an appearance and structural solution (will provide an aesthetically pleasing an acceptable outer surface and will reduce the costs of additional final lining material products).
Threats / Constraints	• Cost of manufacture and supply compared to alternative CLT products • Time for new mid-rise timber market opportunities to develop

Nail laminated timber (NLT)

Product description

Nail Laminated Timber (NLT) is a prefabricated massive timber product that utilises rectangular sawn timber sections, on edge, fastened together with nails (see Figure 5.24). Panel products such as plywood, OSB or particleboard are often also added to one side as a sheathing to provide structural diaphragm action or to improve the products performance when used in bracing wall panel applications; the sheathing can also assist with stitching prefabricated panels together on-site. In structural floor or roof applications the product could be designed and fire-assessed (performance approach) as a massive or heavy (large dimension) engineered timber building element and the intrinsic 'charring' capacity of the timber used to provide resistance. This would allow the appearance grade soffit to be left exposed as the ceiling when viewed from the floor below.

Figure 5.24. Nail laminated timber

Typical product usage

NLT provides a structurally efficient and economic mass panel product that is typically used for mass wall, floor and roof elements.

Country of production/availability in Australia

As production of NLT panels is a relatively simple manufacturing process there are no real restrictions on its ability to be produced. Timber fabricators in Australia currently produce, or have the potential to more widely produce, an NLT mass panel product. A major producer and promoter of NLT in North America is Structurecraft.

Size availability

As a manufactured product, panels can be produced to any size, maximum overall panel dimensions will be set in the main due to transportation restrictions. Widths would typically be 3-4m, lengths to 12m (greater if needed). Panel thicknesses (including sheathing thickness) can range from 75mm (min thickness defined under the NCC) to around 300m (assuming a solid 290mm deep section and 10mm sheathing). If LVL lamella were to be used, greater depths would be achievable.

Structural grades & properties

Any rectangular type timber can be utilised as a feedstock so structural design properties and grades will be defined and provided by proprietary manufacturers based on the feedstock.

Manufacturing adhesives

Physical connection between lamella is based on a nailed connection so adhesives are not generally utilised. Adhesives could be utilised if required.

Importance to Current Advanced EWP Project

MEDIUM – NLT could potentially be produced utilising new rectangular hardwood EWP structural products developed under this project, though they would need to be price competitive with other existing structural products.

Veneer-based mass panels (VMP)

Product Description

Veneer-based mass panels are large-scale (massive) panels constructed using rotary veneer. Panels up to 600mm thick can be manufactured and can used as an alternative to CLT (see Figure 5.25). Veneer-based mass panel systems have several advantages over more traditional CLT systems. These include:

- increased randomisation of defects throughout the cross section,
- increased panel stability,
- increased opportunities to manage feedstock variability,
- potentially less intensive manufacturing requirements,
- reduced panel dimension for similar mechanical performance, and
- increased opportunities to blend different feedstocks for performance gains.

Figure 5.25. Veneer based mass panels

Typical product usage

Typical applications could include massive wall panels, long-span floor elements, roofs and stair & lift shafts.

Country of production/availability in Australia

Mass plywood panels (MPP) have existed in Australia since the 1980's with development mainly focused on bridge decks. Big River Group in Australia currently produces a 170mm thick, H4 treated radiata pine MPP for bridge deck construction or renewal, marketed as Bridgeply (see Figure 5.26). PNG Forest Products are also a major producer of veneer-based mass panels for bridge decks. A US company, Freres Lumber of Lyons, Oregon in association with Oregon State University have recently marketed the development of an MPP product due to be available in 2017 which has a focus more towards mid-high rise construction.

Figure 5.26. Big River's Bridgeply

Size availability
Freres Lumber US panel dimensions are advertised as being up to 12 feet wide by 48 feet long and up to 24 inches thick once on the market. Big River's Bridgeply comes in 1,200mm widths, a standard thickness of 170mm and lengths up to 10m.

Structural grades & properties
Structural grades and properties will be defined by the manufacturer depending on products. BR's Bridgeply has a stress grade of F11. Information from Freres Lumber regarding their proposed MPP panels is currently not available.

Manufacturing adhesives
Adhesives include Non-urea formaldehyde (Freres) and Phenolic/Resorcinol (PR) systems.

Importance to Current Advanced EWP Project
HIGH –

Table 5.13. Importance of Veneer-based Mass Panels to the Current Advanced EWP Project

Project Objective / Measure	Comment
Ability to use sub-optimal feedstock of interest to the project	It is anticipated that the proposed sub-optimal log feedstocks would be appropriate for MPP production. While there are some benefits in using softwood feedstocks for the manufacture of this product type (e.g. lightweight, easily preservative treated etc.), veneer feedstock sourced from native forest resources may offer some additional/alternative benefits including natural durability, different and potentially more attractive appearances, increased mechanical performances, increased fire performance etc. Opportunities to blend both resource types could present a viable and unique opportunity for Australia.

Project Objective / Measure	Comment
Volume of feedstock required *(is there enough volume to achieve required scale)*	It is anticipated that there would be appropriate volumes of sub-optimal log feedstocks for MPP production. The market for mass-panel type products is not well understood due to the relative infancy of the market, however growth in this sector is expected to significantly rise over the coming decade. The inclusion of native forest feedstocks in the manufacture of mass panels may only represent a portion of the overall mass-panel market, and where additional performances are required that softwood products can't provide (e.g. mechanical and fire performances, aesthetics etc.).
Technical suitability *(resource properties – match product needs)*	Hardwood plywood products are already an established and proven engineered wood product. Technical suitability of the hardwood resource for development of mass plywood panels (MPP) will be dependent on the species used and the performance required. As with the discussion on CLT, potentially higher density laminates could be utilised in the outer layers of panels to improve fire resistance performance, or appearance grade veneers used to improve aesthetics and provide a distinctive look. Gluing performance with hardwood or blended products may be an issue; this will need to be investigated in the prototype manufacturing phase of the project.
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	The manufacture of veneer-based mass panels is potentially less capital intensive than CLT manufacture due to the differing feedstock dimensions. Where CLT requires the simultaneous positioning and gluing of many individual boards, veneer-based mass panels are often manufactured using thick plywood sheets. This significantly reduced the number of individual elements in the mass panel construction. At the small scale, veneer-based mass panel manufacture can be undertaken without expensive and complicated pressing systems as readily adopted for CLT manufacture. Instead, plywood panels can be scarf jointed in the longitudinal direction to the desired length before being laminated to desired panel thickness using relatively simple glue and screw systems. Larger scale operations and the provision of further processed panels (e.g. with service cut-outs etc.) would require a much higher level of capital investment.

Project Objective / Measure	Comment
Market Factors - *likely demand* - *price/performance competitiveness*	Mass Plywood Panels (MPP) made from radiata pine are currently produced by Big River for renewal of bridge decks but MPP's could also potentially be used as an alternative for CLT in building construction applications. CLT provides a major emerging product opportunity for the mid-rise market sector particularly for buildings six storeys and above. There are a range of new potential market opportunities for MPP products (as alternatives to CLT) in mid-rise construction, including the following: • Conventional building structural elements: walls, floors, roofs, shafts, stairs, etc.; • Structural elements manufactured with outer laminates of: o higher density species to provide new fire-char design solutions (this will assist in allowing timber elements to be designed to be exposed within a timber building rather than covered with fire-rated linings); or o appearance veneers to provide both an appearance and structural solution (will provide an aesthetically pleasing an acceptable outer surface and will reduce the costs of additional final lining material products). • In mid-rise lightweight wall construction, in lower storeys where high wall stud loadings can cause issues with sawn timber wall top and bottom plates loaded perpendicular to grain, MPP's utilising hardwood plywood with superior mechanical properties (loaded in-plane where compression capacities are high: 60 and 75MPa respectively) could be used as top and bottom plates (70, 90, 120, etc. wide) – *Note: this type of product providing high parallel-to-grain strength would obviously benefit having more laminates oriented in a similar direction (much like a cross-banded LVL) – however larger scale LVL manufacturers have indicated that this would not be cost-effective for them to produce it might better suit a smaller plywood manufacturing facility*
Threats / Constraints	• Cost of manufacture and supply compared to alternative CLT products • Time for new mid-rise timber market opportunities to develop

Panel & bracing type products

Plywood

Product description

Plywood is the oldest and most widely used engineered wood product. Plywood consists of thin veneer sheets, of various thicknesses depending on use, with each lamella laid alternatively at 90 degrees and bonded with adhesive. Both softwood and hardwood veneers are commonly used to manufacture a wide range of structural and appearance type products.

Typical product usage
Plywood is today used in an extremely wide range of structural and appearance (for example: internal lining and external cladding) applications. Structural uses include: floor sheeting, bracing panels, roofing, formwork, as webs for engineered I-beams, in plywood webbed beams. Other applications include as solid deck pallets, and container floors. Higher strength hardwood plywood is often used in industrial or commercial flooring applications or for formwork; appearance grade hardwood plywood can also be used for wall and ceiling panels and cabinetry.

Country of production/availability in Australia
Plywood is widely available throughout the world and in Australia. The major manufacturers in Australia include:

- Big River - NSW
- Ausply - Big River Group - NSW
- Austral Plywoods - Qld
- CHH - Vic
- TaAnn - Tasmania

Size availability
Standard plywood panels dimensions are:

- Length: 2700, 2400 and 1800 mm.
- Width: 1200 mm.
- Thicknesses: 3, 4, 4.5, 6, 7, 12, 13, 15, 17, 19, 21, 25 and 28 mm, size availability should be checked with manufacturers.

Structural grades & properties
Structural plywood is available in a range of different F- grades: F7, F8, F11, F14, F17, F22, F27 and F34. Some typical stress grades and thicknesses for application or shown in Table 5.14.

Table 5.14. Summary of typical applications, thicknesses and stress grades for plywood

Applications	**Thicknesses (mm)**	**Stress Grade**
Residential Flooring	13, 15, 17	F11, F14
Industrial Flooring	17-25+	F11-F22
Diaphragms	9-15	F11, F14
Bracing (Shearwalls)	3-15	F11, F14, F27
Box-beams	7-12	F11, F14
Portal frame gussets	12-25	F11, F14
Formwork	12, 17, 19, 25	F27

Softwood plywood in Australia is available in the following species and stress grades

- Radiata pine (*Pinus radiata*) F11, F14 (Type A bond)

Hardwood plywood in Australia is available in the following species and stress grades (characteristic properties for each of these stress grades is summarised in Table 5.15).

- Rose gum (*Eucalyptus grandis*) F22 (Type B bond)
- Blackbutt (*E. pilularis*) F27 (Type B bond)
- Spotted gum (*Corymbia citriodora*) F27 (Type B bond)
- Sydney blue gum (*E. saligna*) F27 (Type B bond)

Table 5.15. Structural Plywood – Characteristic Properties for F-Grades (EWPAA, 2018).

Stress Grade	Characteristic Strength, MPa				Short duration average modulus of elasticity MPa	Short duration average modulus of rigidity MPa
	Bending (f'_b)	Tension (f'_t)	Panel Shear (f'_s)	Compression in the plane of the sheet ** (f'_c)	(E)	(G)
F34	100	60	6.8	75	21 500	1 075
F27	80	50	6.8	60	18 500	925
F22	65	40	6.8	50	16 000	800
F17	50	30	6.8	40	14 000	700
F14	40	25	6.1	30	12 000	625
F11	35	20	5.3	25	10 500	525
F8	25	15	4.7	20	9 100	455
F7	20	12	4.2	15	7 900	345

***Note for compression capacity of plywood loaded normal to the face, the load is effectively applied perpendicular to grain of the veneers and crushing may occur. EWPAA's design manual states that characteristic bearing strength values need to be obtained from plywood manufacturers.*

Manufacturing Adhesives

Four types of glue bonds are generally available: Types A, B, C and D, in decreasing order of durability under conditions of full weather exposed.

- Type A bond is produced from a phenol formaldehyde (PF) resin
- Type B bond is produced from melamine fortified urea formaldehyde resin (MUF)
- Type C and D bonds are both interior bonds produced from urea formaldehyde resin, (UF)

Importance to Current Advanced EWP Project

MEDIUM –

Table 5.16. Importance of Plywood to the Current Advanced EWP Project

Project Objective / Measure	Comment
Ability to use sub-optimal feedstock of interest to the project	Traditional veneer processing methods have significantly limited the ability to use small, sub-optimal quality log feedstocks for veneer production. Relatively new spindleless veneer lathe systems now provide a very efficient processing method that allows this resource type to be processed and potentially high quality veneers to be extracted. Big River Group's Grafton facility recently adopted spindleless lathe systems to process small diameter plantation softwood and hardwood resources and small diameter native forest hardwood resources.
Volume of feedstock required *(is there enough volume to achieve required scale)*	Would be interesting to get some data from EWPAA regarding volume of plywood imported in Australia and from that amount, how much of it was higher strength (maybe >F14).

Project Objective / Measure	Comment
Technical suitability *(resource properties – match product needs)*	Hardwood plywood products are already an established and proven engineered wood product. These products can offer some unique advantages including higher mechanical performance, superior impact resistance etc., however are generally much heavier than plywood made from softwood and are generally more expensive. Limited markets currently exist for hardwood plywood which include formply, container floors, high load flooring etc. A limited market exists that demand the aesthetic qualities that hardwood offers. Plywood from white cypress has never been commercially manufactured, possibly due to the incompatibility of traditional processing equipment for the log resource. White cypress plywood could provide a unique product with natural termite resistance and different appearance to more commonly available plywood products.
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	The production of veneer and the manufacture of plywood products is well established globally. The equipment and procedures are well understood. Many examples of small, medium and large scale plywood manufacturing operations exist world-wide. The recent availability of relatively new spindleless veneer processing equipment provides a low-cost alternative to more traditional and high capital cost veneer processing equipment. This new approach based on lean-manufacturing techniques is particularly well suited to efficiently converting small-diameter and low quality logs into high quality veneer.
Market Factors - *likely demand* - *price/performance competitiveness*	Plywood is already well established in a wide range of applications both structural and appearance. There are a number of new potential market opportunities for advanced hardwood plywood products in new mid-rise construction. • Thicker ply floor slab elements (where thicker ply floor elements provide both improved acoustic performance and compositely bonded to timber joists provide a more effective structurally composite acting floor system). • Potential development and use of new Ultra High-Performance-Plywood (UHPP) veneer moulded and formed elements for non-structural partition walls: C-sections or Z-sections (as an alternative to lightweight steel framing) (Grabner et al., 2016). • As a substrate for pre-finished engineered timber flooring systems or as a final engineered timber flooring product utilising a higher grade top surface veneer.

Project Objective / Measure	Comment
Threats / Constraints	• One of the major challenges to plywood manufactured from the native forest hardwoods is the identification of markets that demand the performances that hardwood can offer. If these specific qualities aren't appreciated by the market, hardwood plywood becomes a heavy and more costly competitor for commodity softwood plywood products.

Oriented strand board (OSB)

Product description

Oriented strand board (OSB), is an engineered wood board product formed by compressing adhesive covered layers of wood strands (flakes) in specific orientations; the outer layers strands are generally oriented longitudinally in line with the panel length, whereas in the middle layers strands generally lie in a cross wise direction. OSB utilises individual strands which are typically 100 mm along the grain and from 5 to 50 mm across the grain. The final outer surfaces are rather rough and variegated (see Figure 5.27).

Figure 5.27. Oriented strand board

Wikipedia's manufacturing description notes the following (Wikipedia, 2019).

"OSB is manufactured in wide mats from cross-oriented layers of thin, rectangular wooden strips compressed and bonded together with wax and synthetic resin adhesives (95% wood, 5% wax and resin). The resin types typically used include Phenol formaldehyde (PF), melamine fortified Urea Formaldehyde (MUF) or isocyanate (PMDI), all of which are moisture resistant binders. In Europe, it is common to use a combination of binders, typically PMDI would be used in the core and MUF in the face layers and this has the advantage of reducing press cycles whilst imparting a bright appearance to the surface of the panel.

The layers are created by shredding the wood into strips, which are sifted and then oriented on a belt or wire cauls. The mat is made in a forming line. Wood strips on the external layers are aligned to the panel's strength axis, while internal layers are perpendicular. The number of layers placed is determined partly by the thickness of the panel but is limited by the equipment installed at the manufacturing site. Individual layers can also vary in thickness to give different finished panel thicknesses (typically, a 15 cm (5.9 in) layer will produce a 15 mm (0.59 in) panel thickness), see Figure 5.28.

The mat is placed in a thermal press to compress the flakes and bond them by heat activation and curing of the resin that has been coated on the flakes. Individual panels are then cut from the mats into finished sizes."

Figure 5.28. OSB strand mat prior to pressing

Typical product usage
OSB is now used widely in North America and Europe as a structural panel for walls, floors, roofs, I-joists and rim boards. Its take up as an alternative to plywood has increased dramatically over the past two decades.

Its benefits in comparison include the following (Evans, 2016).

- The ability to use lower quality wood feedstock, therefore lower wood costs (can use weed species or agricultural residues).
- Lower waste during manufacture.
- Much lower retail cost (OSB at minimum of ~$US7 per 8 x 4 ft. sheet compared with plywood at ~$US17 to $US20 per 8 x4 ft. sheet).

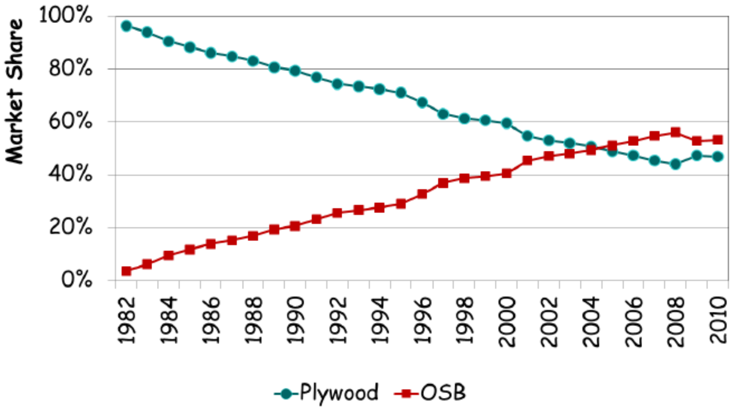


Figure 5.29. US Wood structural panel market share (Source: Prof Phil Evans)

Country of production/availability in Australia
There are a number of producers of OSB globally and importers of the product into Australia but no commercial board production in Australia.

Size availability
OSB is available in Australia (depending on manufacturer/importer) in a range of thicknesses (typically: 6, 9, 12, 15 & 18 mm) and panel sizes including the following: 2500 x 1250 mm; 900 or 1200mm width x 2440, 2745 & 3050mm long.

Structural grades & properties
Structural properties for OSB vary dependant on the manufacturer. For details on European products available see http://www.osb-info.org/technical.html . Egger's OSB floor sheeting (available in Australia) comes in 18 and 21mm thicknesses and has an E-value of 5,200MPa.

Manufacturing adhesives
Weyerhaeuser OSB is manufactured using MDI (methylene diphenyl diisocyanate) adhesive. European manufacturing adhesives include: Phenol formaldehyde (PF), melamine fortified Urea Formaldehyde (MUF) or isocyanate (PMDI).

Importance to Current Advanced EWP Project
MEDIUM –

Table 5.17. Importance of Oriented Strand Board to the Current Advanced EWP Project

Project Objective / Measure	Comment
Ability to use sub-optimal feedstock of interest to the project	It is anticipated that the proposed sub-optimal log feedstocks would be appropriate for OSB production.
Volume of feedstock required *(is there enough volume to achieve required scale)*	It is anticipated that there would be appropriate volumes of sub-optimal log feedstocks for OSB production. OSB could also potentially be manufactured as a by-product from an integrated facility producing the veneers from sub-optimal feedstock that don't meet the minimum quality required for a structural LVL product.
Technical suitability *(resource properties – match product needs)*	Hardwood OSB products are not currently being manufactured in any real volume and could be a new product offering to the market. Technical suitability of the resource for development of OSB panels will be dependent on the species used and the performance required. Gluing performance with hardwood may be an issue although R&D undertaken in the 90's in Victoria produced hardwood OSB. This will need to be investigated with the proposed range of species in the prototype manufacturing phase of the project.
Manufacturing Aspects - *required capital invest* - *scale of operation* - *ability to integrate with existing operations*	OSB manufacture in Europe and North America appears to be large-scale and commodity product driven and as such the initial capital investment for these types of plants appears to be quite high. Some initial on-line searching has been undertaken to determine whether smaller scaled down operations might be available. Nothing specific was identified on this initial search though a number of companies were identified that offer OSB manufacture equipment include the following: Globe, China Shandong Linyi Shengyang and Siempelkamp Europe. Further investigation will be undertaken here if this product is identified as one of interest.

Project Objective / Measure	Comment
Market Factors - *likely demand* - *price/performance competitiveness*	OSB is currently used as structural wall panels and I-joist webs and therefore hardwood OSB would need to have greater performance and cost efficiencies. There are however, new products that could be manufactured using the OSB manufacturing process. For example: 1. Potential development and use of new OSB moulded and formed elements for non-structural partition walls: C-sections or Z-sections (as an alternative to lightweight steel framing). 2. Potential development and use of new structural OSB moulded and formed elements: I-section floor joists, inverted 'T' section bearers. 3. Thick panelised floor slabs similar to that of LVL.
Threats / Constraints	• Scale of operations required • Whether a locally produced product could compete with commodity priced imports

Table 5.18. Summary of Engineered Wood Products and Importance to the Current Advanced Engineered Wood Products Project

Engineered Wood Product	Importance to Project	Ability to use low-grade or residual feedstock	Volume of feedstock required	Technical suitability
Cross Laminated Timber (CLT)	HIGH	Conventional CLT is typically manufactured using dried sawn softwood timber feedstock typically 12 to 45 mm thick and with a 40 to 300 mm wide face. Whether appropriately dimensioned solid rectangular boards can be cost-effectively recovered from the sub-optimal native forest logs will need to be determined from the project's resource processing recovery study, but it is considered unlikely. CLT could however potentially be manufactured using individual veneers mixed with softwood-sawn boards or using new EWP feedstocks such as LVL or LSL components manufactured from the sub-optimal resources. This approach would enable hardwood feedstock with higher performance properties to be included in CLT manufacture by overcoming several technical issues such as board stability and glue-ability that come from using solid sawn feedstock.	If the CLT production process utilised new LVL or LSL components manufactured from the sub-optimal resources, then it is anticipated that appropriate volumes of possible feedstock would potentially be available depending on the species and product performance being targeted.	Due to the nature of CLT and its different product applications, technically there should be opportunities to utilise the available resource properties in a range of ways, depending on the species and its properties and the CLT application. CLT floor members require higher strength outer laminations, whilst wall elements require vertical laminates in compression to have a high strength parallel to grain. For both applications, the laminates perpendicular do not require this higher performance (tending to resist either shear force or simply assisting to hold the element together) and as such could be formed from a sub-optimal resource product. Recent research (WCTE 2016) has also shown that utilising hardwood as cross-layers in hybrid softwood/hardwood cross-laminated timber also assist in improving rolling shear resistance and overall product stiffness and strength. Higher density material products could also be utilised in the outer layers of CLT members to improve fire resistance performance or appearance grade products used to improve aesthetics and provide a distinctive look. The use of veneer for the manufacture of CLT type panels instead of or in combination with sawn boards offers some important advantages including further minimisation of the defects, reduced variations in properties, increased opportunities for feedstock utilisation and increased opportunities for higher performance products through optimised product construction strategies. This is an important consideration given the success with spindleless lathe processing approaches in recovery high volumes of high quality veneer from small diameter, sub-optimal quality logs.

<table>
<tr><th>Engineered Wood Product</th><th>Importance to Project</th><th>Manufacturing Aspects</th><th>Market Factors</th><th>Threats / Constraints</th></tr>
<tr><td>Cross Laminated Timber (CLT)</td><td>HIGH</td><td>CLT manufacture need not necessarily be high capital investment, depending on the level of automation and throughput desired. For hardwood CLT feedstock the more expensive hydraulic press systems may be required to achieve adequate pressing pressures compared with the cheaper lower pressure vacuum press arrangements often used with smaller softwood CLT operations. CLT blank panel manufacture could quite effectively be integrated into existing sawmilling operations already manufacturing the potential feedstock. To provide a full CLT building systems supply service however would also require a design and CNC manufacturing capability.</td><td>CLT provides a major emerging product opportunity for the mid-rise market sector particularly for buildings six storeys and above.
There are a range of new potential market opportunities for advanced CLT products including the following.
• Conventional building structural elements: walls, floors, roofs, shafts, stairs, etc.; if stronger CLT panels can be manufactured using hardwood based resources or hardwood blended with softwood feedstocks, this will allow taller timber buildings to be constructed or smaller timber elements to be used (therefore less overall timber in structure or for walls, thinner wall sections which in-effect means larger lettable floor areas for the developer.
• Structural elements manufactured with outer laminates of:
o higher density species to provide new fire-char design solutions (this will assist in allowing timber elements to be designed to be exposed within a timber building rather than covered with fire-rated linings); or
o appearance veneers to provide both an appearance and structural solution (will provide an aesthetically pleasing an acceptable outer surface and will reduce the costs of additional final lining material products).</td><td>Cost of manufacture and supply compared to alternative softwood CLT products.
Time for new mid-rise timber market opportunities to develop.</td></tr>
</table>

Engineered Wood Product	Importance to Project	Ability to use low-grade or residual feedstock	Volume of feedstock required	Technical suitability
Plywood	MEDIUM	Traditional veneer processing methods have significantly limited the ability to use small, sub-optimal quality log feedstocks for veneer production. Relatively new spindleless veneer lathe systems now provide a very efficient processing method that allows this resource type to be processed and potentially high quality veneers to be extracted. Big River Group's Grafton facility recently adopted spindleless lathe systems to process small diameter plantation softwood and hardwood resources and small diameter native forest hardwood resources.	Would be interesting to get some data from EWPAA regarding volume of plywood imported in Australia and from that amount, how much of it was higher strength (maybe >F14).	Hardwood plywood products are already an established and proven engineered wood product. These products can offer some unique advantages including higher mechanical performance, superior impact resistance etc., however are generally much heavier than plywood made from softwood and are generally more expensive. Limited markets currently exist for hardwood plywood which include formply, container floors, high load flooring etc. A limited market exists that demand the aesthetic qualities that hardwood offers. Plywood from white cypress has never been commercially manufactured, probably due to the incompatibility of traditional processing equipment for the log resource. White cypress plywood could provide a unique product with natural termite resistance and different appearance to more commonly available plywood products.

Engineered Wood Product	Importance to Project	Manufacturing Aspects	Market Factors	Threats / Constraints
Plywood	MEDIUM	The production of veneer and the manufacture of plywood products is well established world-wide. The equipment and procedures are well understood. Many examples of small, medium and large scale plywood manufacturing operations exist world-wide. The recent availability of relatively new spindleless veneer processing equipment provides a low-cost alternative to more traditional and high capital cost veneer processing equipment. This new approach based on lean-manufacturing techniques is particularly well suited to efficiently converting small-diameter and low quality logs into high quality veneer.	Plywood is already well established in a wide range of applications both structural and appearance. There are a number of new potential market opportunities for advanced hardwood plywood products in new mid-rise construction. • Thicker ply floor slab elements (where thicker ply floor elements provide both improved acoustic performance and compositely bonded to timber joists provide a more effective structurally composite acting floor system). • Potential development and use of new Ultra High-Performance-Plywood (UHPP) veneer moulded and formed elements for non-structural partition walls: C-sections or Z-sections (as an alternative to lightweight steel framing). • As a substrate for pre-finished engineered timber flooring systems or as a final engineered timber flooring product utilising a higher grade top surface veneer.	One of the major challenges to plywood manufactured from the native forest hardwoods is the identification of markets that demand the performances that hardwood can offer. If these specific qualities aren't appreciated by the market, hardwood plywood becomes a heavy and more costly competitor for commodity softwood plywood products.

Engineered Wood Product	Importance to Project	Ability to use low-grade or residual feedstock	Volume of feedstock required	Technical suitability
Mass Plywood Panels (MPP)	HIGH	It is anticipated that the proposed sub-optimal log feedstocks would be appropriate for MPP production. While there are some benefits in using softwood feedstocks for the manufacture of this product type (e.g. lightweight, easily preservative treated etc.), veneer feedstock sourced from native forest resources may offer some additional/alternative benefits including natural durability, different and potentially more attractive appearances, increased mechanical performances, increased fire performance etc. Opportunities to blend both resource types could present a viable and unique opportunity for Australia.	It is anticipated that there would be appropriate volumes of sub-optimal log feedstocks for MPP production. The market for mass-panel type products is not well understood due to the relativeness infancy of the market, however growth in this sector is expected to significantly rise over the coming decade. The inclusion of native forest feedstocks in the manufacture of mass panels may only represent a portion of the overall mass-panel market, and where additional performances are required that softwood products can't provide (e.g. mechanical and fire performances, aesthetics etc.).	Hardwood plywood products are already an established and proven engineered wood product. Technical suitability of the hardwood resource for development of mass plywood panels (MPP) will be dependent on the species used and the performance required. As with the discussion on CLT, potentially higher density laminates could be utilised in the outer layers of panels to improve fire resistance performance or appearance grade veneers used to improve aesthetics and provide a distinctive look. Gluing performance with hardwood or blended products may be an issue; this will need to be investigated in the prototype manufacturing phase of the project.

Engineered Wood Product	Importance to Project	Manufacturing Aspects	Market Factors	Threats / Constraints
Mass Plywood Panels (MPP)	HIGH	The manufacture of veneer-based mass panels is potentially less capital intensive than CLT manufacture due to the differing feedstock dimensions. Where CLT requires the simultaneous positioning and gluing of many individual boards, veneer-based mass panels are often manufactured using thick plywood sheets. This significantly reduced the number of individual elements in the mass panel construction. At the small scale, veneer-based mass panel manufacture can be undertaken without expensive and complicated pressing systems as readily adopted for CLT manufacture. Instead, plywood panels can be scarf jointed in the longitudinal direction to the desired length before being laminated to desired panel thickness using relatively simple glue and screw systems. Larger scale operations and the provision of further processed panels (e.g. with service cut-outs etc.) would require a much higher level of capital investment.	Mass Plywood Panels (MPP) made from radiata pine are currently produced by Big River for renewal of bridge decks but MPP's could also potentially be used as an alternative for CLT in building construction applications. CLT provides a major emerging product opportunity for the mid-rise market sector particularly for buildings six storeys and above. There are a range of new potential market opportunities for MPP products (as alternatives to CLT) in mid-rise construction, including the following: • Conventional building structural elements: walls, floors, roofs, shafts, stairs, etc.; • Structural elements manufactured with outer laminates of: o higher density species to provide new fire-char design solutions. o appearance veneers to provide both an appearance and structural solution (will provide an aesthetically pleasing an acceptable outer surface and will reduce the costs of additional final lining material products). • In mid-rise lightweight wall construction, in lower storeys where high wall stud loadings can cause issues with sawn timber wall top and bottom plates loaded perpendicular to grain MPP's utilising hardwood plywood with superior mechanical properties.	Cost of manufacture and supply compared to alternative CLT products. Time for new mid-rise timber market opportunities to develop.

Engineered Wood Product	Importance to Project	Ability to use low-grade or residual feedstock	Volume of feedstock required	Technical suitability
Oriented Strand Board (OSB)	MEDIUM	It is anticipated that the proposed sub-optimal log feedstocks would be appropriate for OSB production.	It is anticipated that there would be appropriate volumes of sub-optimal log feedstocks for OSB production. OSB could also potentially be manufactured as a by-product from an integrated facility producing the veneers from sub-optimal feedstock that don't meet the minimum quality required for a structural LVL product.	Hardwood OSB products are not currently being manufactured in any real volume and could be a new product offering to the market. Technical suitability of the resource for development of OSB panels will be dependent on the species used and the performance required. Gluing performance with hardwood may be an issue although R&D undertaken in the 90's in Victoria produced hardwood OSB. This will need to be investigated with the proposed range of species in the prototype manufacturing phase of the project.
		Manufacturing Aspects	**Market Factors**	**Threats / Constraints**
		OSB manufacture in Europe and North America appears to be large-scale and commodity product driven and as such the initial capital investment for these types of plants appears to be quite high. Some initial on-line searching has been undertaken to determine whether smaller scaled down operations might be available. Nothing specific was identified on this initial search though a number of companies were identified that offer OSB manufacture equipment.	OSB is currently used as structural wall panels and I-joist webs and therefore hardwood OSB would need to have greater performance and cost efficiencies. There are however, new products that could be manufactured using the OSB manufacturing process. For example: • Potential development and use of new OSB moulded and formed elements for non-structural partition walls: C-sections or Z-sections (as an alternative to lightweight steel framing). • Potential development and use of new structural OSB moulded and formed elements: I-section floor joists, inverted 'T' section bearers. • Thick panelised floor slabs similar to that of CLT.	Scale of operations required. Whether a locally produced product could compete with commodity priced imports.

Mid-rise construction market assessment

In this Section, the new 'mid-rise' timber construction opportunity will be examined; how it differs from traditional Class 1 residential construction, and what this means in terms of the increased opportunities for the utilisation of engineered wood products, particularly higher performing EWP's.

First, some contextual introductory points regarding construction of Residential Class 1 buildings.

- Class 1 construction generally involves one or two (or sometimes three) storey dwellings – the key Australian design Standard *AS1684 Residential timber-framed construction* has a general scope limitation of two storeys.
- Lightweight timber framing is extensively used in Australia in residential construction for roofs, walls, upper storey floors and ground floor construction (though much of the ground floor sector has been lost to concrete slab-on-ground over the last decade).
- Residential construction dead, live and wind loadings are generally satisfied using sawn softwood or traditional hardwood products, typically 90mm x 45mm, 90mm x 35mm, or in Queensland 70mm x 45mm or 35mm sawn sections.
- Engineered timber products are often used in residential construction for structural beam, column or tension member applications when higher strength members are required. In recent years' softwood LVL manufacturers have altered their feedstock and layups to achieve F17 properties and then marketed and priced these products to directly compete against F17 sawn hardwood in many F17 traditional residential applications.

Whilst the Class 1 residential construction sector remains the mainstay for timber building products, changes in the 2016 National Construction Code (NCC) now also allow the use of lightweight or massive timber construction, under the Deemed-to-Satisfy (DtS) provisions, for Class 2 (apartments), 3 (e.g. hotels) & 5 (office) buildings up to an 'effective height' of 25m (approx. eight storeys); this is now being termed 'Mid-rise timber construction', as illustrated in Figure 5.30.

Figure 5.30. Terminology for different timber construction options

This new ‘mid-rise timber’ construction sector provides new and very different market share opportunities for a wide range of structural timber products (sawn and engineered) and timber based systems (see Figure 5.31). It also provides new markets for a wide range of timber appearance and fit-out products. There are product, design and specification challenges though that need to be addressed to ensure an acceptable and fit-for-purpose solution.

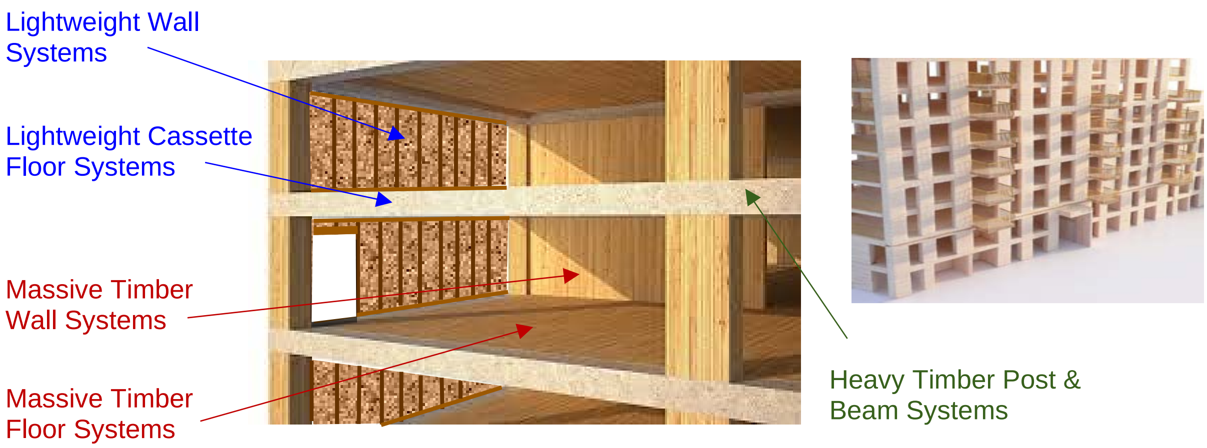


Figure 5.31. Timber based systems used in mid-rise timber buildings

Class 2, 3 & 5 buildings have a range of design considerations different to residential Class 1 construction that impact on the materials and systems used, including:

- the need to meet specific ‘fire and acoustic’ performance levels, standards and application requirements;
- increased ‘floor dead loads’ because of the additional acoustic requirements (concrete toppings, fire-rated plasterboard linings);
- increased’ floor design live load’ requirements under AS1170.1;
- increased ‘lateral load resistance’ requirements (wind & seismic loading) and the need to provide diaphragm action to transfer lateral loads through the structure to the foundations;
- the need to address ‘timber crushing’, ’long-term creep’ and ‘seasonal movement’ impacts (swelling, shrinking) which becomes more significant with each additional level added within a mid to high rise timber building;
- more highly loaded connections.

Each of the above are summarised briefly below providing context regarding their importance and their influence on particular timber products and their design.

Fire and acoustic performance requirements

For Class 1 residential construction, very little acoustic or fire requirements apply (apart for those specific requirements for townhouse construction and construction in bushfire-prone areas).

For Class 2, 3 and 5 buildings, very specific requirements exist for both fire and acoustic performance. These include both minimum performance requirements, as specified in the NCC; and particularly with acoustic performance, minimum acceptable levels expected by the market.

Meeting these requirements has a direct impact on the construction member design and choice of construction systems.

General fire protection requirements for walls and floor/ceiling systems
For fire, buildings above 4 storeys (mid-rise construction) need to meet the highest level of fire performance, being Type A Construction. In general, for typical floor/ceiling and wall systems this means**:

- *Class 2 and 3*: a Fire Resistance Level (FRL)[5] of 90/90/90 and a Resistance to the Incipient Spread of Fire (RISF)[6] of 45min for general timber framed systems and for massive timber systems a Modified Resistance to the Incipient Spread of Fire (MRISF) of 35min.
- *Class 5:* a Fire Resistance Level (FRL) of 120/120/120 and a Resistance to the Incipient Spread of Fire (RISF) of 45min for general timber framed systems and for massive timber systems a Modified Resistance to the Incipient Spread of Fire (MRISF) of 35min.

*(** note this may vary within a building depending on the specific element in question)*

The NCC Deemed-to-Satisfy provisions to meet the RISF/MRISF fire requirements, define systems that must provide 'full encapsulation by fire-rated linings'. For Class 2 & 3 buildings, this means either

- for 'general timber systems':
  - 2 layers of **13mm** fire-grade plasterboard, and
- for 'massive timber systems':
  - 1 layer of **16mm** fire-grade plasterboard.

Under the 'Performance Requirements' of the NCC, a massive or heavy (large dimension) engineered timber building element can be left exposed and designed utilising the intrinsic 'charring' capacity of the timber. That is, the dimensions are determined for structural needs and then a certain additional amount of timber is added dependant on the species and fire load that is needed to be resisted. Design for timber charring is covered in AS1720 Part 4.

Regardless of the NCC demonstration of Performance approach taken, the timber elements in these buildings will need to be designed to include within the Dead Load the increased mass of the fire rated protection (not required in residential construction)

NCC fire concession for stairs
The NCC provides a concession for stairways allowing timber treads, risers, landings and associated supporting framework to be used within a required fire-isolated stairway or fire-isolated passageway subject to several conditions. The conditions specific to the timber product are that the timber treads, risers, landings and associated supporting framework

(i) have a finished thickness of not less than 44 mm; and
(ii) have an average density of not less than 800 kg/m^3 at a moisture content of 12%[7],

Some timber species that would meet this density requirement include: *species (density kg/m^3)* spotted *gum (1,000), red ironbark (1,050), river red gum (900), turpentine (945), blackbutt (900), silver top ash (850), kwila (merbau) (850).*

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[5] Fire Resistance Level is defined in the NCC, as the grading periods in minutes, determined in accordance with Specification A2.3, for the following criteria— (a) *structural adequacy; and/* (b) *integrity; and/* (c) *insulation,* expressed in that order.
[6] Resistance to the Incipient Spread of Fire, RISF, in relation to a fire-protective covering, means: *'the ability of a covering to insulate voids, and the interfaces with timber elements, so as to limit the temperature rise, to a level that will not permit ignition of the timber, and the rapid and general spread of fire, throughout any concealed spaces'.* The performance is expressed, as the period in minutes, that the covering will maintain a temperature below the specified limits. The primary objective for the specification of an RISF, is to *reduce the risk of the timber structural elements being ignited, prior to burn-out of the contents, or fire brigade intervention; in the unlikely event of failure of the automatic fire sprinkler system.*
[7] NCC Clause D2.25, Timber stairways concession

This NCC Stair Concession opens up some specific and unique opportunities for higher density hardwoods and for potential new specialist stair products.

Other fire related considerations -
From a fire perspective, the structural performance of an EWP is influenced by the density of the timber species and the type of glueline adhesive used. Traditionally, EWPs such as plywood, LVL and Glulam have been fabricated using phenol, resorcinol, phenol-resorcinol and poly-phenolic glues and as such the structural product's fire-resistance can be determined in accordance with AS 1720.4-2006 (Standards Australia, 2006). The performance of these adhesive in fire does not change as they are thermos-setting glues and are not affected by fire; therefore, they do not impact on the fire-resistance of the structural member.

The fire-resistance period of a timber members is based on the timber density which is used to calculate a notional char rate. A calculation of the effective depth of charring, in accordance with AS 1720.4, for specific time periods is shown in Table 5.19. As can be seen below, as the species density increases the effective depth of charring decreases.

Table 5.19. Calculation of the effective depth of charring in accordance with AS 1720.4

Species Density (kg/m^3)	Notional Char Rate (mm/minute)	Fire Resistance Period (minutes)			
		30	60	90	120
		Effective Depth of Charring (d_c) (mm)			
550	0.66	27	47	67	87
800	0.52	23	39	55	70
1000	0.48	22	36	51	65

Species	Density
White cypress	700kg/m³
Victorian ash	650kg/m³
Shining gum	700kg/m³
Jarrah	800kg/m³
Blackbutt	900kg/m³
Red gum	900kg/m³
Karri	900kg/m³
Spotted gum	1000kg/m³
Blue gum	1000kg/m³

+ Additional depth of timber required to maintain structural performance for the specified time period.

This effective depth of charring can be "added" to the required section for structural purposes to provide adequate protection for the required fire resistance period.

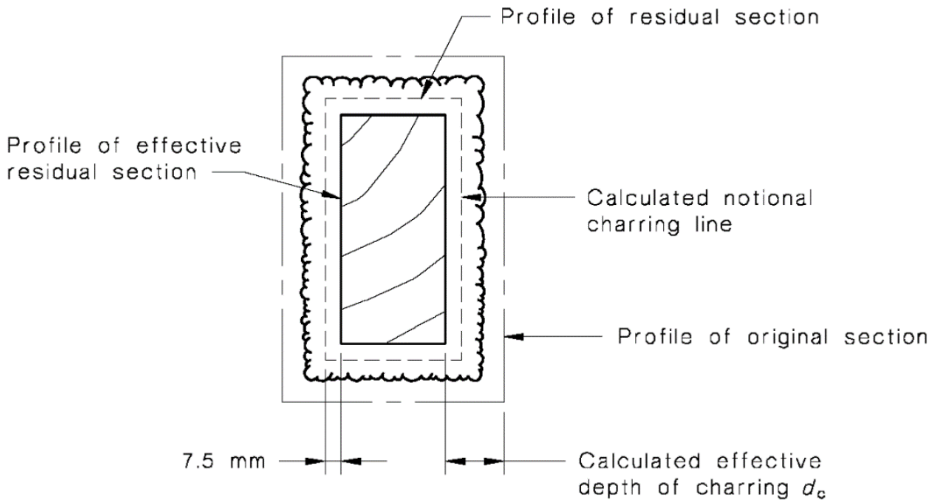

Figure 5.32. Loss of section due to charring

Table 5.20 illustrates the percentage of timber saved with increasing timber density in accordance with AS 1720.4.

Table 5.20. Percentage timber saving in relation to timber species density

Species Density (kg/m3)	Notional Char Rate (mm/minute)	Time Period (minutes)			
		30	60	90	120
		Percentage material saving compared to 550 kg/m3 (%)			
550	0.66	0	0	0	0
800	0.52	14.3%	18.8%	17.9%	18.4%
1000	0.48	21.4%	22.9%	23.9%	25.3%

It can be seen from the figures above that there is a real potential to utilise the advantages of higher density hardwood species in relation to the fire performance of exposed structural timber members; for new EWP's these potentially could be either solid or blended. Spotted gum and blue gum (globulus) with densities of 1,000kg/m^3 would be of particular interest.

Recently, there has been a trend in using different adhesive types in the manufacture of structural EWPs. These adhesives, such as Polyurethane (PUR), Emulsion Polymer Isocyanate (EPI), and Melamine-Urea Formaldehyde (MUF) provide greater flexibility in the manufacture of EWPs (e.g. glue setting times, feedstock moisture content). From a fire resistance perspective, these adhesive types however do not perform as well as Phenol/Resorcinol type gluelines and new design approaches have been developed by the product manufacturers based on fire testing.

An example of how the glueline can impact on the charring rate is shown in Figure 5.33. As can be seen in the illustration, the first lamella chars at a rate of 0.65 mm/minute followed by a doubling of the char rate (1.3 mm/minute) for the next 25 mm, then reverts to 0.65 mm/minute for the remainder on the lamella thickness (5mm in this instance) followed by a doubling of the char rate (1.3 mm/minute) for the next 25 mm and so on.

As mentioned previously, this phenomenon is verified by fire testing by a registered fire authority and will varying depending on the glue type, species and lamella configuration.

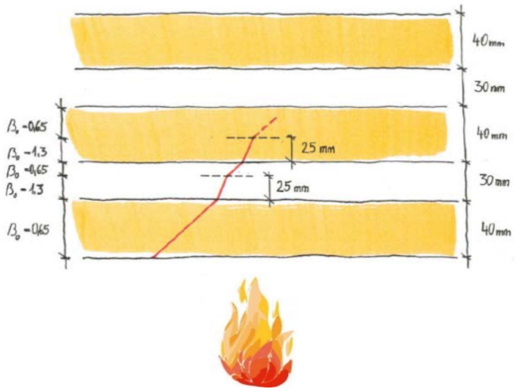

Figure 5.33. Change in Charring Rate with Polyurethane Adhesive *(Stora Enso)*

The use of exposed timber members is currently not permitted under the DTS provisions of the NCC for mid-rise timber buildings; however, a building design incorporating exposed timber members can be undertaken as a Performance Solution by a fire engineer. Examples of such buildings in Australia are Library at the Dock (Melbourne) and International House (Sydney).

To expose timber members is highly desired by Architects and Building Designers who wish to express timber in their buildings and demonstrate the environmental credentials of their designs. To be able to achieve the required fire resistance in commercial buildings (e.g. offices), higher fire resistance levels may be required (e.g. 120 mins.)

Using higher density hardwood timber would enable smaller end sections to be used due to the inherent structural strength and slower charring rate. Simply based on charring rate, a hardwood timber column would be at least 35-45 mm less in each cross-sectional dimension.

Acoustic performance
Acoustically, Class 2, 3 & 5 buildings need to meet minimum requirements set out in the NCC for both airborne and impact sound performance. For impact sound the market actually demands higher performance levels than the NCC specifies.

Achieving appropriate acoustic performance is more difficult in lighter weight timber structures (even massive timber structures) compared to traditional heavy mass reinforced concrete construction. Accordingly, this is a key and urgent area of investigation and discussion at present in Australia by industry technical representatives (though a wide range of options could be used, at this exact time there is no current agreement on the optimal and most economical solution for promotion).

In general terms for lightweight floor/ceiling systems, to achieve an appropriate acoustic rating will require the addition of certain products with higher mass to the top surface (by example it could include: additional timber sheeting, concrete screeds, sand between battens, or fibre cement sheet, see Figure 5.34).

For lightweight timber floors a possible scenario may be:

- 40mm screed or mass board overlay
- 10mm rubber underlay
- Floor sheeting (particle board, ply, OSB)
- Min 240mm deep lightweight floor trusses
- 75mm Glasswool insulation
- Resilient mounts (40mm)
- 2x16mm fire-rated plasterboard
- A suspended false ceiling is also a recommended practice to reduce concerns in breaching the fire rated linings for lights and services.

A similar configuration is also required to meet acoustic requirements with massive timber floors.

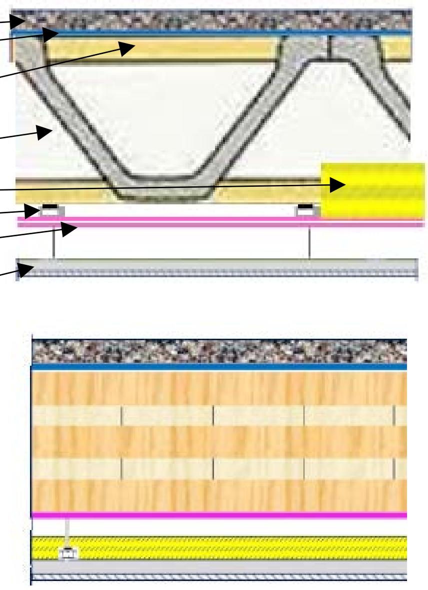

Figure 5.34. Typical lightweight and massive floor/ceiling acoustic compliant systems

As mentioned previously for fire, for acoustic performance also additional dead load weights will need to be considered for the acoustic related materials, this is examined in the next section.

Increased design dead and live load requirements

Increased Floor Dead Loads
As discussed in the previous section, Class 2, 3 & 5 buildings will require additional design dead load considerations over and above a typical Class 1 residential construction.

For floors in Class 1 construction, the dead load calculation would simply include the following:

- the flooring material (typically particleboard or plywood) approx. 15 kg/m^2
- the self-weight of the floor joists, approx. 15 kg/m^2
- for upper storey floor systems a non-fire rated ceiling 10mm plasterboard approx. 10 kg/m^2

TOTAL approx. 40 kg/m^2

For floors in Class 2 or 3 construction, the dead load calculation would also include the weight of materials to meet the appropriate fire and acoustic requirements:

- *the flooring material (typically particleboard or plywood) approx. 15 kg/m^2*
- *the self-weight of the floor joists, approx. 20 kg/m^2*
- Acoustic insulation approx. 2.5 kg/m^2
- Tiles; 6mm ceramic tiles on fibre cement board approx. 30 kg/m^2
- 40mm concrete screed (at 2400kg/m^3) approx. 100 kg/m^2
- Acoustic overlay and resilient mounts approx. 2 kg/m^2
- Two layers of 16mm fire rated plasterboard (12.5kg/m2) approx. 25 kg/m^2
- Suspended non-fire rated ceiling - 13mm plasterboard approx. 15 kg/m^2

TOTAL approx. 200 kg/m^2

So, the typical floor design dead load for Class 2, 3 & 5 construction as can be seen is approx. five times larger than that required for residential construction due the additional materials required to meet the acoustic and fire performance requirements.

Increased floor live loads
Floor design Live loads (Imposed actions) for Class 2, 3 and 5 type buildings are also larger than those required for residential design. A summary of the Imposed actions (Live Loads) as specified by AS *1170. 1 Structural Design Actions Part 1: Permanent, Imposed and Other Actions* are provided in Table 5.21.

Table 5.21. Summary of live load requirement for Class 1, 2, 3 & 5 Buildings

Specific Use	Residential – Class 1		Class 2 (apartments) & Class 3 (hotels		Class 5 Offices	
	Unif Distrib Action (kPa)	Conc Action (kN)	Unif Distrib Action (kPa)	Conc Action (kN)	Unif Distrib Action (kPa)	Conc Action (kN)
Roof	0.25	1.1	(1.8/A + 0.12) but not less than 0.25	1.4	(1.8/A + 0.12) but not less than 0.25	1.4
Floors						
• **General areas**	1.5	1.8	2.0	1.8	3.0*	2.7*
• **Halls & passages**	1.5	1.8	4.0	4.5	4.0	4.5
• **Stairs**	2.0	2.7	4.0	4.5	4.0	4.5
• **Balconies**	<1.0m: 1.5 >1.0m: 2.0	1.5 1.8	4.0	1.8	4.0	1.8

Note: higher loads required in storage and file rooms

Floor design live loads can be seen to be approx. 1.3 times larger for Class 2 & 3 and 2 times larger for Class 5 for general areas, and up to 2.7 times larger for passageways than that required for residential construction.

Implications on floor system design and prefabrication approach
The preferred floor supply systems for mid-rise timber construction is using prefabricated floor cassette systems (see Figure 5.35), which have a wide range of benefits, particularly in regards to speed of construction on-site and safety of site workers. Interest in, and development of, prefabricated floor cassette systems has been strong the last couple of years, though the focus has been mainly on the Class 1 residential sector. The prefabricated floor cassette systems used here have been quite simple:

Figure 5.35. Class 1 Floor Cassettes

- utilising traditional floor sheeting (19mm particleboard, OSB or ply) nailed to floor joists (floor trusses are preferred by frame & truss manufacturers as they can fabricate these themselves, I-joist also an option, sawn section floor joists rarely used), and
- in design, no consideration is generally given to pursuing composite structural action of the flooring and joists.

Use of prefabricated floor cassette systems in Class 2, 3 & 5 buildings offers new approaches to cassette element design to optimise the combined requirements of structural adequacy, fire resistance and acoustic performance (as discussed in the previous sections).

With floor systems in these type of buildings (as shown in Figure 5.36):

- the *surface layer* must provide an acoustic requirement (perhaps also a resistance to fire burn-down though this isn't a regulatory requirement);
- the *soffit layer* must provide the major fire performance resistance (through either fire-resisting linings or charring if designed for) and the materials selected will also impact on acoustic performance;
- the structural elements used in the floor provide the structural resistance capacity.

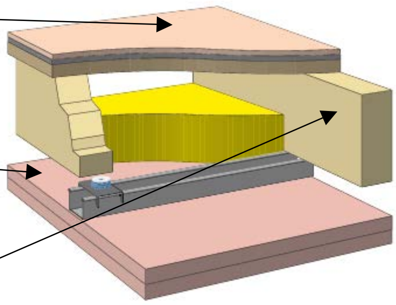

Figure 5.36. Floor system elements

For prefabricated floor cassette systems in Class 2, 3 & 5 buildings there are investigations currently underway in Australia in regard to new cassette design approaches to optimise the structural, acoustic & fire requirements. One approach of interest is the *LVL Rib Slab*, which is a prefabricated structural system constructed utilising thick LVL floor slabs rigidly connected by adhesives and screws to the supporting floor joist beams (see Figure 5.37).

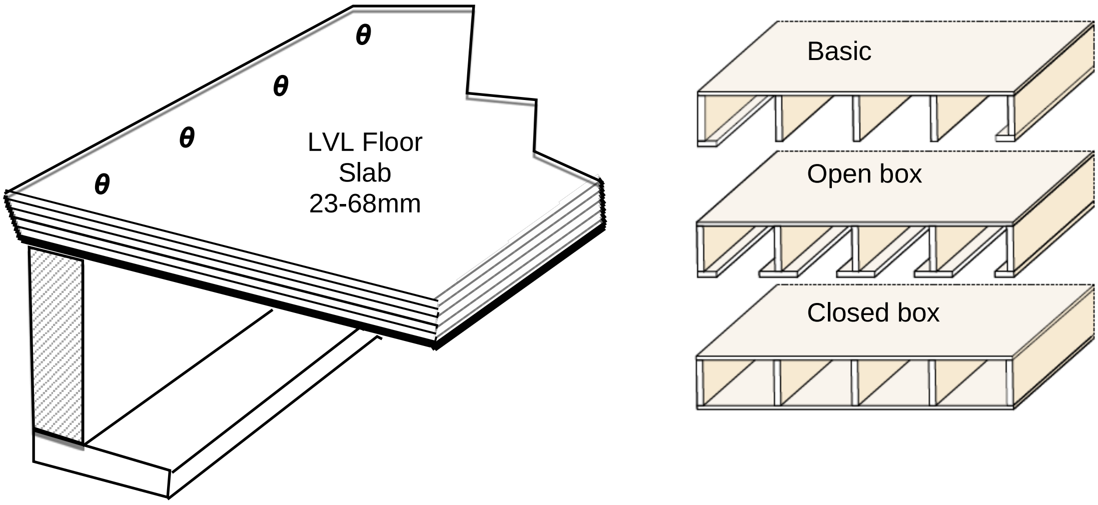

Figure 5.37. LVL Rib Slab – prefabricated floor cassette module options

This approach allows a structurally optimised solution utilising composite action (bending and stiffness) of the thick LVL floor slab and supporting floor joist beams; providing a more material efficient solution than a solid CLT slab[8]. The thick LVL floor slab also provides:

- an acoustic performance improvement, and
- a stiff bracing diaphragm to assist in transferring lateral wind and seismic loads.

This thick floor slab solution in Class 2, 3 & 5 construction may provide new opportunities for LVL oy plywood products, including new hardwood products developed.[9]

Implications for massive wall system design and prefabrication approach

The NCC describes a massive timber as: *an element not less than 75mm thick as measured in each direction formed from chemically bonded laminated timber and includes:*

a) *Cross laminated timber (CLT)*
b) *Laminated veneer lumber (LVL)*
c) *Glued laminated timber (Glulam)*

In mid-rise buildings, with wall construction it is anticipated that buildings up to six storeys will be most efficiently framed using lightweight timber elements; though framing in the lower levels will require multiple studs or closer stud spacing.

Figure 5.38. Wall framing approaches in 6-8 storey buildings

[8] Note: if acoustic performance required the use of a concrete slab overlay, this could also be designed as concrete timber composite member utilising the concrete to provided added structural performance along with its acoustic contributions; appropriate shear connectors would need to be provided to achieve composite action.

[9] Note: This is a very current area of discussion. A new FTMA facilitated Mid-rise Market Implementation Group will be formed in early 2017 to investigate and develop new optimal prefabricated timber solutions.

For buildings above 6 storeys, loading requirements are likely to necessitate the use of massive timber wall panels in the lower more highly loaded floors (see Figure 5.38). Whilst CLT is an obvious product choice in this application, LVL panels also provide a more widely available alternative structural solution (see Figure 5.39). In wall applications where loads are predominately vertical, LVL per unit thickness provides greater vertical loadbearing capacity as all the veneers are oriented so that the load is acting in compression parallel to grain (there may be some horizontal capacity required to resist lateral loading). Additional composite columns could also be utilised if required.

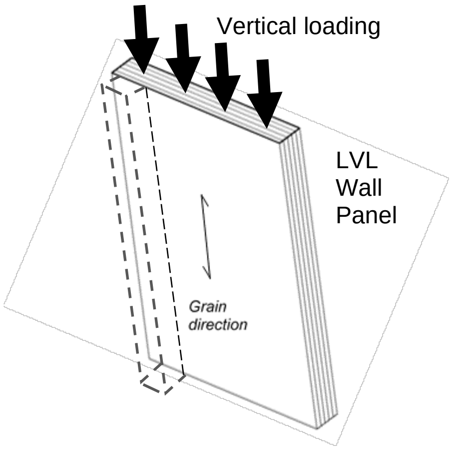

Figure 5.39. CLT wall framing panels

Massive LVL wall systems in Class 2, 3 & 5 construction provides a significant new opportunity for LVL products, including new hardwood LVL products developed.

Timber crushing and movement

With mid-rise timber buildings above three storeys, vertical movement can occur in the timber building elements due changes in environmental conditions (causing shrinkage or material expansion), long-term creep effects, and elastic deformation of the building elements (particularly crushing of timber members due to high compressive loading perpendicular to grain). The taller the building, the greater the cumulative effect of each floor.

Total Building Vertical Movement = Shrinkage + Creep + Elastic Deformation + Settlement

Differential vertical movement is important in mid-rise construction, where some walls maybe more highly loaded than other walls (i.e. internal walls compared with external walls), or where the timber construction joins rigid components utilised in the building; such as external brickwork walls or concrete or masonry lift shafts.

When utilising seasoned structural elements with moisture contents around 11-15% and appropriate building enclosure and air-tightness (so that there are not large variations in Relative Humidity), shrinkage movement should not be highly significant. Appropriate calculations can be undertaken and detailing approaches adopted in areas where high relative humidity changes might be expected.

Elastic deformations due to compression loads are an issue of greater interest with timber structures. Deformation of timber members loaded parallel to grain is generally small, in comparison to potential deformation of members loaded perpendicular to grain (crushing). By example, studs loaded parallel to grain may show little deformation compared with the wall top and bottom plates that they frame into that can crush under high load (see Figure 5.40).

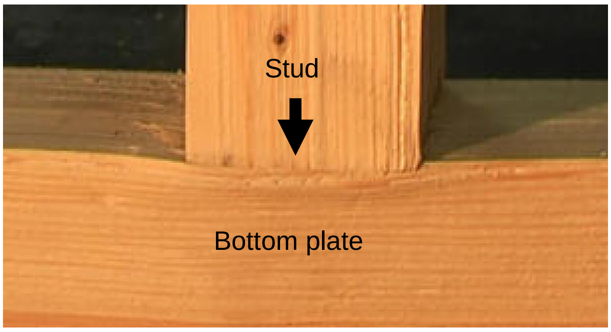

Figure 5.40. Illustration of perpendicular to grain crushing of bottom plate due to stud

In taller timber buildings, crushing perpendicular to the grain may also be an issue where floor cassette system rim-boards, in lower floors, are subject to high point loads from wall studs or columns (see Figure 5.41).

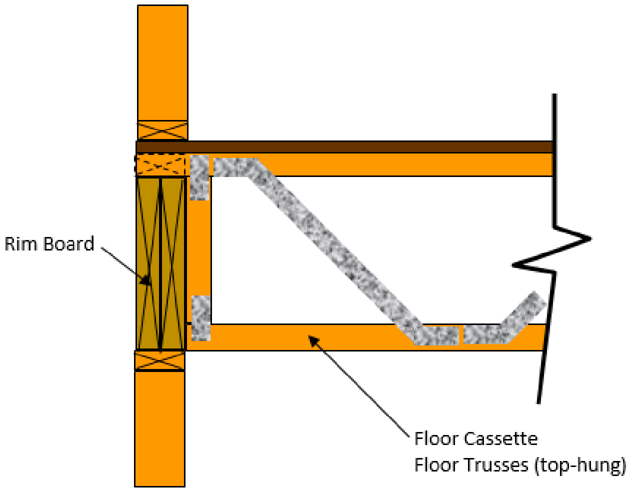

Figure 5.41. Use of a cassette floor with rim-board

Utilising a product such as LVL turned at 90° to its normal use (so the grain runs vertically) would provide more than three times the crushing resistance:

- LVL compression perpendicular to grain 12MPa
- LVL compression parallel to grain 41MPa

For hardwood LVL (HLVL) the value here would be even greater.

LVL products with high compression parallel to grain properties provide opportunities in high point load applications were crushing might be an issue.

Potential new EWP opportunity assessment

In this Section, a preliminary overview of the new potential EWP product opportunities is provided based on the findings of the previous non-Class 1 product/market opportunity analysis. Information includes:

- specific products in terms of the possible applications, and
- minimum product specification such as: sizes (dimensions), lengths, grades, treatment requirements (termites and fire retardant), fall-down product opportunities.

Key issues identified relevant to this new product opportunity assessment include:

- the need to resist higher design live loads and dead loads (due to the additional materials required to meet fire and acoustic requirements),
- fire related concessions for stairs that favour hardwood products,
- improved fire performance of large dimension hardwood based beams & columns and wall panels, and
- consideration of crushing effects on timber elements in 5-7 storey midrise buildings due the increased applied loads.

Preliminary investigations would suggest that products with the most potential would include:

- Hardwood, or hardwood and softwood blended, Laminated Veneer Lumber (HLVL) framing elements
- Massive Composite Hardwood-CLT (CHCLT) panels fabricated from HLVL feedstock
- Hardwood LVL Floor Slabs
- Mass Hardwood-LVL panels for rim-beams and mass panel walls
- Cross-banded Hardwood Laminated Veneer Lumber (X-HLVL)
- Appearance-faced Hardwood, or hardwood and softwood blended, Laminated Veneer Lumber
- Heavy HLVL timber beams and columns
- Oriented Strand Board (OSB)

The species (and densities) of particular interest in terms of the sub-optimal quality feedstock to be studied by this project come from a range of areas nationally and include:

White cypress	*700kg/m^3*	*Red gum*	*900kg/m^3*
Victorian ash	*650kg/m^3*	*Karri*	*900kg/m^3*
Shining gum	*700kg/m^3*	*Spotted gum*	*1000kg/m^3*
Jarrah	*800kg/m^3*	*Blue gum*	*1000kg/m^3*
Blackbutt	*900kg/m^3*		

Each individual species has certain natural attributes and characteristics that will impact on its potential final product usage including: weight (density), strength, stiffness (MoE), stability, natural durability, fire resistance (density) and gluing capability. The focus should be, to capitalise on the inherent advantages of specific species in the make-up of the proposed new engineered wood product whether that be solid or blended.

Hardwood laminated veneer lumber (HLVL)

The main objective of this R&D project is to: *investigate the technical feasibility of using rotary-veneer produced from sub-optimal quality native hardwood forest and plantation logs in combination with other wood-based feedstocks (blended resources to enhance product performance and marketability) to manufacture high performance 'next generation' hardwood based engineered wood products (EWPs), suitable for structural and appearance applications*, so opportunities for Laminated Veneer Lumber particularly Hardwood Laminated Veneer Lumber (HLVL) are obviously one of the key areas of interest.

Hardwood-LVL or blended hardwood/softwood LVL framing elements (beams & studs)

The additional structural loadings associated with mid-rise timber buildings mean that there will be expanded opportunities for stiffer (higher Modulus of Elasticity – E), stronger (higher bending, shear, tension, and compression parallel-to-grain capacity) structural members, if these can be cost-effectively manufactured from the available lower quality feedstock.

Minimum product specification
Grade: Current softwood LVL available in Australia has

- E-values ranging from 13,200 - 15,300MPa
- Bending strength values ranging from 50 – 62 MPa.
- Compression parallel-to-grain values ranging from 41 – 47 MPa

New HLVL, or blended softwood/hardwood LVL products, should be targeting these structural design properties or better (note: existing hardwood LVL values such as SmartLVL19 have an E value of 19,500MPa). It is recommended that all the project species be manufactured and tested (if DAF has not already done this) to determine their structural properties.

Size: HLVL framing construction product options could include:

- Wall studs: 35 and 45mm breadths, and depths of 70, 90mm
- Wall plates: 35 and 45mm thick, and widths of 70, 90, 120, 140mm
- Structural beams
    - breadths, range: 35, 45, 63, 75mm
    - depths, range: 90-450 standard, up to 1,200mm max

Treatment requirements: H2 and H3 treatment as required

Fall-down/alternative product opportunities: feedstock for composite hardwood CLT (CHCLT) panels

Massive composite hardwood-CLT (CHCLT)
Hardwood LVL (HLVL), blended softwood/hardwood LVL, or other composite engineered wood product feedstock of framing sized material could be laid up to produce larger composite formed CLT panels (see Figure 5.42).

Utilising the composite engineered wood product feedstock assists in overcoming potential gluing and movement issues of CLT manufactured from full sawn hardwood boards.

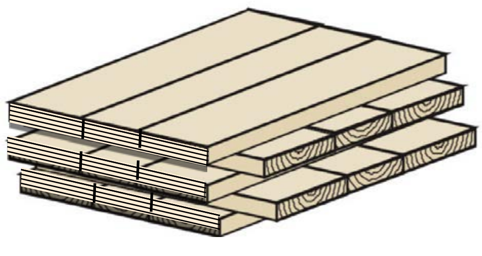

Figure 5.42. CLT fabricated using HLVL feedstock.

A range of different configurations might be considered for investigation here.

- CHCLT formed totally using composite engineered wood product feedstock in both transverse layers (should provide better rolling-shear resistance based on WCTE paper findings)
- CHCLT formed using composite engineered wood product feedstock in the primary resisting layers (for floors: top and bottom outer faces, for walls: vertically resisting layers) and low grade solid softwood in the transverse layers

- CHCLT formed using composite engineered wood product feedstock in the primary resisting layers transverse layers oriented at 45° *(results of a recent study indicate that CLT containing ±45° alternating layers has increased strength and stiffness compared to 90° alternating layers* (Buck et al., 2016).

If of interest, test panel sizes and dimensions to be discussed by Project Steering Committee.

It is suggested that Issues that would need to be investigated in manufacturing CHCLT panels include:

- dimensional stability wood shrinkage (hardwood, compared to softwood),
- glue formulations and bonding performance,
- compatibility when mixing various raw materials,
- delamination performance,
- potential economic differences (need to accurately investigate the potential supply and manufacturing cost savings, and customer perception of value from additional product attributes such as: improved appearance, better dimensional stability and better dimensional tolerance.

Hardwood-LVL or plywood floor slabs

- New floor cassette approaches using thick LVL or plywood floor slabs acting compositely with the supporting beams and providing acoustic performance improvement (see Figure 5.43).
- Concept still needs to be embraced by the frame & truss sector and calculations still required on possible composite structural performance and optimum acoustic benefits when combined with other acoustic performance improvement options.
- Flooring systems will provide the largest single new market opportunity for timber products in volume in mid-rise timber construction.

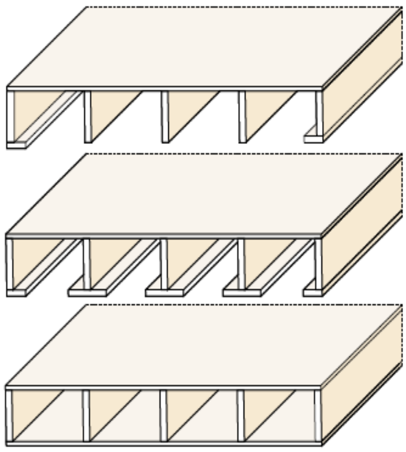

Figure 5.43. LVL floor slab configurations

Sizes: optimal floor slab dimensions would be:

- Thicknesses: from 23 – 68 mm
- Widths: 2,700 – 3,000mm would be preferable (these are the maximum trick travel dimensions, and this would allow single cassette floor sheets – otherwise 1,350 – 1500mm)
- Lengths up to 10m

Production: it is likely that with LVL some level of cross-banding would be required for panel stability:

Hardwood-LVL in high compression parallel to grain loading situations

Lightweight construction

In lower floors of taller lightweight constructed buildings where crushing of timber may pose a problem due to the higher wall stud loads there may be demand for EWP's with superior compression parallel to grain performance. These products could involve higher-performing *wall top and bottom plates*, perhaps LVL (or mass plywood) products oriented with grain running vertically so that strength parallel to grain then in line with direction of vertical stud loads, or in very high loading cases LVL floor cassette *rim-boards* (see Figure 5.44).

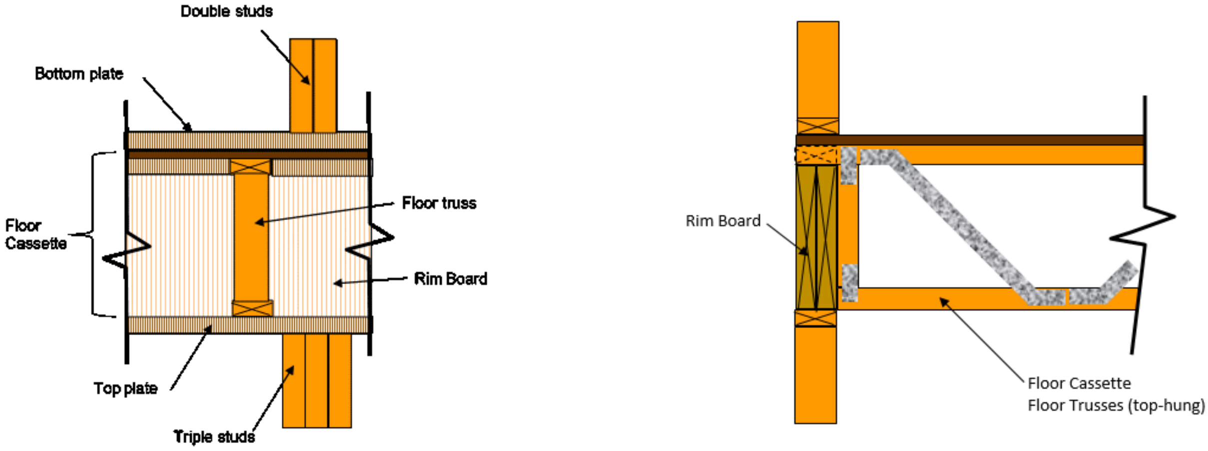

Figure 5.44. Wall and floor cassette products needing superior compression parallel to grain performance

Use of massive LVL wall panels

Massive panel LVL walls provide a potential opportunity for frame & truss manufactures to deliver to deliver simple massive wall system alternatives to conventional CLT construction (see Figure 5.45).

With LVL in this wall application, the majority of the panels' timber veneers are oriented in the optimal direction to maximise the high compression parallel to grain characteristics (unlike CLT where alternative layers are oriented at 90°). Cross-banding of LVL panels may assist here in resisting any cupping movement due to moisture or fabricated panels of multiple layers (screwed together) may utilise some thinner external LVL sheathing panels at 90°.

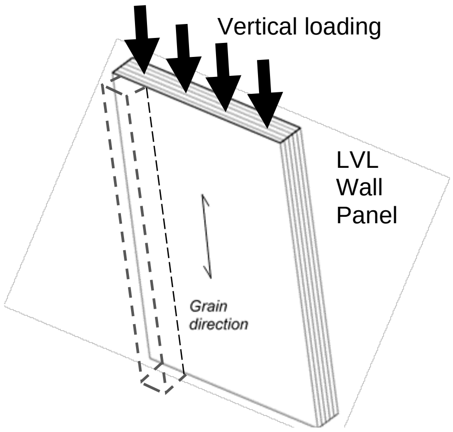

Figure 5.45. Massive LVL wall

Cross-banded hardwood laminated veneer lumber (X-HLVL)

HLVL may also be manufactured utilising cross-bands (X-HLVL) to assist in different product applications including:

- short length highly loaded beams are higher shear stresses need to be resisted,
- moisture movement control and board stability, this will be particularly important for wider LVL wall or floor slabs
- joint connections or cut penetration reinforcement to assist in resisting higher shear and crack prorogation stresses, cross bands at specific joint locations
- utilisation of embedded steel sheets (Figure 5.46) (Pranjic et al., 2016) for very high reinforcement (Big River have also been recently investigating steel reinforced plywood doors for prisons – see Figure 5.47)

Figure 5.46. Embedded steel connection reinforcement plates

Figure 5.47. Steel reinforced plywood doors for prisons (Big River)

High density-faced LVL for fire performance improvement

In mid-rise construction where timber elements are desired to be left exposed and as such the fire design (performance approach) requires an inclusion of the natural charring capacity of the wood, then EWP's could be manufactured with outer laminates of higher density fibre to improve the charring capacity (see Table 5.22).

Table 5.22. Percentage timber saving in relation to timber species density

Species Density (kg/m^3)	Notional Char Rate (mm/minute)	Fire Resistance Period (minutes)			
		30	60	90	120
		Effective Depth of Charring (d_c) (mm)			
550	0.66	27	47	67	87
800	0.52	23	39	55	70
1000	0.48	22	36	51	65

For instance, in design for a fire resistance period of 90min an LVL beam or column could be designed and manufactured with the outer 51mm of laminations utilising Spotted Gum or Blue Gum (density: 1000kg/m^3) to achieve the fire-char resistance, the encapsulated structural member could be of a similar or different material.

Appearance-faced laminated veneer lumber

- Full HLVL with appearance grade veneers used on outer faces, or appearance hardwood LVL veneers on a softwood LVL core, could also be manufactured providing a product with a combined structural and appearance application.

Big River currently produce an appearance clad plywood product, Armourply hardwood which can be utilised as a wall lining or as a hard-wearing flooring surface (see Figure 5.48)

Figure 5.48. Big River Armourply Flooring and lining product

Heavy HLVL timber beams and columns

Large dimension HLVL beams and columns can be manufactured for mid-rise timber post and beam construction use. Beams and columns in these applications are often left exposed for aesthetic reasons so the ability to design for charring is highly advantageous.

Figure 5.49. Example of Heavy HLVL timber beams and columns

Mass plywood panels (MPP)

Mass Plywood Panels (MPP) could potentially be used as an alternative for CLT in mid-rise building construction applications, including:

- conventional building structural elements: walls, floors, roofs, shafts, stairs, etc.; and
- structural elements manufactured with outer laminates of:
    - higher density species to provide new fire-char design solutions (this will assist in allowing timber elements to be designed to be exposed within a timber building rather than covered with fire-rated linings); or
    - appearance veneers to provide both an appearance and structural solution (will provide an aesthetically pleasing an acceptable outer surface and will reduce the costs of additional final lining material products).

As with the composite product CLT, if MPP's were of interest, test panel sizes and dimensions would need to be discussed by Project Steering Committee.

In mid-rise lightweight wall construction, there is also the need in lower storeys where high wall stud loadings can cause issues with sawn timber wall top and bottom plates loaded perpendicular to grain to utilise hardwood plywood MPP's whose superior mechanical properties when loaded in-plane where compression capacities are high: (60 and 75MPa respectively) Conventionally sized top and bottom plates are generally 70, 90, 120mm wide.

Note: this type of product providing high parallel-to-grain strength would obviously benefit having more laminates oriented in a similar direction (much like a cross-banded LVL) – however larger scale LVL manufacturers have indicated that this would not be cost-effective for them to produce it might better suit a smaller plywood manufacturing facility.

Hardwood oriented strand board (OSB)

It is suggested that oriented strand board may provide a possible fall-down opportunity for lower quality veneer production waste that is not suitable for HLVL manufacture. OSB is gaining wider acceptance as both a flooring and wall bracing/sheathing product. Frame & truss manufacturers in Australia as they move top more prefabricated wall systems are now embracing the full wall sheathing approach (seen commonly in North America) as it allows them to omit the use of studs from their wall frames (a slow installation process with prefabrication).

There are also potentially new products that could be manufactured using the OSB manufacturing process. For example:

1. Development and use of new OSB moulded and formed elements for non-structural partition walls: C-sections or Z-sections (as an alternative to lightweight steel framing).
2. Development and use of new structural OSB moulded and formed elements: I-section floor joists, inverted 'T' section bearers.
3. Thick panelised floor slabs similar to that of LVL.

If OSB was of interest to the Project Steering Committee, there would need to be much more detailed investigation of the availably of a small-scale OSB production facility and the costs involved with plant establishment and manufacture compared to current cost of imported ODB product.

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Chapter 6: A preliminary assessment of mixed species plywood to provide protection against subterranean termites

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Introduction

The heartwood of white cypress pine *Callitris glaucophylla* is known to be resistant to termite and fungal attack due to the presence of extractives in the heartwood, though this resistance does not extend to the sapwood. These extractives include e.g. thujaplicin, nootkatin, dolabrin, thujaplicinol and pygmaein. The extractives have been investigated as potential natural preservative treatments (in preference to chemical preservatives) for timber to prevent termite attack.

Previous studies (Evans, P.D. *et al.* 2000 and Evans, P.D. *et al.* 1997) looking at blends of durable e.g. cypress pine and non-durable e.g. radiata pine or hoop pine in both particleboard and MDF have shown enhanced resistance to termite attack when compared to those composed entirely of a non-durable species. The greater the ratio of durable to non-durable plies in the plywood panel then the greater the termite resistance. Similarly, the biological durability of LVL made from durable and non-durable species was tested against decay fungi and shown to have enhanced durability when two faces and one core were from a durable species. Both of these were studies were performed in the laboratory and not in the field.

A study (Faraji *et al.* 2009) looking at such a mix in plywood (*Cupressus sempervirens* and Beech / Poplar / Scots pine) was evaluated against *Reticulitermes santonensis* in laboratory trials in France. Durability was found where the outer layers were:

- Cypress pine heartwood; and
- where 60% of the plies (veneers) consisted of cypress pine heartwood.

Integration of the layers (durable / non-durable) was found to be extremely important whereas the percentage of durable *vs* non-durable was less so. Having the durable layers as faces is a necessary condition for a plywood panel to gain resistance against termite attack. Similar trials with basidiomycete fungi (Faraji *et al.* 2008) showed that the ratio of exposed durable surfaces *vs* non-durable surfaces in plywood is the determiner of resistance rather than the volume of durable *vs* non-durable plies.

Previous durability studies with termites in the laboratory hint at the need for field tests to rigorously confirm these results and test the theory that the durability of face and back veneers are the key factor in natural resistance of plywood panels to attack by subterranean termites.

Experimental

Plywood – veneer configurations

White cypress pine *Callitris glaucophylla* (heartwood durable) and hoop pine *Araucaria cunninghamii* (non-durable) veneers of good quality were selected to manufacture the following 7-ply configurations:

1. Cypress face and back / hoop core
2. Hoop face and back / cypress core
3. Hoop face / back / long bands - cypress cross bands
4. Cypress face / back / long bands - hoop cross bands
5. Full hoop - nominally the control

Sample preparation

Small plywood panels (300 x 300 mm) were manufactured at the Salisbury Research Facility using a polyurethane glue and a small laboratory press and then placed in a conditioning chamber at 65% RH and 20^0 C for two weeks. After this time 16 samples were cut for each plywood configuration from the material available i.e. 16 replicates. The samples were 135 x 70 mm by the thickness of the plywood panel, which varied from 10 to 15 mm, depending on the configuration of cypress and hoop veneers. Pine (predominantly sapwood) feeder blocks were also cut from material obtained from a local hardware outlet. The dimensions of the feeder blocks were 135 x 70 x 20 mm. The total number of pine sapwood blocks was 96. There were 16 exposure boxes each containing five plywood blocks (configurations 1 to 5) and six pine sapwood blocks i.e. 11 blocks per exposure box. The pine feeder blocks (termite susceptible timber) were included to encourage on-going termite foraging in the exposure box and provide an indicator of termite vigour (based on mass loss) within each box.

Test sample configuration in exposure box

In each exposure box plywood blocks were alternated with pine sapwood blocks with corrugated cardboard separating all samples (Figure 6.1). Plywood blocks were randomly assigned to each exposure box such that the same plywood configuration did not sit in the exact same position for every exposure box. This was done to account for any position effects (with regards termite feeding) in each box. The exposure box was a plastic container with lid purchased from a local hardware outlet and measured 270 x 160 x 90 mm. Each set of blocks (plywood and pine sapwood) was wrapped in corrugated cardboard and taped to form an enclosed package ready for exposure to termites (Figure 6.1). The corrugated cardboard was used to provide a series of runways for the termites once they had entered the box. This aided the movement of termites throughout the exposure box. All the blocks were weighed prior to the packages being constructed. This enabled mass loss data to be calculated for each block post-exposure to termites, as well as allowing for a comparison with the visual termite damage score previously assigned to each block.

Figure 6.1. Plywood blocks and pine sapwood blocks prior to placement in termite exposure box

Field exposure

The exposure boxes were placed on concrete blocks sitting atop a trench which had earlier been filled with termite susceptible feeder material (pine off-cuts) at the Esk trial site where *C. acinaciformis* were known to be active. Pine feeder stakes, driven into the ground within the holes in the concrete blocks and touching lengths of pine stud buried just below the surface of the trench, were used to facilitate termite entry into the boxes (Figure 6.2). Once the exposure boxes were in place the entire trench was liberally doused with water using a watering can and then covered with black plastic to maintain a dark, humid environment conducive to sustained termite foraging (Figure 6.3). The boxes were inspected after one month to ensure termites had entered all the boxes and then left un-disturbed for a further 16 weeks culminating in a 20 week exposure period.

Figure 6.2. Exposure boxes placed on concrete blocks atop a termite aggregation trench at Esk

Figure 6.3. The exposure boxes were covered to provide a dark, humid foraging environment

Results and discussion

After the 20-week exposure period the boxes were retrieved from the field and returned to the laboratory at Salisbury Research Facility for assessment of the blocks (plywood and pine feeder). The cardboard enclosed bundle was removed from each box and the plywood and pine blocks separated and cleaned (using a brush and thin metal spatula) to remove any dirt, debris and termites. Live termites were found in all 16 exposure boxes at this time (Figure 6.4).

Figure 6.4. Live termites were found in all exposure boxes when assessed in the lab

Initially each block was examined for damage and assigned a visual termite damage rating based on the following numbered rating system:

- **1** - Sound
- **2** - Superficial damage or grazing by termites
- **3** - Surface damage by termites > 5mm in depth
- **4** - Damage (slight) - 10 - 25% mass loss
- **5** - Damage (moderate) - 25 - 50% mass loss
- **6** - Damage (severe) - 50 - 75% mass loss
- **7** - Damage (destroyed) - 75 - 100% mass loss

Secondly each block was weighed to determine the mass loss due to termite attack and subsequently the percentage mass loss to assess the degree of termite damage to each block. The percentage mass loss was used to verify the visual damage rating.

All the pine sapwood feeder blocks were severely damaged by termites with average mass losses ranging from 47% (box 1) up to 81% (box 9) (Figure 6.5). Visual termite damage ratings ranged from 5 through to 7 for these blocks. Some damaged blocks were reduced to individual pieces held together by a rubber band (Figure 6.6).

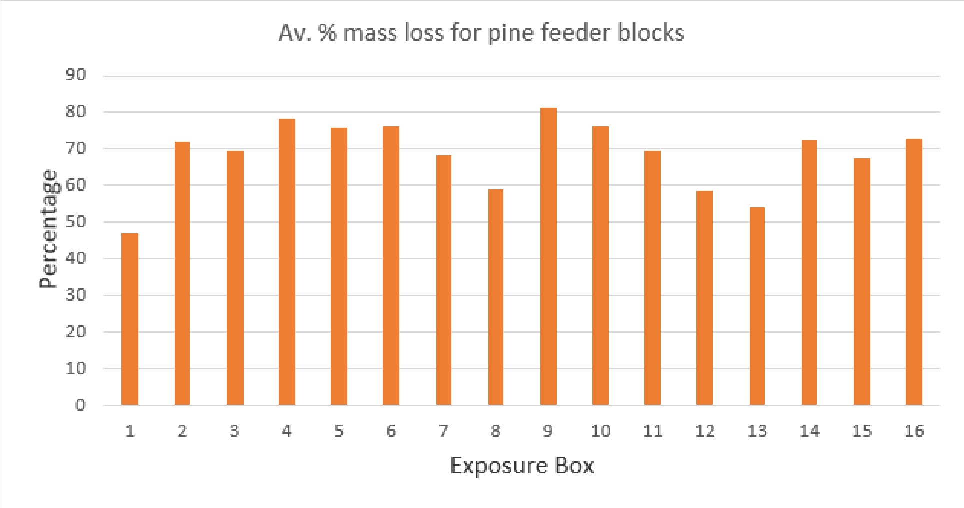

Figure 6.5. Average % mass losses for each exposure box indicative of strong termite vigour

Figure 6.6. All pine sapwood blocks were severely damaged indicative of strong termite vigour

The control (full hoop) plywood blocks (configuration 5) were all damaged by *C. acinaciformis* with mass losses ranging from 11% up 40% for individual blocks. The average mass loss across all 16 boxes was 26%. In all blocks the face, back and inner plies were damaged to some degree and in some blocks the termites had also eaten through the glueline (Figure 6.7). The visual damage rating for these blocks was either a 4 or a 5 i.e. moderate damage to some blocks.

Figure 6.7. All control plywood blocks sustained damage to face and back veneers and inner plies

Plywood configuration 4 (cypress face / back / long bands - hoop cross bands) performed best when exposed to *C. acinaciformis* in the field with all 16 blocks assessed with a visual rating of 1 equating to a zero mass loss and nil damage to the face, back or inner plies (Figure 6.8).

Figure 6.8. Configuration 4 plywood blocks had a visual rating of 1 and zero mass loss

Plywood configuration 1 (cypress face and back / hoop core) had no termite damage to the face or back veneer but in most cases the inner hoop plies were damaged to varying degrees (Figure 6.9). Three blocks were not damaged. Mass losses per plywood block ranged from 1.4% up to 26% with an average mass loss across the 16 boxes of 8.1%. The visual termite damage rating ranged from 1 through to 4 i.e. sound to slight damage.

Figure 6.9. Configuration 1 plywood blocks had no damage to the face or back veneers but inner plies were eaten

Plywood configuration 2 (hoop face and back / cypress core) sustained termite damage to the face and back veneers. In some cases up to 90% of the total surface area of the face and/or back had been eaten by termites (Figure 6.10). None of the inner cypress plies had been eaten. The glueline beneath the face and back veneers was not penetrated by termites.

Mass losses per plywood block ranged from 5.3% up to 11.5% with an average mass loss across the 16 boxes of 5.3%. The visual termite damage rating ranged from 2 through to 4 i.e. superficial to slight.

Figure 6.10. Configuration 2 plywood blocks had damage to the face and back veneers but inner plies were intact

Plywood configuration 3 (hoop face / back / long bands and cypress cross bands) sustained termite damage to both the face and back veneers but the inner plies were not damaged by termites (Figure 6.11). In some cases up to 90% of the total surface area of the face and/or back had been eaten by termites. The glueline beneath the face and back veneers had not been penetrated by termites. Mass losses ranged from 5.1 % up to 15.7% per block. The visual termite damage rating ranged from 2 through to 4 i.e. superficial to slight.

Figure 6.11. Configuration 3 plywood blocks had damage to the face and back veneers but the inner plies were intact

The average % mass loss per plywood configuration and for pine sapwood feeder blocks are shown in Figure 6.12.

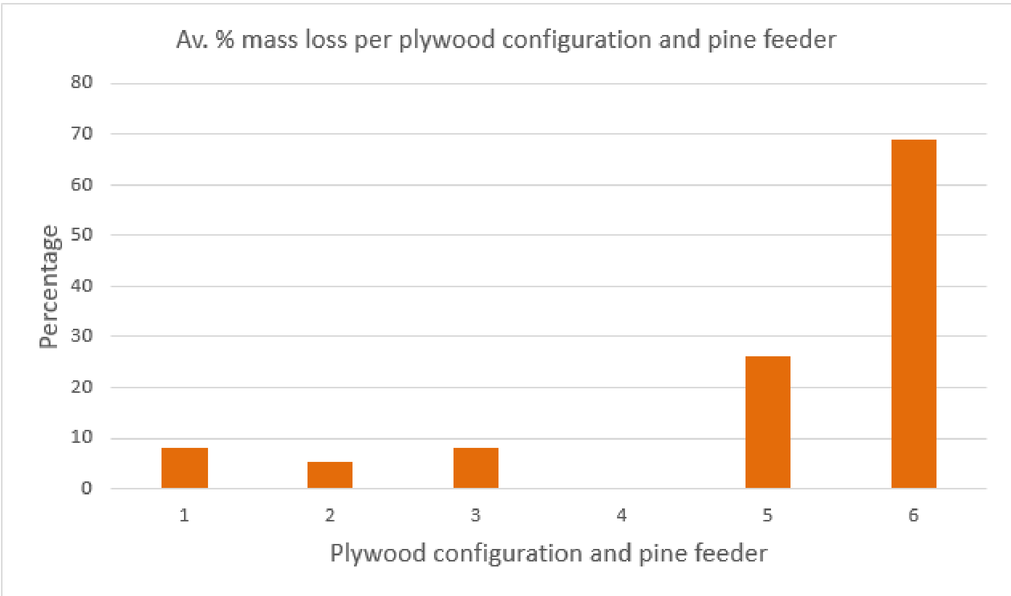

Figure 6.12. Average percentage mass loss due to termite feeding for five plywood configurations plus pine feeder

1. Cypress face and back / hoop core
2. Hoop face and back / cypress core
3. Hoop face / back / long bands - cypress cross bands
4. Cypress face / back / long bands - hoop cross bands
5. Full hoop - nominally the control
6. Pine sapwood feeder block

The results from above incorporating the visual termite damage rating and the average % mass loss for the 5 plywood configurations and the pine feeder blocks are outlined in Table 6.1.

Table 6.1. The visual termite damage rating and average % mass loss for 5 mixed species (durable and non-durable) plywood configurations and pine feeder blocks spread across 16 exposure boxes.

Plywood configuration	Face veneer	Back veneer	Inner Plies	Visual damage rating range	Av. mass loss%
1	-	-	+	1 - 4	8.1
2	+	+	-	3 - 4	5.3
3	+	+	-	2 - 4	8.1
4	-	-	-	1	0
5	+	+	+	4 - 5	26.3
Pine feeder	n/a	n/a	n/a	5 - 7	68.2

+ termite damage - no termite damage

C. acinaciformis did not damage the cypress pine face or back veneers in plywood configurations 1 and 4. In configuration 4, where the longbands were also cypress pine, the plywood block did not sustain any termite damage when exposed to *C. acinaciformis* in the field. However with configuration 1, where the inner plies were hoop pine, these were damaged to varying degrees. The cypress pine face and back did not impart any immunity to the hoop pine core to prevent termite attack. In plywood configuration 2 both the face and back veneers (which were hoop pine) were eaten by termites, in some cases up to 90% of the surface area of the face and/or back was removed. However termites did not penetrate the glueline to the cypress core beneath. There was no damage to the cypress pine core. This confirmed the durability of cypress pine heartwood to subterranean termite attack.

Plywood configuration 3 showed a similar result to configuration 2 with up to 90% of a face and/or back veneers eaten by termites. Surprisingly there were three blocks with this configuration which were not damaged. It is not certain why this has occurred other than the result of a position effect within the exposure box. As with configuration 2 none of the inner plies (cypress or hoop) were damaged by termites. The cypress heartwood helped protect the hoop long bands from termite attack. Configuration 5 plywood blocks (full hoop pine), nominally the control, sustained damage to the face, back and the inner plies. In most instances the termites had penetrated the glueline on the face and/or back to the hoop pine veneer below or even further. These blocks sustained by far the highest average mass loss across the 16 boxes of 26.3%. This was not an unexpected result with hoop pine being the non-durable species in the plywood configurations. The termite vigour in all 16 boxes was considered strong based on the damage sustained by the pine sapwood feeder blocks with an average mass loss across 16 boxes of 68.2%.

The results mirror quite well those found in the laboratory study by Faraji. *et al.* (2009), where durability to termite attack (*Reticulitermes santonensis)* on a mixed plywood configuration (*Cupressus sempervirens*- durable and Beech / Poplar / Scots pine - non-durable) was most pronounced where the outer layers (face and back) were cypress pine heartwood and where at least 60% of the plies consisted of cypress pine heartwood. In this study having the durable veneers (cypress pine) as a face and back is the primary necessary condition for the plywood block to gain resistance against termite attack but secondarily the cross bands must be cypress pine as well. This was the only configuration (4) that provided the plywood block with full immunity to attack by *C. acinaciformis* in the field. All other plywood configurations sustained sufficient termite damage to either the outer layers and/or inner plies as to not be acceptable for use in termite prone situations. While the mass losses in configurations 1, 2 and 3 are less than 10% and may suggest only superficial or surface damage it is the fact that termites have damaged the face, back and inner plies (sometimes to great extent) that is the significant factor in making them unsuitable for use in termite prone situations.

Conclusions

1. A plywood configuration incorporating both a termite durable species (cypress pine heartwood) and a non-durable species (hoop pine) in a 7-ply design must have a cypress pine face and back and a cypress pine long band to be immune to attack by *C. acinaciformis* in a field exposure.
2. No other plywood configuration in this study could be deemed suitable to prevent termite attack to a degree that would be acceptable if the end-use involves exposure to possible subterranean termite attack.
3. Plywood configuration 4 which was immune to subterranean termite attack had inner hoop pine plies 1mm thick. Further research should be undertaken to ascertain if thicker hoop pine plies are equally protected.

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Chapter 7: Product prioritisation and selection of 'best bet' products to guide project product development activities

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Forest resources

A national resource assessment was undertaken and reported in Chapter 3. This report mainly discussed the results from a desktop analysis of available information about the national native forest and hardwood plantation resource. In addition to this assessment, an earlier assessment was also reported Chapter 2 which discussed in detail, the current resource situation in Queensland in relation to the availability of small-diameter peeler logs (~16 to 30 cm diameter) from native forests. These reports indicate that a substantial volume of forest resource within Australia's native forest and hardwood plantations are potentially suited for rotary veneer processing using spindleless lathe technology. The report also identified that the creation of a new market for currently under-utilised small-diameter logs may assist in supporting improved silvicultural management in both native forests and plantations. The reports also identify some challenges with quantifying available log volumes and potential access. A summary of the key finding as reported in Chapter 3 are detailed below:

The main objectives of the resource assessment component of the project were to:

- Describe the quantities, qualities and locations of logs potentially suited for rotary-peeled veneer product manufacture using spindleless lathe technologies, with particular focus on:
  - Native hardwood and cypress pine from both crown and private native forest.
  - Smaller diameter (~16 to 30 cm diameter), sub-optimal quality logs including logs (or portions of logs) that are available for harvesting and/or processing however they are not processed for standard, traditional target products because of size, quality, technical and economic reasons.
  - Current and forecasted future supplies.
- Assist the decision-making process regarding target EWP choices, market options, equipment requirements and investment in EWP processing and manufacturing facilities.
- To contribute key data to the economic analysis component of the project.
- Provide some information on the national plantation hardwood resource availability and suitability for rotary-peeled veneer product manufacture.
- To assist the tree and log selection process for the processing component of the project.

General findings

Many factors influence the potential quantities of small-diameter peeler logs available from native forests and hardwood plantations in Australia. These include but are not limited to:

- Specifications adopted regarding log grade quality and size requirements.
  - Politics, government log supply agreements, policies and regulations, including codes of practice requirements restricting supply.
- Alternative current or future uses of logs of the same quality.
  - Economic and market conditions e.g. increased or decreased harvesting of private forests during economic downturns or upturns in the agricultural industry (as log timber harvesting helps provides cash flow).
- Forest silvicultural practices.

It is difficult to estimate what volume of Australian native forest and plantation hardwood resources might be available and suitable for a rotary veneering industry using spindleless lathe technology. This is mainly because apart from New South Wales, no other state or territory has developed log specifications specifically designed for spindleless lathe processing. There is currently only one spindleless lathe commercial operation in Australia which is located in northern New South Wales and the log specifications adopted by this operation may not be applicable to other species and other states. Most peeler logs in Australia are sold using specifications designed for traditional lathe types such as spindled and hybrid systems. Spindleless lathes can use a smaller diameter and lower log quality specification compared to these other lathe options. A very large range of spindleless lathe equipment options now exist and ideal log specifications may vary depending upon the system adopted. Technically, spindleless lathe equipment options are available that could process logs from as small as 4 cm and up to 80 cm in diameter. However, the ideal log size range for economic viability will be narrower. Log specifications for spindleless lathe processing will need to be developed that suit the fundamental wood properties and characteristics of the different forest resources and that satisfy market requirements.

Most existing native forest inventory data for Australia is based on resource assessments that collect information for traditional products such as sawlogs, poles, girders and pulp logs. There is inadequate or no inventory data on log volumes specifically suited for spindleless lathe veneer processing. Further detailed inventory work is required. It is difficult for forest authorities in each state and territory to estimate log volumes potentially available and suitable for spindleless lathe processing without reliable log specifications, established markets and adequate inventory data.

There are many competing product choices for Australian forest resources and availability of logs for spindleless lathe processing will depend on market and economic factors. There are also existing supply agreements that could restrict supply for alternative uses. However, if the conversion of logs using spindleless lathes is proven to be more profitable than other processing options, processors might choose to divert logs currently destined for sawlogs and other products to a peeler processing operation.

Government policies concerning native forest log supply can have a major influence on log volumes available. In most states across Australia, there have been dramatic reductions over time in the volumes of logs being made available from public native forests. The main reason has been increased conservation of forests for non-wood values. As this trend is expected to continue, it is likely that private native forest will become a more important resource of logs, especially hardwoods. In the long term, this could be the major resource of small-diameter peeler log supply from native forests.

However, a major limitation in log supply and productivity from private native forests in Australia is the general lack of adequate forest management and silviculture treatment of the forest for high-quality wood production. Many of Australia's private native forests are over-stocked. One of the main reasons that they are not being thinned is the lack of viable markets for any thinnings. The use of small-diameter peeler logs resulting from thinning operations for spindleless lathe processing could be an ideal solution to this problem.

Spindleless lathe operations could potentially draw logs from a number of forest resources including plantation hardwood and pine. This could help to augment supply from native forest and improve the overall viability of such operations. The vast majority of hardwood plantations in Australia are being managed to produce pulpwood. However, this does not preclude utilisation of a certain component of this resource as peeler logs. Future peeling operations do not just need to be limited to sawlog or traditional peeler log qualities. In China and other countries in Asia, very small logs, similar in quality to pulp logs from Australian hardwood plantations, are being successfully converted into veneer products using spindleless lathes. Considerable volumes of hardwood logs from Australia's native forests and plantations are also currently being exported for peeling overseas. Research studies have shown that the mechanical properties of rotary veneers recovered from young Australian plantation hardwoods are generally suitable for the manufacture of structural engineered wood products (McGavin *et al*. 2014a and b; McGavin *et al*. 2015a and b). No detailed assessments have been undertaken to determine how much of the current and forecasted pulp log and sawlog production from hardwood plantations in Australia might be available and suitable for spindleless lathe processing.

The field case studies undertaken in Queensland demonstrated that substantial volumes of logs that meet the small-diameter peeler log specifications adopted for this project are potentially available from native forests. However, in the case of hardwood, most of this volume is currently left standing in the forest for the following reasons:

- Part of the future growing stock for the next and subsequent selective harvesting events.
- Current lack of 'demonstrated' viable markets for this log size and quality.
- Current tree marking, harvesting and sale practices focusing on mainstream larger log size products such as compulsory sawlogs, poles and girders.
- Code of Practice and other regulations.

Current native hardwood forest sales in Australia are mainly for products such as sawlogs, pulp logs, poles, girders, landscaping and fencing because of existing market demand. It is possible that if there was a demand for small-diameter peeler logs there may be a shift in tree marking and harvesting procedures to facilitate the supply of small-diameter peeler logs. This would need to consider economic viability for processors and forest managers.

Figure 7.1. Field assessments in Gurulmundi State Forest

Figure 7.2. Private native forest plot at the Ironpot property

Processing approaches

Processing options for small-diameter native forest resources that target higher value end-products are limited. For this reason, the market for this log resource has been relatively small and largely restricted to sawlogs. In addition, low volume and product recoveries experienced when sawing small-diameter logs into marketable product dimensions also contributes to the low demand and low value of these logs.

The alternative processing approach is through the use of new emerging spindleless veneer processing technology. Earlier research with plantation grown hardwood logs concluded that recoveries using a spindleless lathe were much higher than that achieved by traditional sawing methods (McGavin *et al*. 2014a and b; McGavin *et al*. 2015a and b). This processing approach has several key advantages. Without the reliance on spindles (as used in more traditional veneer processing technologies) to hold the billet in position during the peeling process, veneer is able to be recovered from logs down to quite small peeler cores (around 40 mm). The small peeler core size also means that billets with smaller starting diameters can be successfully peeled. Forest resources more prone to end-splitting can be peeled with a reduced risk of the splits worsening during peeling. In fact, unlike spindles that force the splits further apart, the drive mechanism on a spindleless lathe effectively presses the splits together during peeling. For these reasons, spindleless lathes have been adopted mostly where there is a large supply of small diameter and sub-optimum quality billets (i.e. from young, fast-grown hardwood plantations) (Leggate *et al.* 2017).

As part of the *Increasing the value of forest resources through the development of advanced engineered wood products* project, a processing study was conducted evaluating the performance of spindleless veneering technology for processing small-diameter logs sourced from native forests. The study also directly compared the recovery of product from veneer processing with product recoveries from a modern 'small log' sawing line. A summary of the key finding as reported in Chapter 4 are detailed below:

Two native forest tree species were included in the study: spotted gum *(Corymbia citriodora* subsp. *varigata)* and white cypress pine *(Callitris glaucophylla).* These species were selected as they are the dominant hardwood and softwood species harvested from native forests for timber products in Queensland, Australia.

The spotted gum logs were selected during a commercial harvesting operation within the Gurulmundi State Forest, located in south-west Queensland. For the study, 2.7 m long logs were chosen that contained small-end diameters under bark (SEDUB) within three target groups (target diameters of 19 cm, 24 cm and 28 cm). Due to physical restrictions with processing equipment at the commercial sawmill, the minimum SEDUB was set at 18 cm. Where possible, logs for the study were cut from within trees harvested as part of the commercial harvest.

The white cypress pine logs were sourced from within full-length logs in the log yard of a commercial sawmill (original sourced from Barakula State Forest). In Queensland, it is common practice for harvested white cypress pine trees to be docked to 16 cm SEDUB (unless defects necessitate cutting at a larger small-end diameter) and the full-length logs are delivered to the sawmill where they are further cut into more desirable logs lengths in preparation for sawmilling. Similar to the spotted gum logs, 2.7 m long logs were chosen that contained SEDUB within three target groups (target diameters of 16 cm, 22 cm and 28 cm). The minimum SEDUB was set lower for the white cypress pine logs at 16 cm SEDUB to align with the current commercial sawlog criteria for this species.

Sawing was undertaken in commercial sawmills while the veneering was undertaken in Australia's only commercial operation using spindleless lathe technology. The study demonstrated that processing small-diameter logs from native forests into rotary veneer using spindleless lathe technology can yield higher recoveries compared to using traditional solid wood processing techniques. This processing method also produced a more consistent recovery result across the range of log sizes included in the study. For spotted gum, processing small-diameter logs into dried and graded rotary veneer recovered twice the volume of saleable product compared to the same log quality sawn into flooring type products (43-46% versus 15-22%). The recovery benefits were not as great for white cypress pine as the larger dimension sawn boards aided in achieving a higher recovery compared to the spotted gum and product grading was limited. Comparable dried and finished product grading was not undertaken as part of the study for white cypress pine however, this would be expected to further improve the comparative performance of veneer processing.

For both species, the graded veneer recovery was dominated by D-grade veneer. While D-grade is the lowest visual grade quality for structural veneer, the veneers are suitable for face veneers on non-appearance structural panels as well as the core veneers for the vast majority of appearance and non-appearance structural panels. The low recovery of higher grade veneers (C-grade and better) may make the commercial production of structural panel products challenging (because of insufficient quantities of face veneer) if a processor were relying solely on this grade of resource. However, the blending of veneers from small-diameter logs with higher appearance grade veneer, potentially from larger diameter logs from the same forest type, may produce a suitable mix for a range of composite end-products. In addition, white cypress pine veneer has no commercial history and therefore the willingness for the market to accept the range of natural characteristics present with this species is untested. The presence of some natural characteristics may indeed provide a marketing advantage for this species.

There was a relatively narrow variation of veneer properties within species. This is an advantage for industry as sorting and segregation systems can be simplified compared to the management of more variable resources. The spotted gum logs produced veneer with very high stiffness properties. Eight-five percent of the sampled veneer contained a modulus of elasticity above 19,000 MPa and 25% above 25,000 MPa. Stiffness properties in this range could be a key marketing asset for this resource and would support its use in high performance structural products. The white cypress pine veneer had inferior mechanical properties compared with the spotted gum; however, the properties are suitable for structural applications.

While the study demonstrated that rotary veneer processing can be a more efficient processing system to convert small-diameter native forest logs compared to sawing (see Chapter 4), it was noted that the identification of veneer-based engineered wood products with connected market demand are critical to further encourage industry to consider the adoption of this approach.

Figure 7.3. Spotted gum logs being allocated into diameter classes and processing facility (sawmill or peeler)

Figure 7.4. Spotted gum logs being sawn

Figure 7.5. White cypress pine veneers being clipped and stacked

Market assessment

One of the key objectives of the *Increasing the value of forest resources through the development of advanced engineered wood products* project is to investigate the technical feasibility of using rotary-veneer produced from 'sub-optimal quality' native forest logs in combination with other wood-based feedstocks (blended resources to enhance product performance and marketability) to manufacture high performance 'next generation' engineered wood products (EWPs), suitable for structural and appearance applications (this could include mixed species EWPs such as hybrid hardwood and softwood combinations and also combinations of veneer, sawn and other feedstocks).

One of the major benefits of physically engineering wood products, is that feedstock materials with a wider range of wood properties can be accommodated, and high performing products can be manufactured for both structural and appearance applications. Engineered wood products manufactured from plantation softwood feedstocks are well accepted and widely used in the residential construction market. It is anticipated that in the new emerging Class 2-9 markets, such as: multi-residential apartments, hotels, office, and public building applications (i.e. schools and healthcare buildings), there will be increased market opportunities for higher performing and stronger wood based EWPs. Wood feedstocks sourced from sub-optimal quality logs sourced from Australia's native forests could play a key role in lifting the performance of some EWPs through improved structural performance, natural durability and aesthetic qualities.

To provide an insight into possible products and markets that the project may target during dedicated product development activities, Chapter 5 detailed:

- A description of the different structural engineered wood products currently being produced globally, their current use in Australia, and suggestions for their potential for further investigation under this project in terms of possible manufacture utilising a sub-optimal forest resource feedstock.
- A description of the new non-residential market opportunities particularly: Class 2 (apartments), Class 3 (hotels), Class 5 (office) and Class 9 (schools, hospital), type buildings and the requirements of these building Classes, compared with traditional Class 1 (residential) construction that potentially provide a market opportunity for higher performing EWPs. Key design issues here include: higher design live loads and

dead loads (due to the additional materials required to meet fire and acoustic requirements), fire related concessions for stairs that favour higher density hardwood products, improved fire performance of large dimension hardwood based beams & columns and wall panels, consideration of crushing effects on timber elements in 5-8 storey midrise buildings due the increased applied loads. This description provided some additional detail and understanding regarding possible new non-residential market opportunities.

- A brief summary of a selection of potentially new high performance EWP opportunities for further consideration which included:
    - Hardwood or hardwood and softwood blended Laminated Veneer Lumber (HLVL).
    - Cross-banded hardwood or softwood blended hardwood Laminated Veneer Lumber (X-HLVL).
    - Appearance-faced hardwood or hardwood and softwood blended Laminated Veneer Lumber.
    - Large dimensioned structural HLVL timber beams and columns.
    - Oriented Strand Board (OSB).
    - Mass hardwood-CLT (HCLT) panels fabricated from HLVL feedstock.
    - Mass hardwood or hardwood and softwood blended veneer based panels for highly vertically loaded structural elements such as rim-beams and mass panel walls.

It was noted from Chapter 5 that the new ‘mid-rise timber’ construction sector provides new market opportunities for a wide range of structural (and appearance) timber products, both sawn and engineered. More specifically, opportunities for higher structural performing EWPs may provide attractive opportunities for many of Australia’s high strength hardwood species; due to the resulting higher structural loads with the increased building heights involved. Figure 7.6 was provided and summarises the different EWP type, by manufacturing process, and possible mid-rise structural market applications.

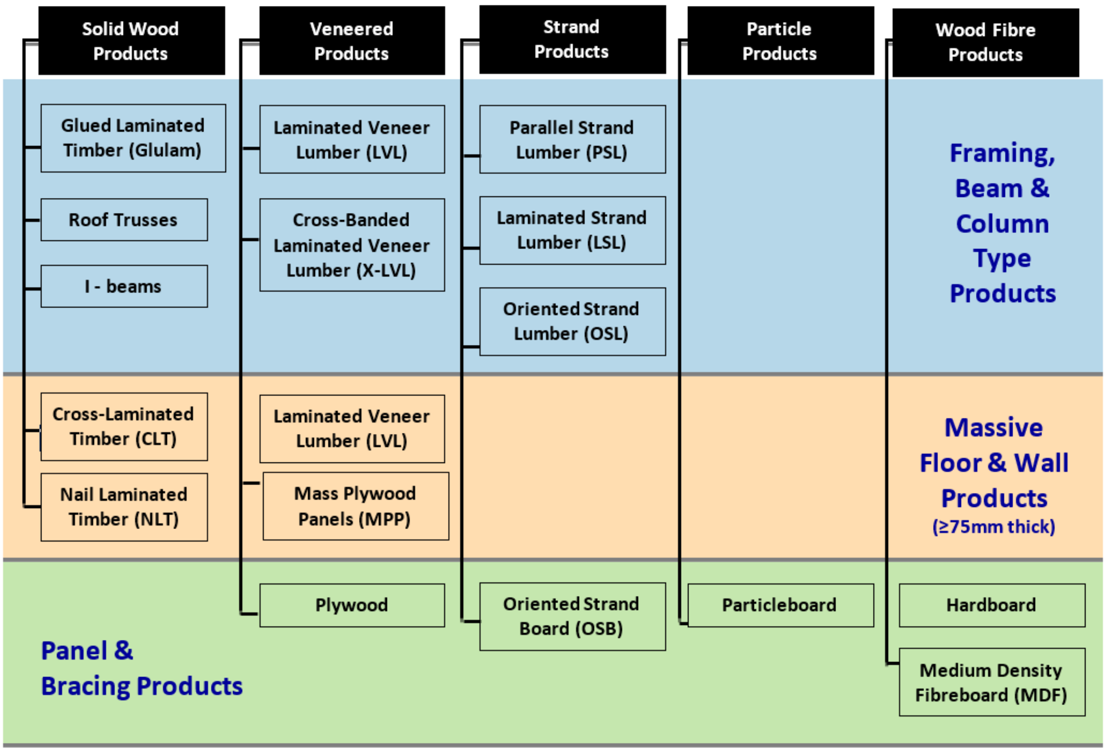

Figure 7.6. Engineered wood products by product type and manufacturing process

‘Best bet’ products selection

A project steering committee has been established to provide guidance and direction throughout the project along with facilitate a mechanism to communicate project developments to industry. The committee consists of the following members:

- Simon Dorries (Chair)– Responsible Wood
- John McNamara – Parkside Group
- Jason Blanch – Big River Group
- Mick Stephens – Timber Queensland
- Andy McNaught – Engineered Wood Products Association of Australasia (EWPAA)
- Scott Matthews – Austral Plywood
- Ian Last – HQ Plantations
- Bob Engwirda – Hurford Wholesale
- Dr Alastair Woodard – Wood Products Victoria
- Dr Tyron Venn – University of Queensland
- Dr Kerrie Catchpoole – Queensland Government
- Dr Rob McGavin – Queensland Government.

One responsibility for the project steering committee was to identify a number of potential ‘best bet’ product(s) taking into account the strengths and weaknesses of the available timber feedstocks, outcomes of the forest assessments, results of the project processing studies and an understanding of potential products and markets. The selected ‘best bet’ products are to be further developed and up-scaled from prototypes, semi-industrial scale and where possible, industrial scale during the latter stages of the project.

To facilitate the selection process, an information collection sheet was provided to each steering committee member present at the May 2017 project meeting. Each member were invited to indicate their level of interest in pursuing the various products (or product groups) that had been identified through the market assessment or tabled and discussed during the meeting. Table 7.1 provides a summary of the collected data.

Table 7.1. Summary of steering committee's interest in further developing products

Product	**Level of Interest**		
	High	**Medium**	**Low**
• ***Hardwood-LVL or Plywood Floor Slabs***	6	1	0
• ***Hardwood-LVL or Blended Hardwood/Softwood LVL Framing Elements:(beams & studs)***	5	3	0
• ***Mass Plywood Panels (MPP's)***	5	1	1
• *High Density-faced LVL for Fire Performance Improvement*	4	3	1
• *Heavy HLVL timber beams and columns*	4	2	1
• *Cross-banded Hardwood-LVL (X-HLVL) or Blended Hardwood / Softwood LVL*	3	4	1
• *Hardwood-LVL in high compression parallel to grain loading situations (for lightweight construction and / or use in massive LVL wall panels)*	3	3	1
• *Massive Composite Hardwood-CLT (CHCLT) made from HLVL*	3	2	2
• *Appearance-faced Hardwood-LVL or Blended Hardwood/Softwood LVL*	2	4	2
• *Stress-skinned floor panel*	2	0	4
• *Hardwood Oriented Strand Board (OSB)*	1	2	3
• *Engineered Floor (cypress)*	1	1	5
• *Large Section Veneer-based elements*	0	1	4

The information gathered identified several key product areas. The dominant product groups included laminated veneer lumber (LVL) based products and mass-panels. Laminated veneer lumber is a solid wood substitute manufactured from rotary-peeled veneers adhered in layers (usually all parallel) to form a beam. This product group has made inroads to many markets as a substitute for sawn timber or steel in load carrying beam applications (Leggate *et al.* 2017).

Mass wood panels are emerging as a popular engineered wood product choice for the construction of medium to tall timber buildings. The most common type of mass wood panel is cross-laminated timber (CLT) made using sawn timber feedstock. Veneer-based mass panels provide an alternative to CLT and potentially offer superior mechanical properties and more efficient use of the forest resources (Leggate *et al.* 2017a). Recognising a significant research project being led by Queensland Department of Agriculture and Fisheries (DAF) on the manufacturing of mass panel systems (including veneer-based mass panels), was scheduled to commence within the newly formed Centre of Future Timber Structures, the committee agreed to avoid duplication and minimise efforts with this product group.

The committee agreed that the LVL product group would be the main focus of the product development activities that follow. More specifically, it was agreed to pursue the following LVL product development areas/opportunities:

- Opportunities for superior mechanical performances while blending different forest resources and varying quality feedstocks.
- Opportunities for increased fire performance by strategically using hardwoods in the product construction.
- Opportunities for improved aesthetics (e.g. appearance grade LVL).
- Naturally durable/termite resistant LVL.

These product performance objectives support a range of final product applications and are expected to provide strong guidance and baseline information for the project to further refine product development activities being undertaken in later components of the project.

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Chapter 8: A comparative study on the mechanical properties of laminated veneer lumber (LVL) produced from blending various wood veneers

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Introduction

Australia's native forest resources cover approximately 137 million hectares and constitute about 90% of Australian forests (ABARES 2018). For many years, mainly larger diameter logs from these forests have been transformed using traditional sawmilling technologies, into a range of end-products such as beams, bridge members, flooring, decking, and landscaping timbers. However, despite there being a significant volume of small-diameter native forest logs potentially available to the timber industry from the sustainable management of these forests, these log types have been demonstrated to yield poor recovery rates when processed by traditional sawmilling technology. This has resulted in much of this resource being under-utilised and under-valued, despite the wood properties being well-suited to a range of high-value products (McGavin and Leggate 2019). Recently, spindleless veneering technologies have been demonstrated as capable of efficiently processing small-diameter plantation and native forest logs and hence offering the potential of utilising these resource types for veneer-based products, such as laminated veneer lumber (LVL) (McGavin 2016; McGavin and Leggate 2019).

An appropriate commercialisation pathway for rotary veneer produced from small-diameter native forest resources may be through blending with existing commercial plantation softwood resources. Blending may support efficient use the spread of veneer qualities while enabling high-value and high-performance LVL to be manufactured for structural applications. Blending resources in product manufacture has been identified in previous research as advantageous as these products possess apparent advantages in comparison to traditional sawn products, including increased product performances, efficient resource utilisation and compatibility with modern building systems (Burdurlu *et al*. 2007; Keskin 2004; Kilic and Celebi 2006; Kilic *et al.* 2012; Xue and Hu 2012). More importantly, these product types allow the increased use of lower cost, low-grade and low-density wood veneers as core veneers in mixed-species LVL products in order to not only reduce product cost (Burdurlu *et al.* 2007; Keskin and Musa 2005; Wang and Dai 2013; Xue and Hu 2012) but also increase the mechanical properties of predominately low-density wood LVL (Bal 2016; H'ng *et al.* 2010; Wong *et al.* 1996; Xue and Hu 2012).

According to Wong *et al.* (1996), it was possible to increase the use of low-grade wood veneers from fast-growing trees such as rubberwood (*Hevea brasiliensis*) into high-performance products by processing them into mixed-species structural LVL with higher quality mangium (*Acacia mangium*) veneers. The study showed that the mechanical properties of rubberwood LVL can increase up to 13% in the modulus of elasticity (MOE) and 12% in the modulus of rupture (MOR) by positioning mangium veneers in the surface or face layers. Another study on manufacturing 7-ply LVL in 8 different lay-up strategies that blended higher-density Austrian pine (*Pinus nigra*) veneers and lower-density lombardy poplar (*Populus nigra*) veneers was conducted by Kilic *et al.* (2010). Results showed that as the ratio of Austrian pine veneers increased in mixed-species LVLs, the MOR and MOE increased up to 40% and 69% on average, compared to LVL manufactured of only Lombardy poplar.

A study reported by Burdurlu *et al.* (2007), in which the MOE and MOR of LVL manufactured from beech (*Fagus orientalis L.*) and lombardy poplar (*Populus nigra L.*) veneers were investigated through eight different lay-up strategies, showed that (i) increasing the proportion of high-density beech veneers led to an increase in the MOE and MOR; (ii) the flatwise MOE and MOR of LVL with two beech veneers on each of the outer layers were observed to be 49% and 27% higher on average in comparison with LVL manufactured from poplar alone. The results were consistent with the study conducted by Xue and Hu (2012) which considered 10-ply LVL manufactured from poplar (*Populus ussuriensis* Kom.*)* as core layers, and birch (*Betula platyphylla* Suk.) as outer layers. The authors also reported that the bending strength of LVL with high strength birch veneers on the outer layers was much greater than LVL with low strength poplar veneers on the surface layers.

Although manufacturing LVL from blending different wood species has been advanced in some countries, the opportunities for adopting this approach in Australia are not well understood. The key objectives of this study are to examine the structural performance of LVL products manufactured from rotary veneers recovered from small-diameter selected Australian native forest timber species and an Australian commercial plantation grown softwood, and various blends of veneers from these species.

Methodology

Rotary veneers

Spotted gum (*Corymbia citriodora*, SPG), white cypress pine (*Callitris glaucophylla*, CYP) and hoop pine (*Araucaria cunninghamii*, HP) were selected in the study. The spotted gum and white cypress pine veneers were sourced from the small-diameter log processing trials previously undertaken and reported by McGavin and Leggate (2019), and represent two different resources commercially available to the timber industry from Australia's native forests. These species represent a high-density, durable hardwood (SPG) and a mid-density, durable softwood (CYP). The processing was completed using a spindleless rotary veneer lathe targeting a nominal dried veneer thickness of 3.0 mm. The hoop pine veneers were recovered from approximately eight logs peeled by a commercial veneer producer during standard commercial operations and also targeted a nominal dried veneer thickness of 3.0 mm.

Veneer properties

To evaluate the distribution of the dynamic properties; such as the elastic modulus parallel to the grain direction (E_{L_Veneer}), the acoustic properties of the SPG, CYP and HP veneers were measured using a non-destructive grading device (Brancheriau and Baillères 2002) on sample strips (approximately 1200mm × 200mm) removed from a subset of recovered veneers, as reported by McGavin and Leggate (2019). Sample strips were positioned on elastic supports and a simple percussion was then induced in the direction of the grain at one end of the sample, while at the other end, a Lavalier type microphone recorded the vibrations before transmitting the signal via an anti-aliasing filter (low-pass) to an acquisition card that included an analog-to-digital converter to provide a digitized signal (Figure 8.1). A Fast Fourier Transform processed the signal to convert the information from the time to the frequency domain. The mathematical processing of selected frequencies was undertaken using BING (Beam Identification using Non-destructive Grading) software in combination with the geometrical characteristics and the weight of the specimen, to provide the dynamic MOE, among other specific mechanical characteristics (CIRAD 2018).

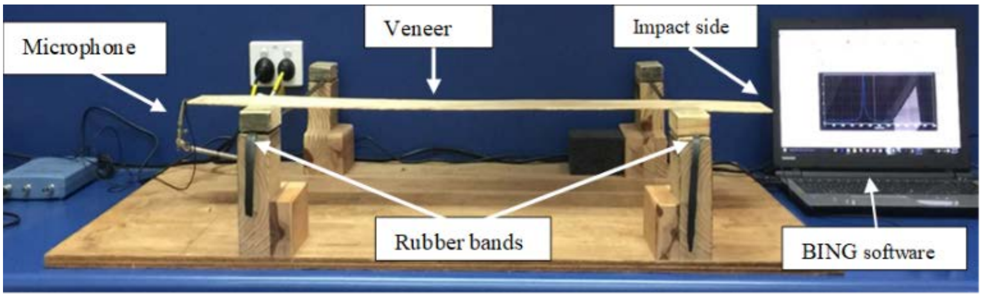


Figure 8.1. Experimental setup for the acoustic properties testing

Veneer grading

The veneer quality was assessed by visual grading in accordance with AS/NZS 2269.0:2012 (2012). This standard is widely used across the Australian veneer industry and follows the same principles as other international veneer visual grading classification systems. The standard separates structural veneers into four veneer surface grades with each grade corresponding to a quality group in accordance with the standard. The grading was based on visual characteristics of the veneers such as splits, various knot types and roughness.

Target LVL construction strategies

Six different LVL construction or lay-up strategies were implemented to manufacture 12-ply LVL from the three species to demonstrate the impact of construction strategies on manufactured product mechanical properties. They comprised of three single-species reference LVLs and three blended-species LVLs (Figure 8.2). The construction strategies are outlined below, with the veneer selection process explained in the following section:

- LVL1 - 12 CYP veneers throughout the panel thickness;
- LVL2 - 12 HP veneers throughout the panel thickness;
- LVL3 - 12 SPG veneers throughout the panel thickness;
- LVL4 - SPG veneers on the outside faces and 10 HP veneers for the internal core;
- LVL5 - alternating SPG and HP veneers with SPG veneers on the outside faces; and
- LVL6 - alternating CYP and HP veneers with CYP veneers on the outside faces.

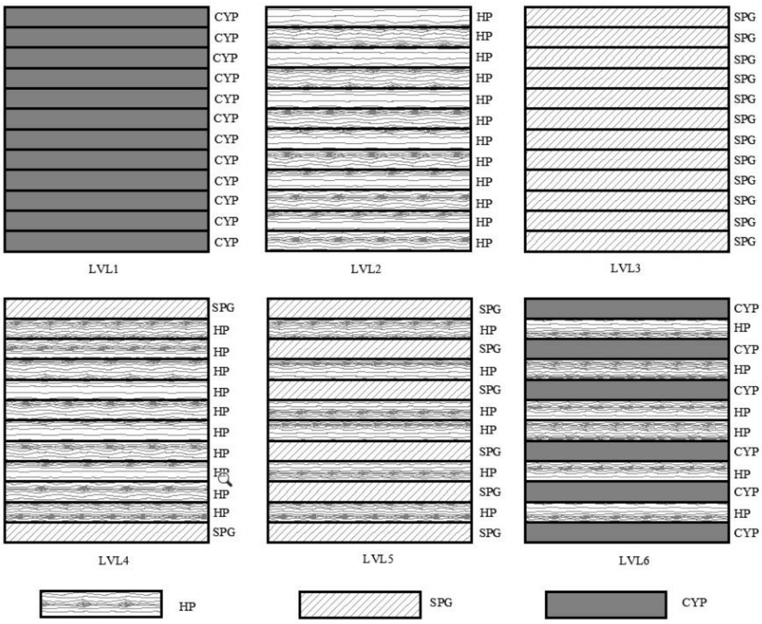


Figure 8.2. LVL panel construction lay-up types

Veneer selection and allocation

The strategy to select individual veneers from the available stocks and their placement within the LVL panels had the following main objectives:

- To minimise the within-species veneer MOE variation for veneers included in the LVL panel manufacture.
- To target 'average' structural quality veneers (*i.e.* veneers with MOEs that are similar to the mean veneer MOE of the available stocks of each specie).
- To ensure individual veneers are in the optimum position within the allocated panel to maximise the panel mechanical properties (*i.e.* biasing higher MOE veneers towards the outer layers of the LVL panels).
- To minimise the within-species variation between LVL panels of the same construction type.

Veneer selection and placement followed these steps:

1. From the available veneers of the three species, those veneers that did not achieve a visual grade of D-grade or better were discarded. For the remaining veneer sheets, the mean dynamic MOE of the veneer population was calculated and used to guide veneer selection.
2. Veneers within each population were sorted by their MOE in descending order.
3. The required subset of each species (the number of veneers required from each species to manufacture the required LVL panels including contingency veneers) were taken as a series of consecutive veneers to minimise MOE variation. Then, the mean dynamic MOE (as per Step 1) was calculated for each possible subset.
4. The subset of veneer that had a mean MOE closest to the entire population MOE mean were selected for panel manufacture.
5. The veneers from each subset were systematically distributed among the final panels of each construction type. Veneers were distributed, in order of decreasing MOE, commencing with the outer layers of all panels and progressing to the core. This ensured that veneers were optimally located from a structural perspective with higher MOE veneers located towards the panel periphery, and that consistency was achieved across the panels of the same construction type. Once all the veneers were assigned, the statistics for the desired combinations of panels and positions were reviewed to ensure the objectives were achieved.

LVL panel manufacturing

A total of 18 LVL panels (approximately 1200 mm × 1200 mm × 36 mm) were manufactured with three panels for each construction type. A melamine urea formaldehyde adhesive was selected, aiming at achieving a B-bond glue line, the service conditions for which are outlined in Australian Standard AS/NZS 2754.1 (2016).

The adhesive was applied to each face of the veneers targeting a total spread rate of 400 gsm (grams per square metre) per glue line. The assembly stage included an open assembly time of approximately 22 minutes (measured from adhesive application to the first veneer to when pressure was applied in the press). Pre-pressing was undertaken at 1 MPa for a duration of 8 minutes. At the completion of pre-pressing, the panels were transferred to the hot press and pressed at 1.1 MPa, for a duration of 26 minutes, and at 135°C.

Test samples and mechanical properties test method

Figure 8.3 illustrates the LVL panel cutting pattern and test sample locations. Six samples per construction lay-up type (*i.e.* 2 samples per panel) were cut from each panel to experimentally evaluate their (1) static edgewise bending MOE (E_{b_e}), (2) static flatwise bending MOE (E_{b_f}), (3) edgewise bending MOR (f_{b_e}), (4) flatwise bending MOR (f_{b_f}), (5) longitudinal-tangential shear strengths (f_s), and (6) bearing strength perpendicular to grain strength ($f_{c\_\perp}$). For tension perpendicular to grain ($f_{t\_\perp}$), nine samples per construction lay-up type (*i.e.* 3 samples per panel) were tested. After the test samples were removed from the LVL panels, they were conditioned at 20°C and at a relative humidity of 65% in accordance with Australian Standard AS/NZS 4357.2 (2006) targeting a sample moisture content of approximately 12%.

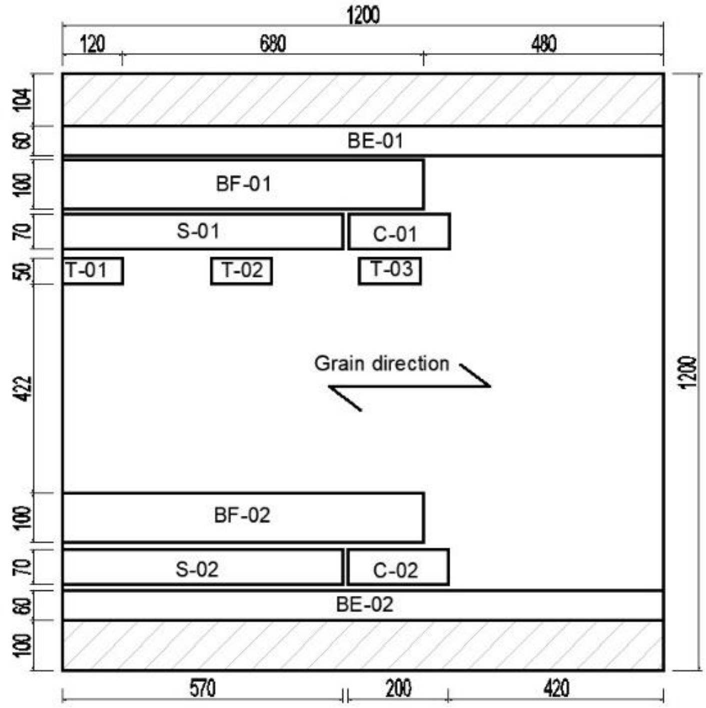


Figure 8.3. The cutting pattern for the LVL for property tests
Note: BE – edgewise bending tests, BF – flatwise bending tests, S – longitudinal-tangential shear bending tests, C – compression perpendicular to the grain tests, T – tension perpendicular to the grain tests.

All testing was undertaken within the NATA accredited test laboratory at the Department of Agriculture and Fisheries' Salisbury Research Facility or testing laboratory at Griffith University. The testing methodology for each test are described in Nguyen *et al.* (in press) and summarised as below:

(i) Static bending was tested following the Australian standard AS/NZS 4357.2 (2006) using a four-point bending test configuration. From each panel, two 60 mm (height) × 1,200 mm (long) samples were tested in the edgewise bending and two 100 mm (wide) × 800 mm (long) samples were tested in flatwise bending. A 100 kN Shimadzu Universal Testing Machine (AG-100X) was used with a constant load application rate of 5 mm/min, so that failure was achieved within 3 to 5 minutes as per the standards specifications (Figure 8.4).

(ii) Bearing strength perpendicular to the grain was measured using the bearing strength test method from Australian Standard AS/NZS 4063.1:2010 (2010) on 70 mm (height) × 200 mm (long) test samples. A 100 kN Shimadzu Universal Testing Machine was used and the load was applied at a constant rate of 1.0 mm/min so that failure was achieved within 2 to 5 minutes and therefore tested in accordance with the standard (Figure 8.5).

(iii) The tensile strength perpendicular to the grain was measured following the configuration in the ASTM D143-14 (2014) which was devised for solid timber specimens. The procedure has been previously applied to LVL samples and proven successful (Ardalany et al. 2011; Gilbert et al. 2018). The samples were inserted into an aluminium jig as demonstrated in Figure 8.6b. The jig was gripped in the jaw of a 30 kN capacity Lloyd universal testing machine which ran in displacement control at a stroke rate of 2.5 mm/min so that failure was achieved within 1 to 3 minutes.

(iv) Longitudinal-tangential shear strength testing was undertaken following the Australian Standard AS/NZS 4063.1 (2010). In this method, a three-point bending test configuration was used as illustrated in Figure 8.7. The stroke rate was set to ensure failure was achieved within 2 to 5 minutes, as specified by the standard. Two 70 mm (height) x 570 mm (long) samples were cut per panel for testing.

Figure 8.4. Testing configuration for flatwise (left) and edgewise bending (right)

Figure 8.5. Testing configuration for bearing strength perpendicular to the grain

(a) (b)

Figure 8.6. Testing configuration for tensile strength perpendicular to the grain

Figure 8.7. Testing configuration for longitudinal shear strength

Results and discussion

Veneer properties and selection

The veneer population statistics for each species are shown in Table 8.1, and the statistics of the selected subset of veneers for the LVL panel manufacture are presented in Table 8.2. The SPG yielded much higher veneer stiffness with over 85% of the veneers exceeding the maximum MOE recorded for HP. This highlights the opportunities to use SPG and other high-density Australian hardwoods to manufacture veneer-based products, such as LVL, to achieve structural performances superior to that possible from plantation softwood resources. The CYP recorded a lower average MOE (8,998 MPa) compared to HP (12,169 MPa) and the SPG (22,437 MPa).

Table 8.1. Veneer population statistics

	Spotted gum	White cypress pine	Hoop pine
Veneer count	127	91	246
Average MOE (MPa)	22,437	8,998	12,169
Std. Dev. MOE (MPa)	3,541	1,509	2,338
Coeff. Of Variation (%)	15.8%	16.8%	19.2%
Min MOE (MPa)	13,407	6,070	4,655
Max MOE (MPa)	29,679	11,813	18,716

Table 8.2. Veneer subset statistics

	Spotted gum	White cypress pine	Hoop pine
Veneer count	70	63	119
Average MOE (MPa)	22,449	9,015	12,174
Std. Dev. MOE (MPa)	1,724	964	779
Coeff. Of Variation (%)	7.7%	10.7%	6.4%
Min MOE (MPa)	19,955	7,513	10,699
Max MOE (MPa)	25,684	11,014	13,485

Comparative statistics for veneers allocated to each LVL panel are shown in Table 8.3.

Table 8.3. Panel statistics for each investigated construction lay-up

Construction lay-up	Panel	Average Veneer MOE (MPa)	Std. Dev. MOE (MPa)	Coeff. Of Variation (%)	Min. Veneer MOE (MPa)	Max. Veneer MOE (MPa)
LVL1 (CYP)	1	9,428	1,845	19.6%	6,435	11,604
	2	9,380	1,356	14.5%	7,292	11,479
	3	9,405	1,697	18.0%	6,948	11,628
LVL2 (HP)	1	12,364	993	8.0%	11,037	14,457
	2	12,842	1,310	10.2%	11,030	15,079
	3	12,275	826	6.7%	10,955	13,454
LVL3 (SPG)	1	22,378	2,352	10.5%	19,918	26,885
	2	22,536	2,750	12.2%	19,579	26,558
	3	23,014	2,232	9.7%	20,229	26,546
LVL4 (SPG face & HP core)	1	13,953	4,949	35.5%	8,966	26,280
	2	13,854	4,833	34.9%	8,997	25,684
	3	13,929	4,429	31.8%	8,455	24,298
LVL5 (SPG & HP alternate)	1	17,616	5,458	31.0%	10,936	24,134
	2	17,580	5,666	32.2%	8,889	24,679
	3	17,666	4,968	28.1%	11,496	23,493
LVL6 (CYP & HP alternate)	1	11,000	2,234	20.3%	7,888	16,095
	2	11,046	2,494	22.6%	8,031	16,271
	3	10,912	2,013	18.4%	8,091	13,683

Mechanical properties testing

Table 8.4 provides the test results of MOE and MOR in both flatwise and edgewise bending, tension strength, bearing strength and shear strength for the six different LVL construction lay-up types. The results show relatively narrow variation within the construction lay-up types which is reflective of the veneer selection and positioning strategies adopted during the LVL panel manufacture. There was, however, wide variation between the six LVL constructions which highlights the substantial differences between fundamental wood properties of the species included.

Table 8.4. Mechanical properties of mixed-species LVL

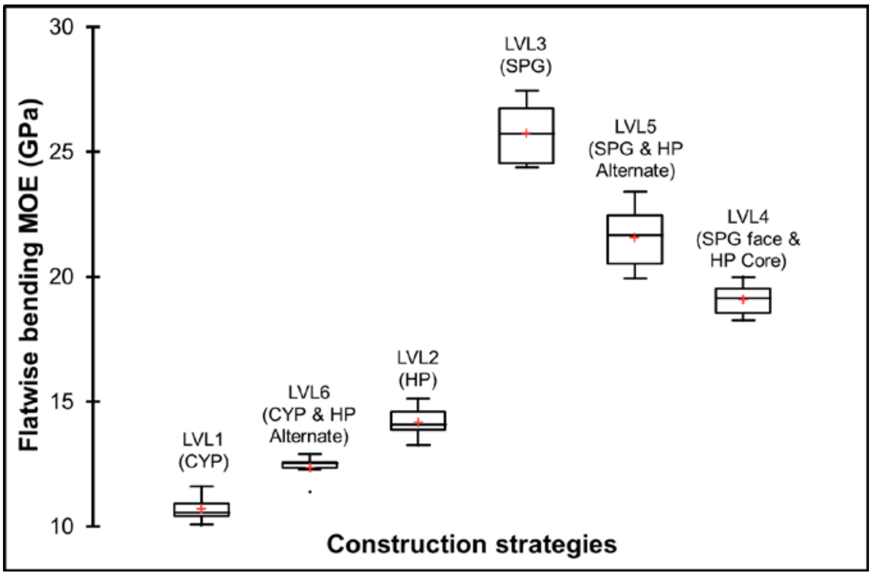
Type	Panel	Flatwise bending		Edgewise bending		Tension strength ($f_{t\_\perp}$) (MPa)	Bearing strength ($f_{c\_\perp}$) (MPa)	Shear strength (f_s) (MPa)
		MOE (E_{b_e}) (GPa)	MOR (f_{b_e}) (MPa)	MOE (E_{b_f}) (GPa)	MOR (f_{b_e}) (MPa)			
LVL1 (CYP)	1	11.1	60.7	10.2	55.5	2.01	29.7	6.0#
	2	10.3	50.1	9.7	48.7	1.80	30.7	6.4#
	3	10.7	62.7	9.6	44.3	2.16	31.8	5.5#
	Mean	**10.7**	**57.8**	**9.8**	**49.5**	**2.0**	**30.7**	**5.9#**
LVL2 (HP)	1	14.3	72.5	12.0	68.3	2.89	16.0	7.0#
	2	14.2	81.1	12.2	69.4	2.78	16.1	6.5#
	3	14.1	78.3	11.5	62.2	2.38	15.9	5.8#
	Mean	**14.2**	**77.3**	**11.9**	**66.6**	**2.7**	**16.0**	**6.4#**
LVL3 (SPG)	1	25.7	161.8	25.4	143.7	3.65	40.9	14.9#
	2	25.6	139.4	23.4	140.0	3.54	40.9	13.5#
	3	25.9	167.1	22.7	134.2	3.40	40.8	13.9
	Mean	**25.8**	**156.1**	**23.9**	**139.3**	**3.5**	**40.8**	**14.1#**
LVL4 (SPG face & HP core)	1	19.3	110.2	14.2	76.6	2.72	17.7	7.0#
	2	19.2	109.2	12.0	65.0	3.19	17.9	7.3#
	3	18.8	101.8	14.6	83.2	2.67	17.9	7.3#
	Mean	**19.1**	**107.1**	**13.6**	**74.9**	**2.9**	**17.8**	**7.2#**
LVL5 (SPG & HP alternate)	1	21.2	141.1	17.6	100.9	3.56	32.1	10.4#
	2	22.2	141.3	19.3	108.5	3.05	30.4	10.5#
	3	21.4	110.2	17.5	101.3	2.82	29.0	10.6
	Mean	**21.6**	**130.9**	**18.1**	**103.6**	**3.1**	**30.5**	**10.5#**
LVL6 (CYP & HP alternate)	1	12.7	69.1	11.8	66.6	2.78	24.2	4.7#
	2	12.0	70.6	12.1	68.3	2.56	22.9	7.1#
	3	12.5	77.6	11.2	66.7	2.26	24.4	5.2#
	Mean	**12.4**	**72.4**	**11.7**	**67.2**	**2.5**	**23.8**	**5.7#**
# represents failure in bending modes.								

Flatwise bending tests

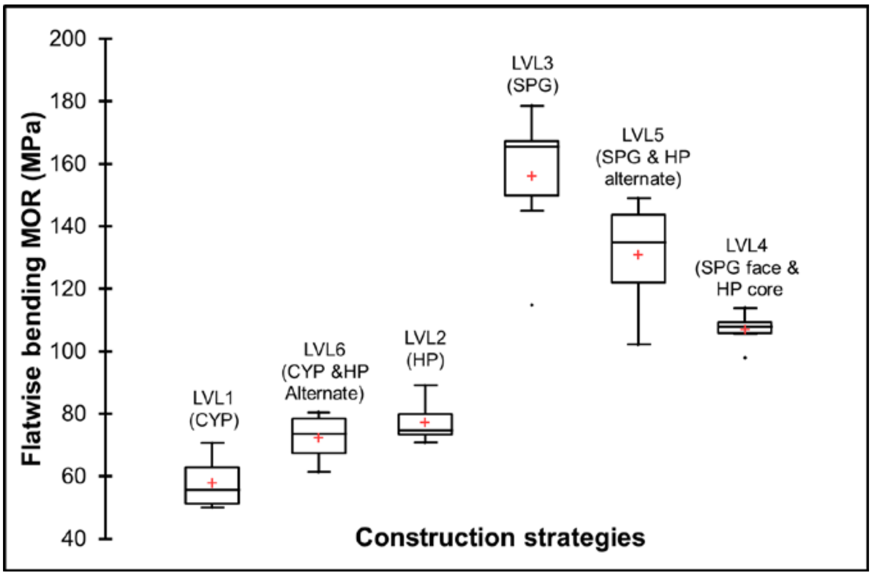
The static flatwise bending test results for the six LVL construction lay-up types are further presented in Figure 8.8. For single species LVL, the construction that utilised all-SPG veneers (LVL3) yielded the highest performance with an average MOE of 25.8 GPa and an average MOR of 156.1 MPa. The all-HP construction (LVL2) had an average MOE of 14.2 GPa and an average MOR of 77.3 MPa. The all-CYP construction (LVL1) provided the lowest test result with an average MOE of 10.7 GPa and an average MOR of 57.8 MPa.

The constructions that utilised a blend of both SPG and HP veneers performed in between and in line with the proportion of the blend. The construction (LVL5) that included an alternate mix of both species (6 SPG and 6 HP veneers) had an average MOE of 21.6 GPa and an average MOR of 130.9 MPa, while the SPG face and HP core construction lay-up type (LVL4) provided a slightly lower average MOE of 19.1 GPa and an average MOR of 107.1 MPa. The construction that alternated CYP veneers with HP veneers (LVL6) performed between the LVL1 (all-CYP) and LVL2 (all-HP) constructions.

Construction lay-up type LVL4 clearly demonstrates that substantial gains in performance can be achieved with the substitution of even a small amount of higher performing veneers when positioned in the optimal location within the LVL cross-section, when tested in the flatwise direction.



(a)



(b)

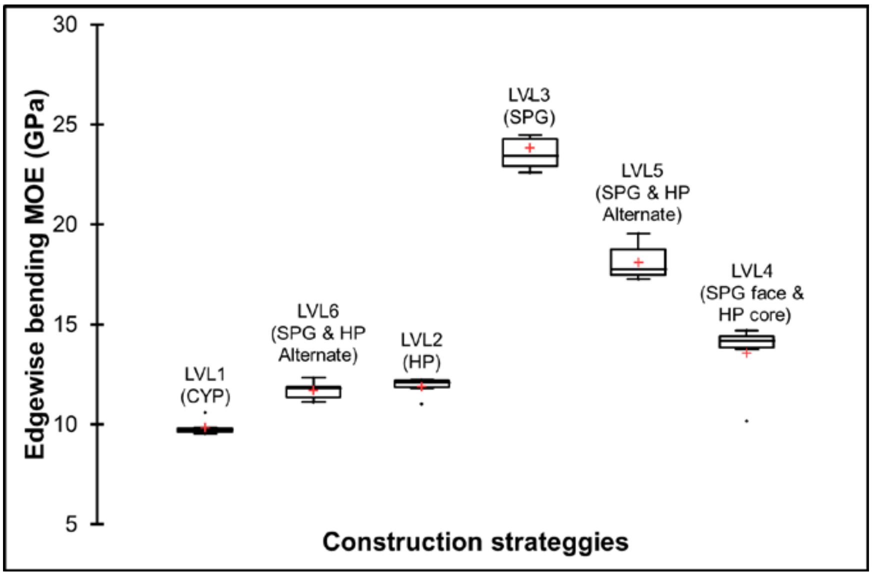
Figure 8.8. Flatwise bending MOE (a), and flatwise bending strength (MOR) (b) per LVL construction lay-up type

Edgewise bending tests

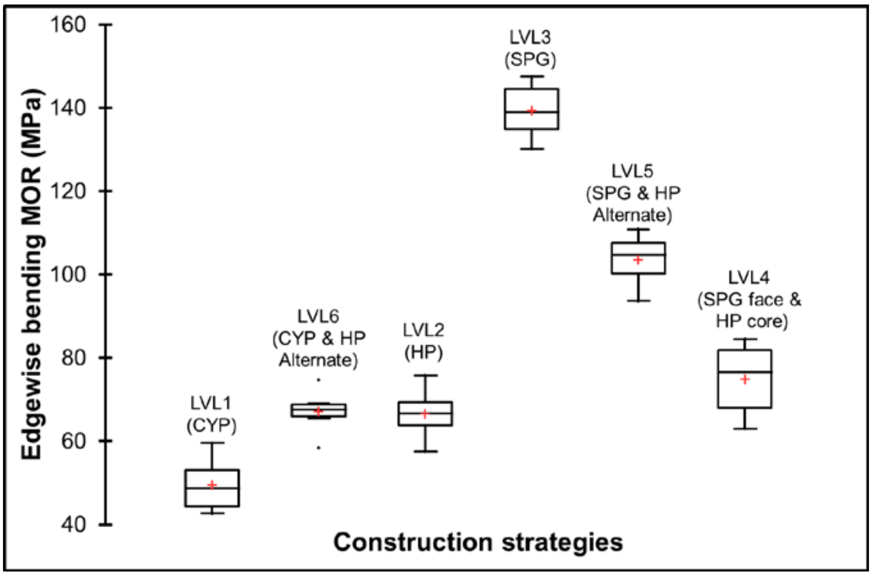
The static edgewise bending test results for the six LVL construction lay-up types are further reported in Figure 8.9. The trend of edgewise bending results between construction lay-up types was similar to the flatwise bending results with the LVL3 (all-SPG) construction providing the highest performance with an average MOE of 23.9 GPa and an average MOR of 139.3 MPa, and the LVL1 (all-CYP) construction provided the lowest performance with an average MOE of 9.8 GPa and an average MOR of 49.5 MPa. The all-HP construction (LVL2) was slightly better than the all-CYP (LVL1) with an average MOE of 11.9 GPa and an average MOR of 66.6 MPa.

The blended constructions performed in between the relevant single species lay-up constructions. Construction lay-up type LVL4 (SPG face and HP core) was found to have higher MOE (up to 34.5%) and higher MOR (up to 38.5%) than the single species HP lay-up (LVL2). However, compared to the single species SPG lay-up (LVL3), the bending properties of LVL4 was up to 43% (MOE) and up to 46% (MOR) lower.

Compared to flatwise bending tests, the performance gains with the blended species construction lay-up types remained, although the gains were not as strong as the flatwise bending tests because the strategic positioning of the higher performing veneers towards the outer laminations had less of an impact when tested in the edgewise direction. Instead, all the veneers within a construction equally contribute to the final beam performance.



(a)



(b)

Figure 8.9. Edgewise bending MOE (a) and edgewise bending strength (MOR) (b) per LVL construction lay-up type

Tensile strength perpendicular to grain

Figure 8.10 further shows the tension strength perpendicular to the grain for all investigated products. The rank of the single-species products was similar to the bending performance in both edgewise and flatwise mode. Particularly, LVL3 construction lay-up type (SPG) displayed the highest average tensile strength of 3.5 MPa followed by the all-HP construction LVL2 with a mean tensile strength of 2.7 MPa. The all-CYP LVL1 had the lowest tensile strength of 2.0 MPa that is partly due to the high proportion of natural defects in the CYP veneers.

The tensile strength of the blended-species constructions performed in between the relevant single species constructions. To illustrate, the tensile strength of the construction LVL5 (six SPG and six HP veneers) was observed to be 15% higher than that of single-species HP LVL2, but 13% lower than that of single-species SPG LVL3.

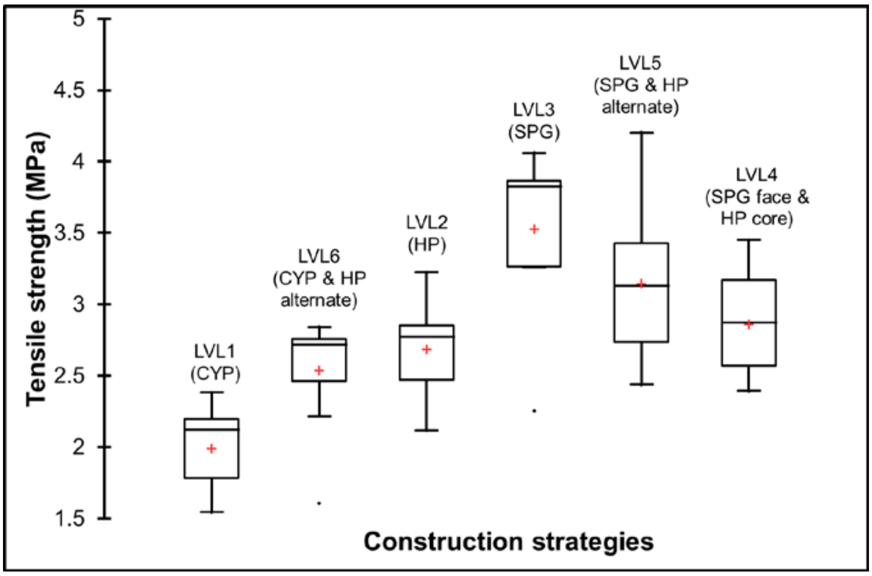


Figure 8.10. Comparison of tension strength perpendicular to the grain for all the investigated products

Bearing strength perpendicular to grain

Figure 8.11 further presents the bearing strength (perpendicular to the grain direction) tests results conducted on the six LVL constructions. Compared to tensile strength, the bearing strength values of all the construction strategies were about 6 to 17 times higher.

The all-SPG LVL3 was again the highest performing construction type achieving a mean bearing strength of 40.8 MPa. The second ranked construction was the all-CYP LVL1 which achieved an average bearing strength of 30.7 MPa, followed by the construction that alternated spotted gum with hoop pine (LVL5) (30.5 MPa).

The all-HP LVL2 achieved the lowest mean result of 16.0 MPa. Minimal gains in bearing strength were observed when positioning SPG on the faces and using HP in the cores (LVL4) compared with the all HP construction (LVL2) with the former achieving a mean bearing strength result of 17.8 MPa.

While the all-CYP LVL1 did not perform well in other mechanical tests, it did perform very well in the bearing strength testing with a mean bearing strength of 30.7 MPa which is approximately two times higher than the bearing strength value of single species HP LVL2. This could be an attractive asset for this species for the manufacture of products that require high bearing strength.

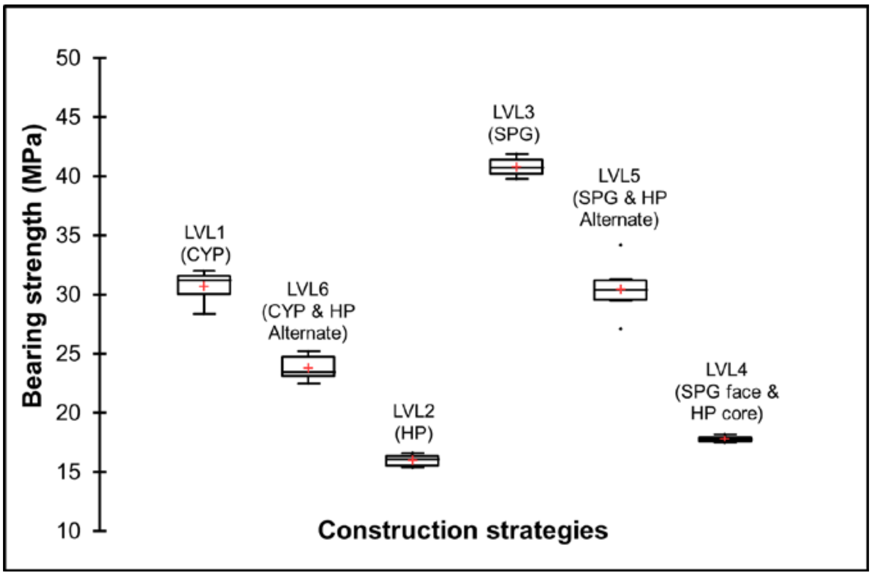


Figure 8.11. Bearing strength perpendicular to grain between investigated products

Longitudinal-tangential shear strength

The shear strength test method adopted has a propensity for inducing failure in bending rather than shear. As a result, the actual shear strength of the LVL specimens is unknown. The results presented were calculated based on the shear stress present in the sample at the time of failure, whether it was in bending or in shear. The maximum shear stresses reached during the tests are conservatively reported in Table 8.4 and Figure 8.12 and therefore represents lower band values of the possible shear strengths. A failure as a result of bending may also indicate beam shear need not be taken into consideration as a failure criterion, as outlined in the standard.

The all-SPG construction lay-up type (LVL3) performed the best with an average beam shear strength greater than 14 MPa. The three construction types (all-CYP LVL1, all-HP LVL2 and LVL6 (CYP and HP alternating) not containing SPG veneers showed varying, yet similar results, with all displaying an average beam shear strength greater than 5.7 MPa. The LVL4 (SPG face and HP core) performed only marginally better than the all-HP construction LVL2 (average of 7.2 MPa versus 6.4 MPa) as the better performing SPG veneers were not positioned optimally to counteract the shear stress. Including more SPG veneers throughout the LVL beam, such as the SPG and HP alternating construction lay-up type (LVL5), improved the shear strength performance (average 10.5 MPa).

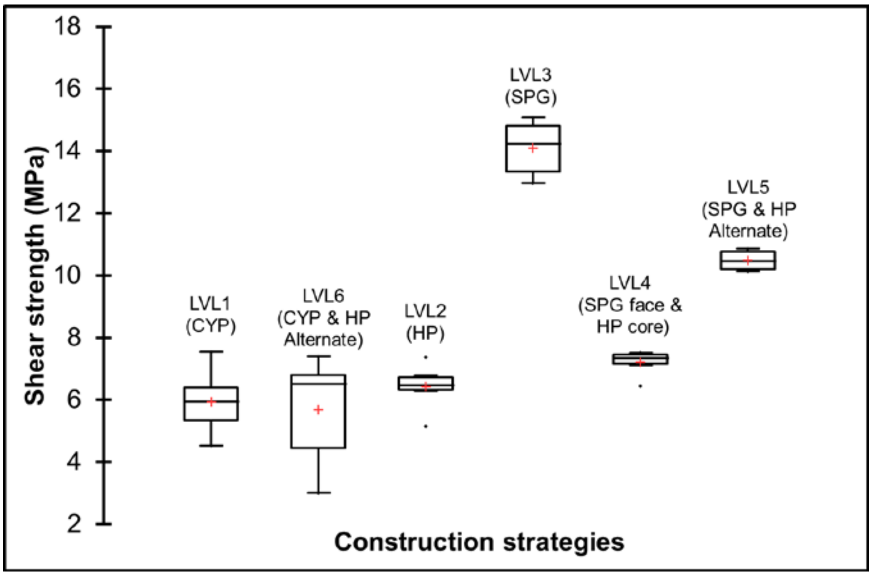


Figure 8.12. Shear strength results per construction lay-up type

Conclusions

The work investigated selected mechanical properties of 12-ply LVL manufactured from mixing native forest SPG and CYP and commercial plantation-grown HP veneers. The following conclusions can be drawn:

1. This study demonstrated that there is a considerable difference in dynamic MOE between native hardwood species and either native softwood or softwood plantation species. SPG veneers showed superior stiffness properties (an average of 22.4 GPa), followed by HP veneers and CYP veneers (an average of 12.2 GPa and 9.0 GPa, respectively).
2. LVL products are able to be manufactured from the three included species using a variety of different construction strategies. It should be noted that the adopted construction strategies used veneers with MOEs close to the population mean for each species. This therefore suggests that opportunities exist to manufacture LVL products targeting specific performances while optimising the use of the variable veneer qualities generated from log processing.
3. For both edgewise and flatwise bending, the all-SPG construction lay-up type (LVL3) performed the best among the investigated single-species construction types (25.8 GPa for MOE and 156.1 MPa for MOR for flatwise bending), while the lowest values were found in all-CYP LVL1 (10.7 GPa for MOE and 57.8 MPa for flatwise bending). The construction strategy that included all-SPG consistently outperformed the other construction strategies across all mechanical testing. The substitution of only two SPG veneers on the faces of the HP 12-ply LVL yielded an increase of up to 34.5 % (MOE) and 38.5% MOR compared with the all HP LVL2. Replacing every second HP veneer with SPG (LVL5) resulted in a flatwise MOE increase of 52% compared with the all HP construction (LVL2).
4. The bearing strength perpendicular to grain was approximately 6 to 17 times higher than tensile strength perpendicular to grain, with the all-SPG LVL3 having the highest tensile and bearing strength. The lowest tension strength was observed in single-species CYP LVL1, however this configuration ranked second for bearing strength. On average, the tensile and bearing strengths of the mixed-species LVL were superior to the reference single-species HP LVL and the single-species CYP LVL.

5. The majority of samples tested for longitudinal-tangential shear strength, failed in bending rather than shear. The highest shear strength was observed in single-species SPG LVL3 (>14 MPa) and mixed-species LVL5 (average >10.5 MPa).
6. The study has revealed that LVL products are able to be manufactured from the three included species using a variety of different construction strategies. It should be noted that the adopted construction strategies used veneers with MOEs close to the population mean for each species. This therefore suggests that opportunities exist to manufacture LVL products targeting specific performances while optimising the use of the variable veneer qualities generated from log processing. With accurate product performance criteria, construction strategies that minimise manufacturing cost, and product weight, as well as maximising the utilisation of variable feedstocks could be achieved, while still manufacturing fit-for-purpose products. The exploration of construction strategy modelling would provide guidance for developing the most efficient construction strategies taking into account the various constraints and objectives, and the targeted product performance.

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Chapter 9: Market assessment for laminated veneer lumber (LVL) products

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Introduction

The aim of the assessment is to:

- identify, assess and discuss potential products / applications - particularly uses in the mid-rise market which are challenging, or indeed impossible, for current commercially available sawn or EWP products to achieve because of material technical limitations or availablity of the current products;
- identify the critical properties or performance criteria for these products / applications and provide guidance for the DAF team regarding:
    - target property ranges (E, f'b, f'c, f't, f's, etc),
    - product requirements (ie durablity, shrinkage, hardness, fire resistance, appearance, etc),
    - specific species attributes/benefits (ie durablity, shrinkage, hardness, fire resistance, appearance, etc);
- provide an initial estimate of the potential size of these new market opportunities, that can be used in the project's economic analysis studies to determine whether they might be commercially viable to pursue.

Table 9.1 illustrates that a range of new structural and structural/appearance product opportunities are available for new advanced hardwood and blended hardwood-softwood LVL products if the manufacturing costs can be kept competitive and if industry so desires to produce them.

Table 9.1. Summary of market assessment findings for new advanced LVL products in potential new mid-rise timber building market opportunities

Application	Key Issue or Opportunity	Critical Properties / Performance Criteria	Current common Products / Grade	Suggested Targets for New Advanced LVL Properties	Other Key New Advanced LVL Dimensions or Other Attributes
LVL Framing Elements - Hardwood-LVL or Blended Hardwood/Softwood					
LVL Floor Truss Chords *High E LVL*	Aim to minimize the overall depth of the floor/ceiling system Aim to achieve particular span & truss support configurations for different applications (minimising the need for internal loadbearing walls)	• Element stiffness E and I (vibration minimization) – increased 'E' beneficial	MGP10 & 12 Softwood LVL14 F17 (F27 NSW)	Target improved E values suggest • 18,500 MPa (F27 equiv.) • 21,500 MPa (F34 equiv.) • Higher if possible	Widths: 70 & 90mm (typical) Thicknesses:35, 45mm Typical lengths: stock up to 12m
		• Increased 'I' beneficial			Increased top and bottom chord width ('I') (>90mm), 120, 150mm
	Aim to provide floor truss chords with improved web nail plate holding capacity	• Fastener holding capacity		Minimum joint group JD3 *Note: The development of new nail plates would be required to take advantage of JD1 material (Spotted Gum).*	New 90° orientation of floor truss chord members to allow teeth to penetrate face grain and high-density outer laminates for improved holding capacity
LVL Wall Studs *High Strength LVL Parallel to Grain*	Aim to allow the use of timber framed walls in taller buildings (>6 storeys) and to minimize wall stud depth and therefore wall thickness (thicker walls mean less effective saleable floor area)	• Compression parallel to grain – F'c (strength) • Stiffness – MOE	MGP10 & 12 Softwood LVL14 F17 (F27 NSW)	Target improved f'_c values suggest • f'_c = 51 MPa (F27 equiv.) • f'_c = 63 MPa (F34 equiv.) • Higher if possible	Typical thicknesses: 35, 45, 63, 75 (multiple) Typical depths: 70, 90, 150, 200 Typical lengths: 3.6, 7.2m (two-storeys)
Wall Plates & Rim-Boards *Improved Perp to Grain LVL*	Aim to reducing crushing of highly loaded horizontal wall plate timber members in lower stories so to minimize vertical movement of the building	• Compression (crushing) perpendicular to grain • Density	MGP10 & 12 Softwood LVL14 F17 (F27 NSW)	Target improved f'_p values suggest f'_p = 23 MPa (SD2 strength Grade)	Typical thicknesses: 35, 45 Typical depths: 70, 90, 150, 200 Typical lengths: up to 12m

Application	**Key Issue or Opportunity**	**Critical Properties / Performance Criteria**	**Current common Products / Grade**	**Suggested Targets for New Advanced LVL Properties**	**Other Key New Advanced LVL Dimensions or Other Attributes**
LVL Structural Beams *Higher Stiffness, smaller dimensioned*	Aim to provide a timber solution to meet a 9x9m office grid layout To improve 'span-to-depth' or 'load-to-cross-section' performance	• Stiffness/deflection – MOE • Strength – MOR (beams) • Compression parallel to grain – F'c (columns)	Glulam GL21 (Spotted Gum) GL18 (Vic Ash) GL17 (Slash Pine)	Target improved E values suggest • 18,500 MPa (F27 equiv.) • 21,500 MPa (F34 equiv.) • Higher if possible	Typical thicknesses: 35, 45, 63, 75 (multiple) Typical depths: 500-1200 Typical lengths: up to 12m
LVL Structural Columns *Higher Strength, smaller dimensioned*	Aim to provide a timber solution to meet a 9x9m office grid layout To improve 'span-to-depth' or 'load-to-cross-section' performance	• Stiffness/deflection – MOE • Strength – MOR (beams) • Compression parallel to grain – F'c (columns)	Glulam GL21 (Spotted Gum) GL18 (Vic Ash) GL17 (Slash Pine)	Target improved f'c values suggest • f'c = 51 MPa (F27 equiv.) • f'c = 63 MPa (F34 equiv.) • Higher if possible	Typical thicknesses: 35, 45, 63, 75 (multiple) Typical depths: 150-600 Typical lengths: 2.1-3.6, 7.2m (two-storeys)
Fire Exposed LVL Beams and Columns	Aim to provide new solutions for exposed timber elements using the natural fire resistance of timber	• Outer material density and charring rate • Glue-line performance	None – element would have to be encapsulated or high density	Utilising higher density external veneers	Typical thicknesses: 35, 45, 63, 75 (multiple) Typical depths: 150-500 Typical lengths: 2.1-3.6, 7.2m (two-storeys)
Hardwood-LVL Floor Slabs					
LVL Rib-Slab Floor Cassettes	Aim to develop an improved low depth, long span floor cassette solution.	Element stiffness E and I (dynamic minimization)	Softwood LVL14	Target improved E values suggest • 18,500 MPa (F27 equiv.) • 21,500 MPa (F34 equiv.)	Panel thicknesses: 45, 63, 75mm (multiple) Widths: 1.2m Lengths: up to 12m
Mass LVL Panels					
Mass LVL Floor Panels	Aim to offer an improved LVL mass panel floor alternative to CLT	Element stiffness E and I (dynamic minimization)	Softwood CLT (var) Softwood LVL14	Target improved E values suggest • 18,500 MPa (F27 equiv.) • 21,500 MPa (F34 equiv.)	Panel thicknesses: 45, 63, 75mm (multiple) Widths: 1.2m and Lengths: up to 12m

Application	Key Issue or Opportunity	Critical Properties / Performance Criteria	Current common Products / Grade	Suggested Targets for New Advanced LVL Properties	Other Key New Advanced LVL Dimensions or Other Attributes
Mass LVL Wall Panels	Aim to offer an improved LVL mass panel wall alternative to CLT	• Compression parallel to grain – F'c (strength) • Stiffness – MOE	Softwood CLT (var) Softwood LVL14	Target improved f'_c values suggest • f'_c = 51 MPa (F27 equiv.) • f'_c = 63 MPa (F34 equiv.) • Higher if possible	Panel thicknesses: 45, 63, 75mm (multiple) Widths: 1.2m and Lengths: up to 7.2m (2-storey)
Mass LVL Shaft Panels	Engineered LVL alternative to CLT	Element stiffness E and I (inter-storey drift minimization)	Softwood CLT (var) Softwood LVL14	Target improved E values suggest • 18,500 MPa (F27 equiv.) • 21,500 MPa (F34 equiv.)	Panel thicknesses: 45, 63, 75mm (multiple) Widths: 1.2m and Lengths: up to 12m
Fire Exposed LVL Stair Elements	Ensuring appropriate fire performance	• Outer material density and charring rate • Glue-line performance	Hardwood densities greater than 800 kg/m^3	Average density of not less than 800 kg/m^3 at an MC off 12%	NCC specifies a finished thickness of not less than 44 mm

With structural timber framing products, a significant market related issue is the overly large number of different types of: timber members, stress grades, product dimensions, and species, produced and marketed by the wood products industry. This regularly provides confusion to building designers, engineers, architects and consumers. If the industry continues down the path of developing some new LVL timber framing options for the market, then this really needs to be pursued in a logical and considered way. With a new suite of advanced LVL framing products, it would be logical to:

1. work in alignment with the currently accepted structural timber product grade system, and
2. limit the additional grade market offerings with some logical grade-step improvements (so as not to add too many more products – and more market confusion).

Following the market assessment undertaken in this report, suggested targets for MoE for new manufactured advanced hardwood/hybrid LVL's should consider:

- 14,000 MPa (referred to as E14 in this report – an F17 equiv. and effectively the current softwood LVL grade)

- 18,500 MPa (referred to as E18.5 in this report – an F27 equiv.)

- 21,500 MPa (referred to as E21.5 in this report – an F34 equiv.).

This approach of targeting an F27 and F34 LVL product structural grades[10] could provide a real and significant potential opportunity for new hardwood and blended hardwood-softwood LVL products.

The reasoning behind this is as follows:

- **Australian produced <u>F27 and F34 LVL products do not currently exist</u> – so it provides a 'market opportunity/gap'** (some tropical hardwood LVL19 (Keruing) is imported in limited quantities but some of the reported properties for this product are less than F27 sawn timber)
- **F27** is already **established and a known structural product** for which markets already exist – F27 sawn timber is the core high strength structural product in NSW but also known in other states (therefore may require minimal market development effort to introduce an equivalent but new product to market)
- **F27 has demand and applications in the Class 1 (houses) market** - so an established market already exists.
- **F27 and F34 also have a great deal of potential opportunities as higher strength options to LVL E14 in the emerging mid-rise timber-framed market**
  - F27: particularly for general framing products (truss chords, wall plates, etc.) and mass timber applications
  - F34: lift shafts
- Material cost will obviously be a significant factor in new product take-up, however the current pricing of F27 sawn timber in the NSW market (approx. twice that of F17), illustrates that in specific, more niche, high-strength applications (where no other competing products exist), good margins and returns can be achieved.

The following report details and presents this position.

[10] Note: The value given in F-grade structural products (e.g. F27) refers to the bending strength of the timber whereas the value used for engineered timber products (e.g. LVL, glued-laminated timber) refers to the Modulus of Elasticity (MoE)

New potential mid-rise timber building advanced LVL product opportunities

After review of the Phase 1 Report, the PSC prioritised both 'LVL' as the EWP product group of focus, and the following new potential LVL product applications in the mid-rise timber construction sector for investigation in the Phase 2 Market Assessment study:

- hardwood LVL or blended hardwood / softwood LVL *framing elements*,
- hardwood LVL *slabs*,
- mass LVL *panels*.

As discussed in the Phase 1 Report, the 2016 NCC provisions now permit:

- the use, of '*fire-protected' general*[11] timber frame systems, and *massive*[12] timber systems,
- for, apartments (Class 2), hotels (Class 3), and office (Class 5) buildings, see Figure 9.1,
- up to, an 'effective height[13]' of 25m (approx. eight stories),
- under, the simple *'Deemed-to-Satisfy'* provisions (DtS); a straight forward prescriptive 'cookbook' approach to demonstrating performance compliance - *follow these prescribed steps and the building complies*.

Buildings more than 25m in height are also allowed but are assessed under the NCC's '*Performance Solution'*, and require detailed fire, acoustic, and other regulatory compliance requirements to be demonstrated as having been met – *this can be quite costly for some projects*.

Figure 9.1. NCC 2016 Allowable building classes and effective height

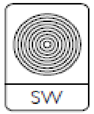
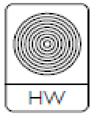
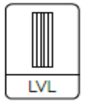
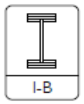
The new 'mid-rise timber' construction sector provides totally new market share opportunities for a wide range of structural and appearance timber products.
A summary of the structural timber products commonly used in mid-rise timber construction is provided in Table 9.2.

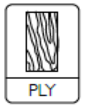
[11] **General Timber-Framed Systems**: includes small dimension framing products similar to that used in the Class 1 housing market such as lightweight timber-framed wall systems, prefabricated floor trusses (often provided as floor cassettes) and roof trusses. It also includes heavier timber post & beam construction that might utilise larger glulam columns and beams

[12] **Massive Timber**: is defined under the NCC as an element not less than 75mm thick as measured in each direction formed from chemically bonded laminated timber and includes: a) Cross laminated timber (CLT), b) Laminated veneer lumber (LVL) c) Glued laminated timber (Glulam)

[13] **Effective height** means the vertical distance between the floor of the lowest storey included in the calculation of rise in storeys and the floor of the topmost storey (excluding the topmost storey if it contains only heating, ventilating, lift or other equipment, water tanks or similar service units).

Table 9.2. Commonly used structural timber products in mid-rise timber construction (see also WS Design Guide #46 Guide to Wood Construction Systems)

Product		Description	Common Application	Common grades	Common typical dimensions	Other
Seasoned softwood		Structural sawn timber mainly pine species	Wall framing for upper storeys, non-loadbearing walls, truss elements	MGP10, MGP12 (AS 1720.1)	Lengths up to 6m Depths: 70,90,120,140,190 Thick: 35, 45 mm	Treated available MC < 15%
Seasoned hardwood		Structural sawn timber from hardwood species	Wall framing for middle to lower storeys, high strength wall plates and truss elements	A17, F17, F27 (AS 1720.1)	Lengths up to 6 m Depths: 70,90,120,140,190 Thick: 35, 45 mm	Treated available MC < 15%
LVL (Laminated Veneer Lumber)		Manufactured by gluing thin veneers with grain parallel to form beams or panels. Cross-banded LVL has one or two layers with grain perpendicular to the main grain direction.	Wall and floor framing; billets can be glued together for use as panels in cores or floors.	Manufacturers' information	Lengths up to 12 m, Panel (billet) width 1.2m max Depths: 95-400mm typical Thick: 35,45,63,75mm	Treated available MC < 15%
Glulam (Glued Laminated Timber)		Manufactured by gluing sawn timber laminates with grain parallel to form beams and columns	Beams and columns in post and beam construction	GL grades (AS 1720.1)	Lengths: 12m stock, 27m spec. Depths: variable 195-1,000mm Thick: 65,85,115,135mm (typ)	Treated available MC < 15% Camber possible
I-Beams		Top and bottom flanges from sawn timber or LVL glued to webs made from light gauge steel, plywood or OSB	Floor joists and floor cassettes	Manufacturers' information	Lengths: 8.4m typ, 12.6m spec. Depths: 200,240,300,360,400 Thick Flange: 45,51,63,90mm	Treated available

Product		Description	Common Application	Common grades	Common typical dimensions	Other
Plywood		Manufactured by gluing thin veneers with alternate grain directions to form sheets	Bracing panels; flooring	Manufacturers' information	Panel lengths 2.4, 2.7m Panel width 1.2 m, Thick: 3,4,6, 7,12,13,15,17,19,21,25mm	Treated available MC < 15%
OSB (Oriented Strand Board)		Manufactured by gluing and pressing timber flakes to form sheets	Bracing panels; flooring	Manufacturers' information	Panel lengths 1.2m Panel width: 2,440, 2745 mm Thick: 9.5, 18.5mm	

These products can be used individually or combined into timber construction systems, typically prefabricated in offsite manufacturing facilities. Off-site prefabrication of timber systems is a major focus of significant industry interest. This practice dramatically reduces on-site construction costs, making mid-rise timber construction equal to, or more cost effective, compared to traditional concrete construction methods.

A summary of the prefabricated timber systems used in mid-rise timber construction is provided in Figure 9.2 It should be noted that LVL products can be used in some way in all of the systems shown in Table 9.3 (see column highlighted in yellow).

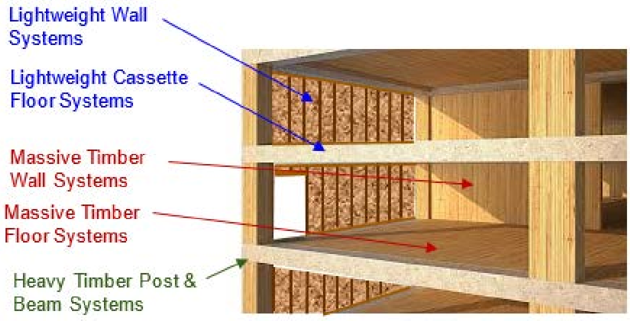


Figure 9.2. Typical timber-based systems used in mid-rise timber buildings

Simplistically, mid-rise timber framed buildings can be assembled using one or more of the following approaches:

- lightweight timber-framed construction systems,
- heavy timber post and beam construction systems, or
- massive timber panel construction systems.

Specifically, for LVL the typical products in each of the above systems includes the following.

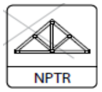
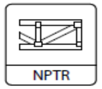
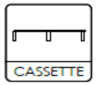
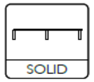
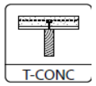
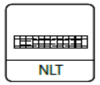
Table 9.3. Typical LVL product uses in mid-rise timber construction

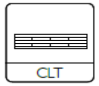
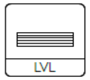
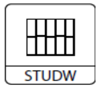
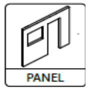
System / Product	**Lightweight timber framed members**	**Heavy timber framed members**	**Massive timber panels**
Floors	• LVL Floor truss chords • LVL I-beam chords • LVL Rim-boards, strong-backs, etc.	• LVL floor-slab cassettes • LVL structural beams	• LVL mass floor panels
Walls	• LVL Studs • LVL Plates	• LVL structural columns	• LVL mass wall panels
Roofs	• LVL roof truss members • LVL purlins	• LVL rafters	• LVL mass roof panels
Lift & Stair Shafts	• LVL studs in highly braced frames		• LVL mass shaft panels

The following sections discuss a range of these product applications in detail.

Advanced LVL 'Lightweight Framing' Elements for Mid-rise Timber Buildings
Advanced LVL 'Heavy Timber' Elements for Mid-rise Timber Buildings
Advanced LVL 'Massive Timber' Elements for Mid-rise Timber Buildings

Table 9.4. Prefabricated timber systems used in mid-rise timber construction (see also WS Design Guide #46 Guide to Wood Construction Systems)

System		Description	Common mid-rise application	Common dimensions	Typical Floor Spans (2kPa LL)	Potential LVL Application*
Nail plate trusses triangular		Engineered trusses utilising lightweight framing (35, 45mm thick) and nail plate connectors	Roof systems	Up to around 3m in depth		Truss chords and webs
Nail plate trusses parallel chord		Engineered trusses utilising lightweight framing (35, 45mm thick) and nail plate connectors	Floor systems (singularly laid or utilised in floor cassettes)	Typically, up to 12m long* Depths 150mm to 550mm	Flr joists, 450crs 300mm deep: 5.5m 400mm deep: 6.0m	Truss chords (and possibly webs for some manufacturers)
Cassette floor panels		Prefabricated engineered elements using floor joists or trusses overlain by timber flooring	Floor systems (very quick to install and safe)	Typically, up to 12m long*, 3m wide* Depths 300 - 550mm	Span/depth: 15-18 4 - 8m	Might use solid LVL joists or LVL floor trusses and floor slab
Timber-timber composite floors		Prefabricated floor cassettes using a heavy timber floor slab (and/or ceiling) connected compositely to floor joists	Floor Systems	Typically, up to 12m long*, 3m wide* Joist depth 150-600mm	Span/depth: 12-20 6 - 9m	LVL used in floor joists and floor slab
Timber-concrete composite floors		Composite timber-concrete floor (concrete acting in compression, timber in tension), connected by shear studs/keys	Floor Systems	Joist depth 150-600mm Cast-in-situ or prefab	Span/depth: 12-20 5 – 10m	LVL used in floor joists
Nail Laminated timber		Sawn timber nailed together to form larger mass panel elements	Floor systems, wall systems, shafts and cores	Typically, up to 12m long*, 3m wide* 75-300mm thick		NLT panels could be constructed from solid LVL elements

System		Description	Common mid-rise application	Common dimensions	Typical Floor Spans (2kPa LL)	Potential LVL Application*
Cross Laminated Timber		Mass wood panels made by gluing layers of timber with the grain direction of alternating layers at right angles.	Floor systems, wall systems, shafts and cores	Typically, up to 12m long 3m wide* 50mm – 500mm thickness	Span/depth: 24-30 4 - 7m	CLT panels could be manufactured from solid LVL elements
Laminated Veneer Lumber		Mass wood panels made by peeled veneers with the grain of most veneers running in the same direction.	Floor systems, wall systems, shafts and cores	Typically, up to 12m long* 1.2m wide billets Thick: 35 ,36, 39, 46, 63, 75		LVL billets used as mass wood panels for floors, walls, roofs, shafts
Open wall frames		Prefabricated wall elements assembled by nailing vertical studs between horizontal plates, often panel braced.	Wall systems	Variable		Higher strength LVL wall studs and top and bottom plates
Panelised wall fames		Prefabricated wall elements can be lined one side (partially enclosed) or lined both sides (fully enclosed)	Wall systems	Variable		Higher strength LVL wall studs and top and bottom plates
Volumetric Modules		Prefabricated 3-dimensional rooms, that can be assembled as whole buildings or components stacked on one another	Fully finished modules (floors/walls)	13m long, 4.2m wide, 3.1m high*		Higher framing used for all types of members

* Two scenarios have been undertaken in an endeavour to quantify the potential market opportunity for various timber elements opportunities identified (e.g. lift cores).

Advanced LVL lightweight framing elements for mid-rise timber buildings

As summarised previously, a wide range of product opportunities exist for LVL in mid-rise timber framed buildings in floor, wall, roof and shaft systems.

All the existing lightweight timber framing products used in the residential (Class 1) sector, can be used in some areas of mid-rise timber building construction. However, mid-rise buildings must resist higher design loads, and are obviously constructed with more storeys, so at some point the capacity of current timber products will be exceeded. This is where the opportunities arise for new stronger advanced hardwood-LVL or blended hardwood/softwood LVL framing elements. Typical structural framing applications in timber framed mid-rise buildings are detailed in Table 9.5.

Table 9.5. Typical mid-rise timber building framing member applications

Area of use	Application
Roof framing members	Roof truss chords and webs
	Rafters
	Purlins
Floor framing members	Floor truss chords (or LVL I-beam chords)
	Solid floor joists
	Floor bearers
	Rim-boards
	Strong-backs
Wall framing members	Wall studs
	Wall top and bottom plates
Structural members	Beams, lintels, etc.
	Columns

For structural framing members, the key design properties are generally:

- stiffness (resistance to deflection), which from a materials perspective is governed by the products Modulus of Elasticity (MoE);
- strength, in either bending, shear, tension, compression, or bearing; and
- in some cases, dynamics and/or vibration of the structural elements.

A comparison of the structural design properties for the existing sawn and engineered wood products commonly available in Australia is provided in Table 9.6.

New advanced hardwood LVL, or blended softwood/hardwood LVL products, should be targeting the existing structural design properties of LVL14 as a lower bound level; and obviously aiming to achieve improved structural design properties for their use in higher strength applications. To get a feel for some initial potential structural properties, DAF has undertaken some initial prototype testing of the following 6 construction strategies of hardwood and blended hardwood-softwood LVL products:

1) 100% spotted gum (SPG)
2) 100% cypress pine
3) 100% hoop
4) SPG face and hoop core
5) SPG and hoop alternate
6) Cypress and hoop alternate

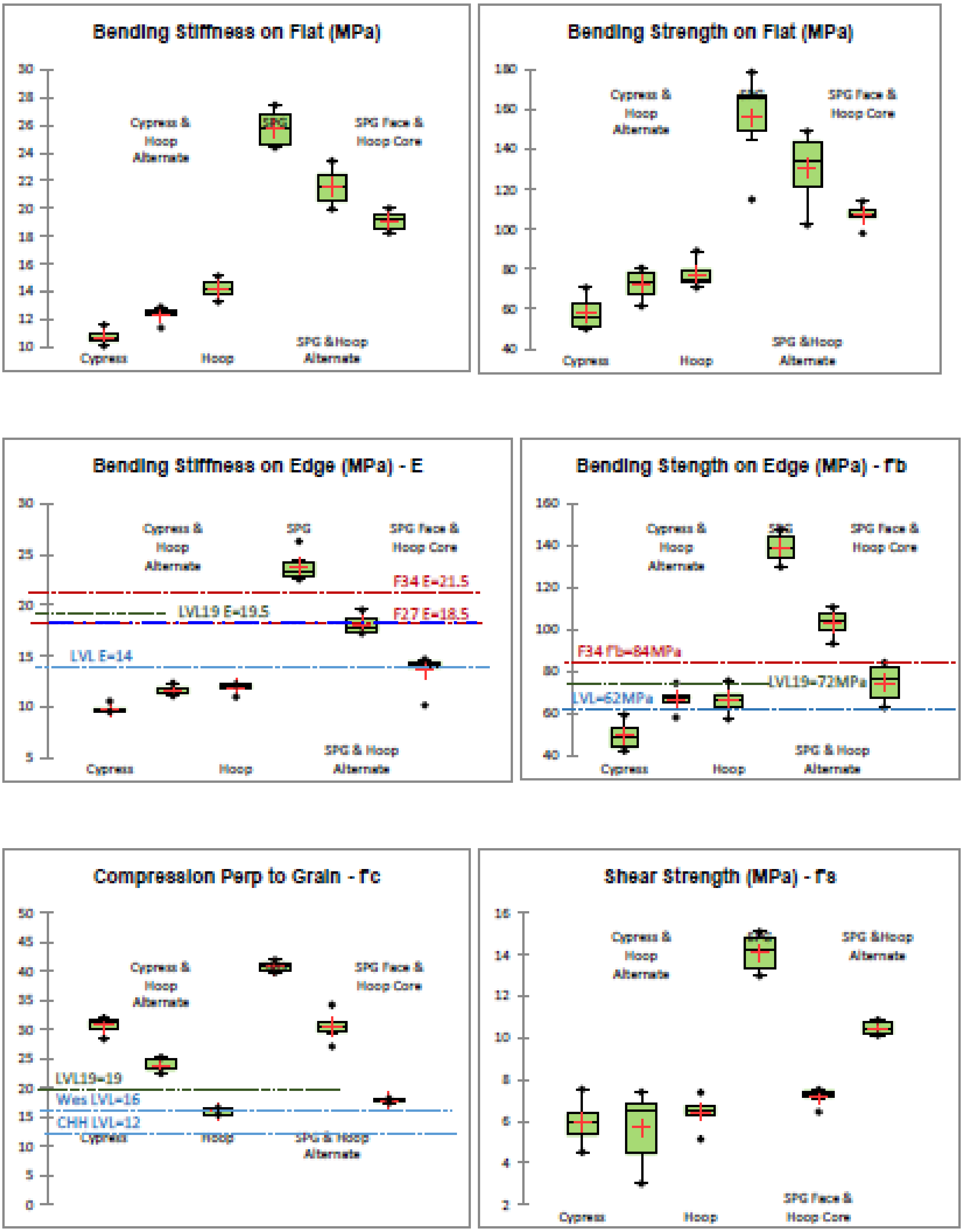
Figure 9.3 provides a summary of the initial structural property test results for these blends.

Table 9.6. Comparison of Structural Design Properties of Different Structural Products: Sawn and Engineered Wood Products

Capacity Reduction Factors Ø:	**Ø: Capacity Reduction Factors**		
Secondary members & member in domestic situations	0.9	0.95	0.95
Primary members in non-domestic situations	0.7	0.85	0.90
Primary members with post disaster function	0.6	0.75	0.80

			Solid Sawn Timber								**Laminated Veneer Lumber (LVL)**					
Timber Strength Properties:[1]			Pine Cypress F5	Pine MGP10	Pine MGP12	Pine MGP15	Seas F17	Seas Hwd A17	Seas Hwd F27	Seas Hwd F34	CHH HySpan LVL13.2	CHH Hyspan F17 LVL14 (F17)	Wesbeam e-beam LVL13.2	Wesbeam e-beam F17 E14 (F17)	Tilling PWC LVL15	Hardwood SmartLVL19 Keruing
Average Elastic Modulus (MoE)	**E**	**MPa**	**7900**	**10,000**	**12700**	**15200**	**14000**	**16000**	**18500**	**21500**	**13,200**	**14,000**	**13,200**	**14,000**	**15,300**	**19,500**
Average Modulus of Rigidity	G	MPa	530	670	850	1,010	930	930	1,230	1,430	660	700	660	700	0	975
Bending Strength	f'_b	MPa	18	17-14	28-22	39-31	42	45-40	67	84	42-50	42-50	50	62	59[2]	72
Tension Parallel to grain	f'_t	MPa	8.9	7.7-6.1	12-9.9	18-14	25	26-17	42	51	25	25	34	34	35[4]	47
Tension Perpendicular to grain	f'_{tp}	MPa	0.5	0.5	0.5	0.5	0.6	0.6	0.8	0.8	0.5	0.5	4.2	4.2	0.5	0.6
Compression Parallel to grain	f'_c	MPa	13	18-16	24-22	30-27	34	40-25	51	63	41	41	47	47	39	45
Compression Perpendicular to grain	f'_p	MPa	10	10	10	10	17	17	23	23	12	12	16	16	12	19
Shear	f'_s	MPa	1.9	2.6-2.3	3.5-3.1	4.3-3.8	3.6	5.1-3.3	5.1	6.1	4.6	4.6	5.3	5.3	4.2	6
Moisture Content		%	10-15%	10-15%	10-15%	10-15%	10-15%	10-15%	10-15%	10-15%	7-15%	7-15%	8-15%	8-15%	12-15%	12-15%
Joint Group			JD3	JD5	JD4	JD4	JD3	JD3	JD1	JD1	JD3/JD4	JD3/JD4	JD3	JD3	JD3	JD2
Strength Group			SD6	SD6	SD6	SD6	SD4	SD4	SD2	SD2	SD6	SD6	SD6	SD6	SD6	SD3
Timber Species			Cypress	Radiata	Radiata	Radiata	Ash	Ash	Sp Gum (Grd2)	Sp Gum (Grd1)	Radiata	Radiata	Pinaster	Pinaster	Softwood	Keruing
Average Density	□	kg/m³	700	500	540	570	650	650	1100	1100	560-650	560-650	650	650	610	900
Durability Class: above ground			1	4	4	4	3	3	1	1	4	4	4	4	4	3

(1) Characteristic values apply to dry service conditions
(2) Items in red are assumed.



6 Prototype LVL Construction Strategies:

100% cypress pine   *cypress and hoop alternate*   *100% hoop*

100% spotted gum (SPG)   *SPG face and hoop core*   *SPG and hoop alternate*

Figure 9.3 Summary of the initial 6 LVL construction strategies property testing results

Note: The 6 LVL construction strategies used average MoE veneers with placement of veneers controlled.

Advanced LVL floor framing opportunities for mid-rise timber buildings

Summary of mid-rise floor framing systems design considerations

In mid-rise timber framed construction, a significant new market opportunity for timber products overall in potential volume and financial return, is in 'floor systems'.

Key 'design considerations' in this application include the following:

- The 'maximum spanning' capabilities for floor systems supporting the increased loadings typical with mid-rise construction.
- Limiting the 'overall depth' of the floor/ceiling system, as the current NCC DTS provisions restrict a mid-rise timber building to an effective height of 25m. Therefore,
  - o a reduction in structural depth of the floor/ceiling system may improve the number of floors that can fit into the current NCC DtS restrictions, a really important issue for designers;
  - o additionally, thinner systems will also mean slightly higher floor to ceiling heights, which may also attract a higher sales value.
- Whether apartment building floor systems can span freely across individual apartments or whether they are supported on internal load-bearing walls.

Note: Engineering calculations have been undertaken in this report and use "E" as the traditional engineering symbol for modulus of elasticity (MoE) – the symbols "E" and "MoE" are interchangeable throughout this report.

Mid-rise timber framed floor system approaches and design depth considerations

A number of floor system types are suitable for use in timber framed mid-rise buildings, though the preferred floor systems in Australia today would be either

- a prefabricated lightweight cassette floor system (see Figure 9.4), or
- a solid mass slab floor.

Figure 9.4 Lightweight cassette floor systems

These are favoured because of their on-site construction benefits, including:

- speed of installation (and as such reduced on-site construction time and cost), and
- inherent safety (dramatically reduces fall from height risks for on-site workers).

Timber-framed floor, floor cassettes can utilise a range of floor joist members including:

- sawn timber joists,
- solid Laminated Veneer Lumber (LVL) joists,
- I-beam joists, or
- floor trusses.

Whilst it is possible to use any type of timber joist as listed above, it is convenient for the designer and builder to use joists that allow services to pass through the joists, e.g. floor trusses and I-beams, as shown in Figure 9.5.

Prefabricated floor cassettes are generally designed by the frame and truss manufacturer supplier. The design includes: floor-joists, rim-boards, strong-backs, lifting points, and connections between the cassettes as illustrated in Figure 9.6.

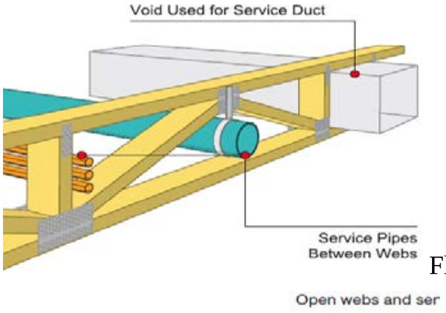


Figure 9.5. Openings in floor joist webs allow access for services

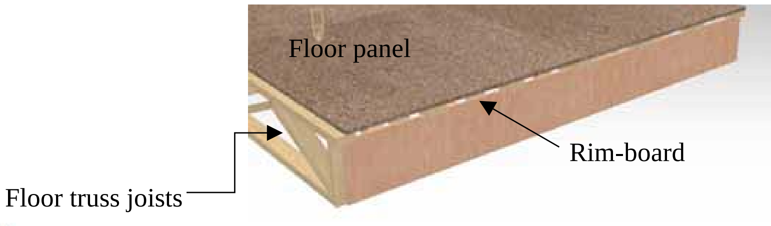


Figure 9.6. Floor cassette components

Different types of flooring panel products can be used with timber floor cassettes, including:

- particleboard;
- plywood;
- Orientated Strand Board (OSB);
- LVL floor slabs,
- cementitious based floor sheets e.g. Fibre cement, Magnesium Oxide (MgO); or
- autoclaved aerated concrete.

The floor material chosen can assist with both the floor system's acoustic performance and vibration/dynamic performance design. Floor systems in apartment buildings must satisfy specific NCC fire and acoustic performance requirements, which will influence the structural system design and detailing.

For instance,

- to achieve the appropriate acoustic performance, some type of mass-type floor overlay is going to be required to assist in deadening and absorbing noise transmission.
  Dense panel overlay products or concrete screeds are often added to timber floor systems to improve acoustic performance. This can add a significant additional design dead load to the floor: 40kg/m^2 is generally taken as a minimum mass for acoustics. The weight of concrete overlays, however, can be higher than this simply because a certain thickness is required (70-100mm) to avoid curling and crumbling.

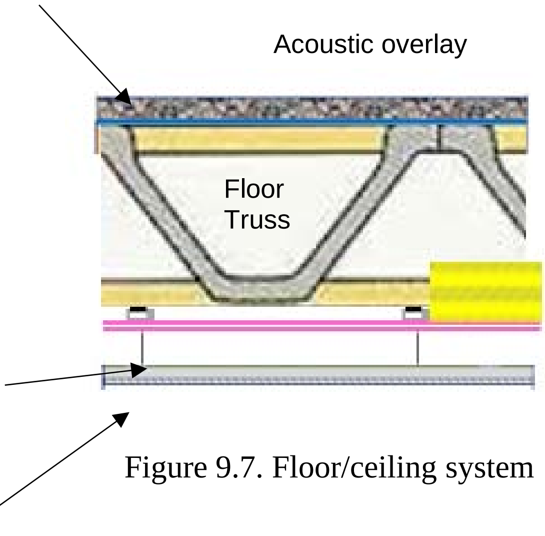


Figure 9.7. Floor/ceiling system

- to achieve the appropriate fire performance, one or more layers of fire resisting ceiling lining will be required, this adds to the design dead load.

  For mid-rise buildings a suspended non-fire rated false ceiling, below the fire rate floor/celling system, is also recommended for running downlights and sprinklers; again, an additional dead load.

One of the key market related design issues for mid-rise floor systems is 'minimising the overall depth of the floor/ceiling system', as architects often have to work within specific building planning height limitations/restrictions.

The depth of a full acoustic and fire rated floor system would include:

- acoustic overlay (40-100mm),
- a typical floor joist depth (300-500mm),
- fire-rated ceiling on resilient mounts (70mm),
- suspended non-fire rated false ceiling (100-200mm);

which sums to give an overall depth between 460 and 870mm+.

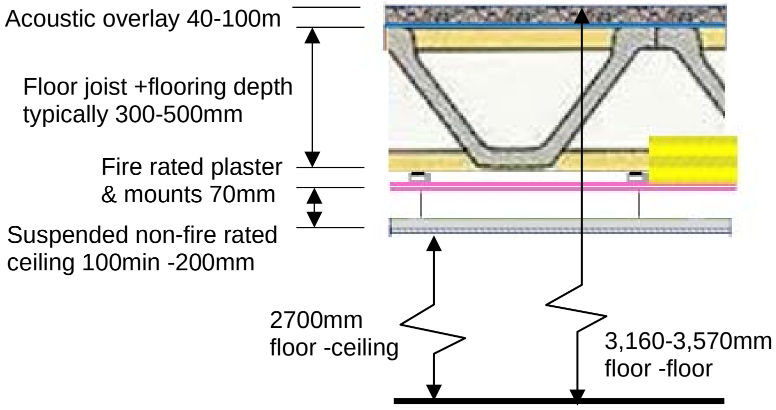


Figure 9.8. Typical mid-rise floor system build-up

Add to this, for apartments a minimum floor to ceiling height of 2,700mm in habitable rooms, and the resulting overall floor-floor heights can therefore be up to 3,160mm to 3,570mm+ (see Figure 9.8).

At this max floor-to-floor height, an eight storey mid-rise timber building would just fit within the current NCC DtS provisions of an 'Effective Height' of 25m: i.e. 3.57 x 7 = 24.99m; 10mm short of the maximum regulatory height.

So, for timber framed floors in mid-rise construction, a max of 500mm is a noted design target limitation for joist/truss depth.

Mid-rise floor system span targets and layout design considerations

In terms of target design floor spans for apartment buildings, these are highly variable as market offerings in Australia come in all shapes and sizes - from palatial penthouses, to dog-box student accommodation'.

State governments have over the last few years attempted to regulate apartment size, particularly to ensure 'minimum community acceptable living areas'. The NSW, Dept. of Planning's *Apartment Design Guide* 2015, stipulates *minimum internal areas for different apartment types*, see Figure 9.9:

- 50m^2 for a 1-bedroom apartment
- 70m^2 for a 1-bedroom apartment
- 90m^2 for a 1-bedroom apartment

Design criteria

1. Apartments are required to have the following minimum internal areas:

Apartment type	Minimum internal area
Studio	35m^2
1 bedroom	50m^2
2 bedroom	70m^2
3 bedroom	90m^2

The minimum internal areas include only one bathroom. Additional bathrooms increase the minimum internal area by 5m^2 each

A fourth bedroom and further additional bedrooms increase the minimum internal area by 12m^2 each

Figure 9.9. NSW DG minimum apartment sizes

The minimum apartment floor area requirements above, can be used to estimate approximate apartment widths. Using the square root of the minimum internal floor area (m^2) yields the breadth and width dimensions (m) of a square configuration, see Table 9.7 below.

Table 9.7. Typical apartment building widths or floor spans

Consideration	One-bedroom Apartment	Two-bedroom Apartment	Three-bedroom Apartment
Minimum internal floor area (approx.)	50m^2	70m^2	90m^2
Max width of apartment (if square)	$\sqrt{50} = 7.1m$	$\sqrt{70} = 8.4m$	$\sqrt{90} = 9.5m$

These widths provide typical design floor span targets* for different apartment types. For a:

- 1-bedroom apartment 7.1m,
- 2-bedroom apartment 8.4m,
- 3- bedroom apartment 9.5m.

* These can also be considered as 'maximum span' targets, as apartment are unlikely to be square, rather rectangular, and floor elements will typically be orientated to span across the shortest dimension.

The above floor span estimates are in alignment with typical concrete construction methods in Australia for mid and high-rise apartment construction, which predominately use 200mm post-tensioned flat plate concrete slabs, typically spanning between 5 to 8m, supported by concrete blade columns. In addition to the 200mm of concrete, an allowance of 100-150mm is generally assumed for a false ceiling below to carry services; summing to a total of 300 –

350mm overall depth. A typical post-tensioned concrete apartment layout is depicted in Figure 9.10.

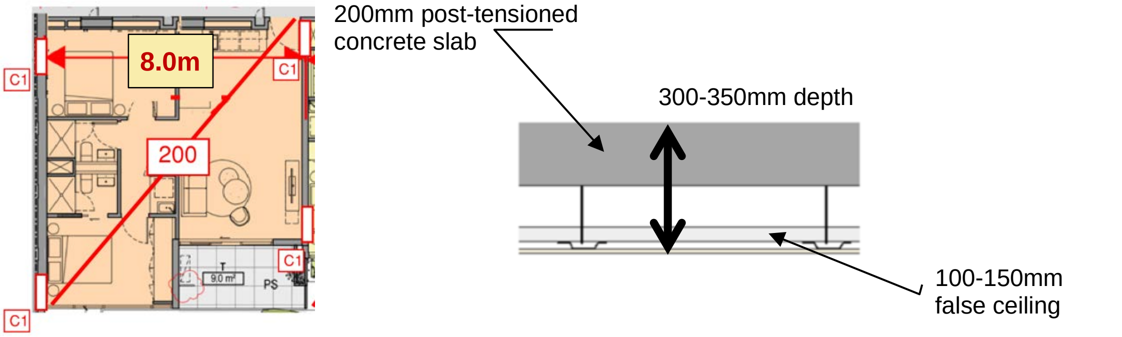
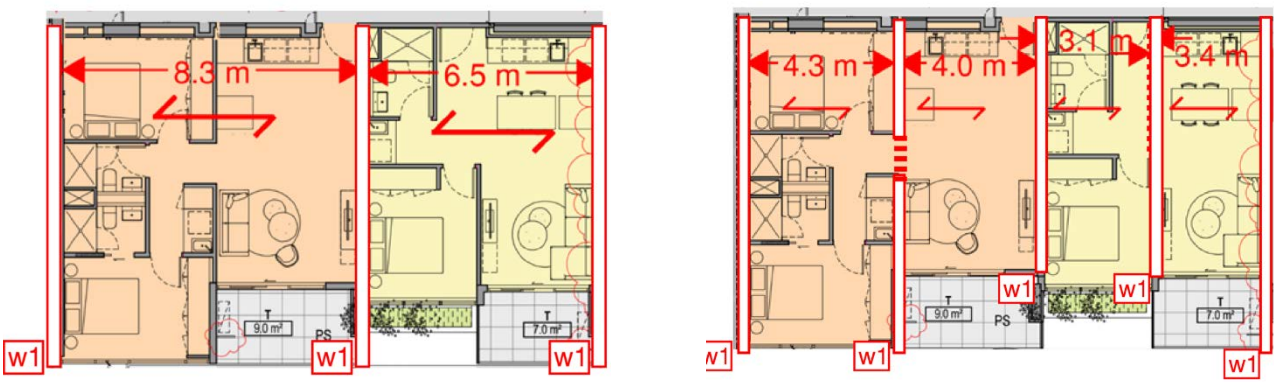


Figure 9.10. Typical post-tensioned concrete construction

Rather than spanning between isolated columns, mid-rise timber apartment construction typically utilises floor elements spanning one-way between and/or over supporting wall systems.

As illustrated in Figure 9.11 below, floor elements can either, a) span entire apartments if internal walls are not designed to be loadbearing or; b) can be supported by internal apartment walls, to reduce the overall span lengths and therefore the depths of the floor elements.



a) Floor elements spanning full apartment width

b) floor elements utilising internal LB walls

Figure 9.11 Options for floor element span and support in mid-rise timber apartment buildings

If the apartment floor structure can be designed to clear-span the full width of the building, then this is highly beneficial, as it allows the future occupants in apartments below, the full flexibility of altering wall positions over the future life of the building without impacting on the above neighbouring apartment, see Figure 9.12.

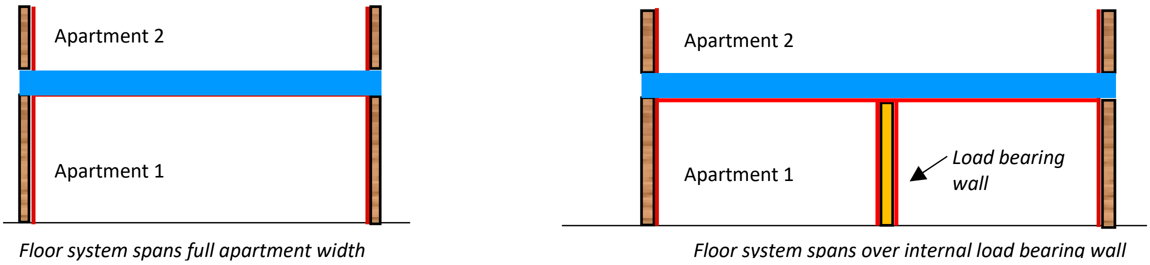


Figure 9.12. Impact of free spanning vs internally supported floor elements in apartments

If a free span is not possible, and internal walls have to be used as load-bearing walls to assist in the structural design of the over-spanning floor systems, then these supporting load-bearing walls must be fire rated, acoustically separated, and effectively become fixed in position (any future alteration would require detailed structural and fire consideration).

Having the ability for floor systems to be able to 'free-span' between apartment walls is a significant advantage for apartment owners in terms of future alterations to their living spaces, and as such sets another design consideration

Identification of critical floor system design criteria

A comparative analysis has been undertaken to investigate the types of floor truss chord dimensions and grades needed for typical apartment applications (and their limitations). The following design assumptions have been utilised:

- Live Load: 1.5kPa UDL – 1.8kN point load (AS1720, T3.1 apartments)
- Dead Load: 115kg/m^2 TOTAL
    - o 40kg/m^2 overlay product mass for acoustics,
    - o 15kg/m^2 22mm flooring self-weight,
    - o 15kg/m^2 floor-joists self-weight
    - o 5kg/m^2 acoustic insulation, acoustic overlay, resilient mounts
    - o 25kg/m^2 2 x 16mm fire rated plasterboard,
    - o 15kg/m^2 false ceiling (13mm regular plasterboard)
- Vibration and dynamic performance

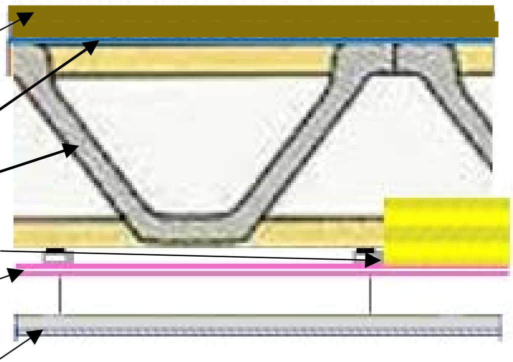


Figure 9.13. Floor loading

Note: if a concrete overlay topping is used, dead load will be higher

For the design of floor systems, Table 9.8 summarises the relevant serviceability load combinations, factors and limits.

Table 9.8. Serviceability limit state load combinations for floor members

	Load combination	Load	j_2		Typical Limit
(a)	$G + \psi_\ell Q$	G $\psi_\ell Q$	2 2	Long-term serviceability load	Span/300 or 9 mm
(b)	$(1 - \psi_\ell)\ Q$	$(1 - \psi_\ell)\ Q$	1	Transient serviceability load	Span/360
(c)	g_{41} x 1 kN (applied at mid-span)		1	Point load for vibration check	2 mm (apartments) 1.5 mm (other buildings)

G = Permanent actions; Q = Design imposed action; ψ_ℓ = Long-term factor

j_2 is the duration of load factor for creep (inelastic deflection)

g_{41} is a factor used to evaluate the proportion of out-of-plane load that is not distributed in a grid system e.g. where a point load is applied immediately above a floor joist or truss,

Using the aforementioned loading and design criteria in a worked design example for a 400mm deep floor truss, at 450mm crs, spanning 6m, Figure 9.14 illustrates the relative impact of the different design checks and provides a utilisation comparison, i.e. how close to failure each design criterion is.

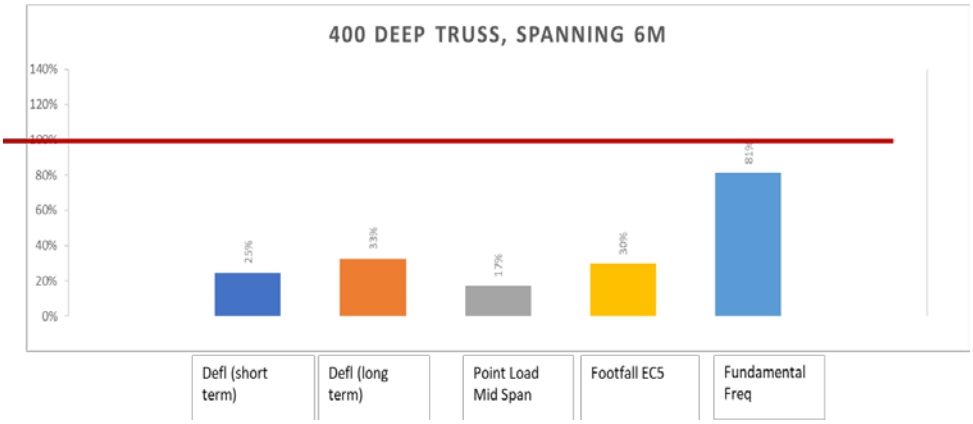


Figure 9.14 Floor truss design criterion comparison

It can be noted from Figure 9.14 that the ‘fundamental frequency’ criterion is governing the overall design, rather than deflection or strength which often governs the design of beam-type members. For longer span, lightweight floor systems, the critical design factor is generally dynamic performance.

From Eurocode 5, for the fundamental frequency[14] of floors: $f_1 = \frac{\pi}{2L^2}\sqrt{\frac{EI_j}{m}}$

-that the key relevant design criteria for floor dynamic performance, **is the floor stiffness (EI).**

- **E: Modulus of Elasticity (MoE)** - being a measure of a material’s stiffness, or its resistance to being deformed elastically. A material with a higher MoE will be stiffer and will experience less deformation than a lower MoE material.
- **I: Second Moment of Area** – a geometrical property of the element used to predict deflection and bending stress, which reflects how the element’s points are distributed in regard to its centroid. More material, further away from the centroid the stiffer the element. It is determined using the following equation for any shape.

$$I = \sum\left(\frac{bd^3}{12} + A_i D_i^2\right)$$

As the depth of a section increases and the resisting elements are placed further away from the centroid, the stiffness increases exponentially, and conversely, if the overall depth of the section reduces then the stiffness of the section is exponentially decreased.
This is why a floor truss is more efficient, by mass, than a solid floor joist, as trusses have the center of mass of the top and bottom chords positioned further away from the neutral axis (see Figure 9.15).

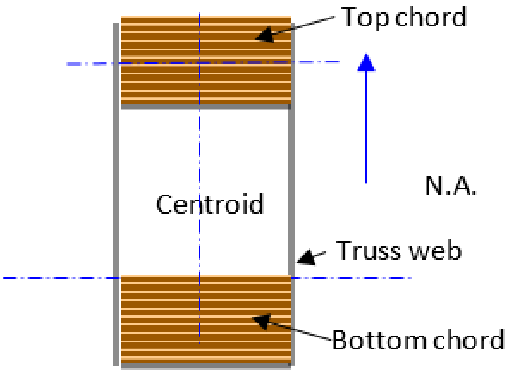


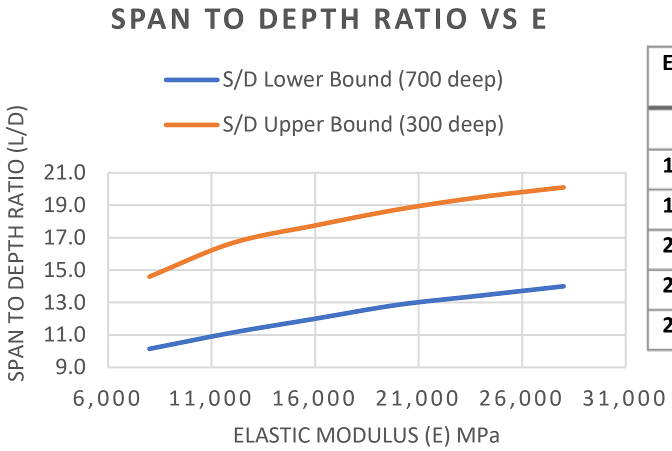
Figure 9.15. Floor truss elements

[14] The first natural frequency for floors is generally recommended to be more than 10Hz, while natural frequencies below 3Hz and between 5 Hz to 8 Hz should be avoided to prevent human discomfort.

Effect of improved stiffness (E and I) on floor design spans

By improving the variables that effect stiffness of a floor section (E & I), the 'span to depth ratio' can be increased; meaning

- a specific span can be achieved, for a smaller overall structural depth; or
- for a beam of fixed depth, increasing the E value of the material used increases the distance it can span. Figure 9.16 illustrates this for a 300mm and 700mm deep floor truss.



E	S/D Lower Bound 700 deep (span))	S/D Upper Bound 300 deep (span)
8,000	10.1 (7,070)	14.6 (4,380)
12,000	11.1 (7,770)	16.7 (5,010)
16,000	12.0 (8,400)	17.8 (5,340)
20,000	12.9 (9,030)	18.7 (5,610)
24,000	13.4 (9,380)	19.5 (5,850)
28,000	14.0 (9,800)	20.3 (6,090)

Figure 9.16. Span to depth ratio improvements from increasing the Elastic Modulus

Figure 9.17 further illustrates the E-I, span-depth relationship by plotting for various floor truss depths (300, 400, 500, 600 and 700mm), their span for a specific floor truss chord E value.

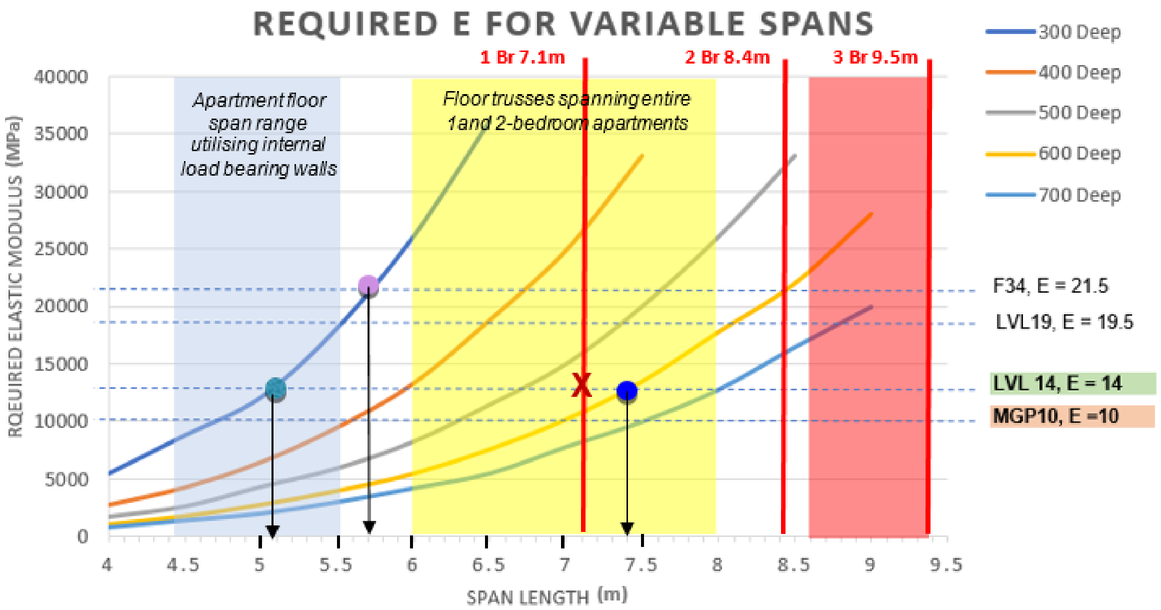


Figure 9.17. Spans for floor trusses of variable depth and E

Note: this assumes that the floor trusses are spaced at 450mm crs, the trusses utilise 90x45mm top and bottom chords.

From Figure 9.17 it can be seen that:

- a 300mm deep floor truss made with LVL14/F17 chords (E14) will span approx. 5.1m
- a 300mm deep floor truss made with F34 chords (E21.5) will span approx. 5.7m
  - o *this equates to approx. 11.7% increase in span for a 53% increase in E.*

- if a floor truss twice the depth is used: 600mm deep LVL14/F17 chords (E14), then the span increases to approx. 7.4m 🔵
    - o *this equates to approx. 45% increase in span for a doubling in depth.*

- Additionally, it can be noted that for a floor truss made using LVL14/F17 chords to clear span across a 1-bedroom apartment:7.1m
    - o *would require a depth of around 550mm which is greater than the recommended 500mm depth limit for floor-truss elements.*

Figure 9.18 provides a similar plot of the E-I, span-depth relationship for various floor truss depths, but in this case highlighting specific product E value opportunities above LVL14 (F17 equiv. – *one of the most commonly available and used LVL products with an E of 14,000MPa*).

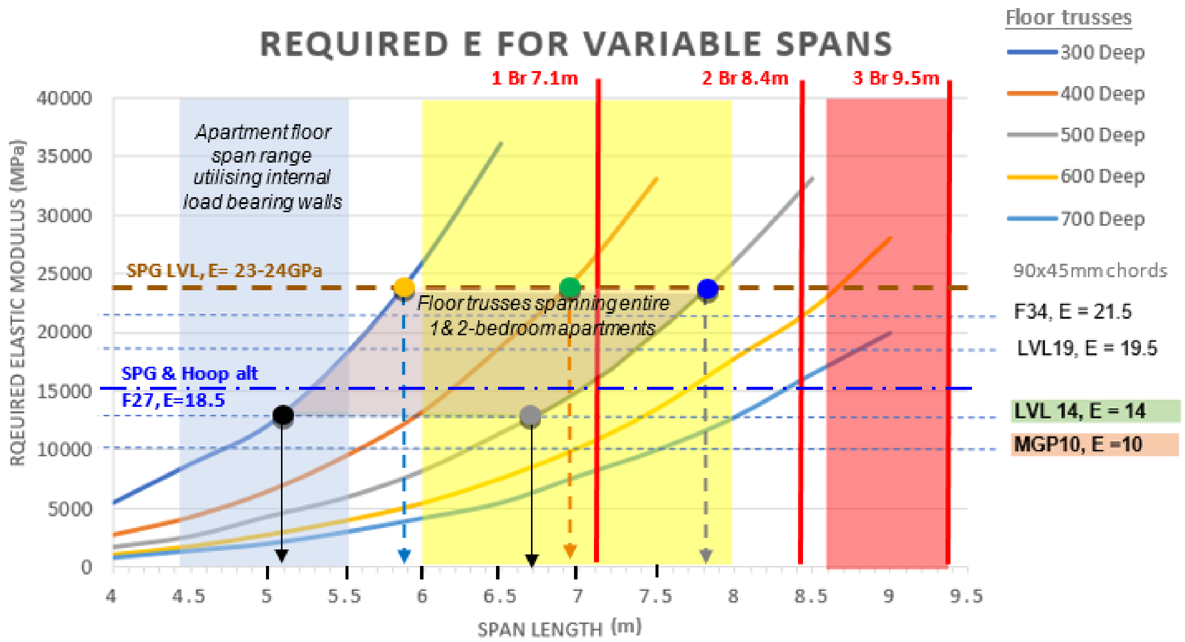


Figure 9.18. New floor trusses opportunities using higher E grade materials

With LVL14, as illustrated in Figure 9.18:

- a 300mm deep floor truss @450mm crs with 90x45mm chords will span approx. 5.1m ⚫
- a 500mm deep floor truss @450mm crs with 90x45mm chords will span approx. 6.7m ⚪

The brown shaded portion of the graph above illustrates the design span ranges for 300, 400, and 500mm deep floor trusses, for varying E values above E14, to an upper limit of E24. The E24 figure is an indicative value of potentially what might be achieved with an LVL product manufactured using 100% spotted gum veneers, (value provided by DAF from prototype testing during this research project). Also plotted is an E18.5 line, effectively F27; which is also the indicative E value from the prototype test for an alternate spotted gum and hoop pine blend.

It can be seen from Figure 9.18, that above the current E14 level, increased spans can be achieved up to:

- 5.9m for a 300mm deep E24 floor truss 🟡 (or approx. 5.5m for an E18.5 chord)
- 7.0m for a 400mm deep E24 floor truss 🟢 (or approx. 6.4m for an E18.5 chord)
- 7.8m for a 500mm deep E24 floor truss 🔵 (or approx. 7.3m for an E18.5 chord)

These figures illustrate that by using higher E grade chord materials, floor trusses can span greater than the 7.0 metres, identified as a free-span for 1-bedroom apartments, and still have depths below the 500mm recommended maximum depth limit.

A 500mm E24 floor truss (max span 7.8m) would probably also be appropriate to free-span many 2-bedroom apartments. Recognising that the suggested 8.4m is a 'maximum span, based on a square apartment calculation', and that most apartments will in fact be rectangular in nature, with smaller cross-apartment free-spans.

These examples quite clearly illustrate that having additional E grade options above E14 would be very beneficial in floor truss chords providing additional improved design spanning options.

Effect of improved E grade on reducing the required material cross section

Discussions with frame and truss manufacturers confirmed their timber product selection was primarily influenced by the following factors (in priority order based on the current market experience):

1) cost of the material,
2) availability, and
3) design performance.

Cost of material is often based around members' size, and certainly the price per m^3 depending on species and grade.

Using a higher E grade material can mean that a smaller dimensioned product could be used. This is illustrated in Figure 9.19 which compares for a 400mm deep floor truss (450mm crs), a range of floor truss chord sizes (70x35, 70x45, 90x35, and 90x45mm), and the span that different E grade chords might achieve.

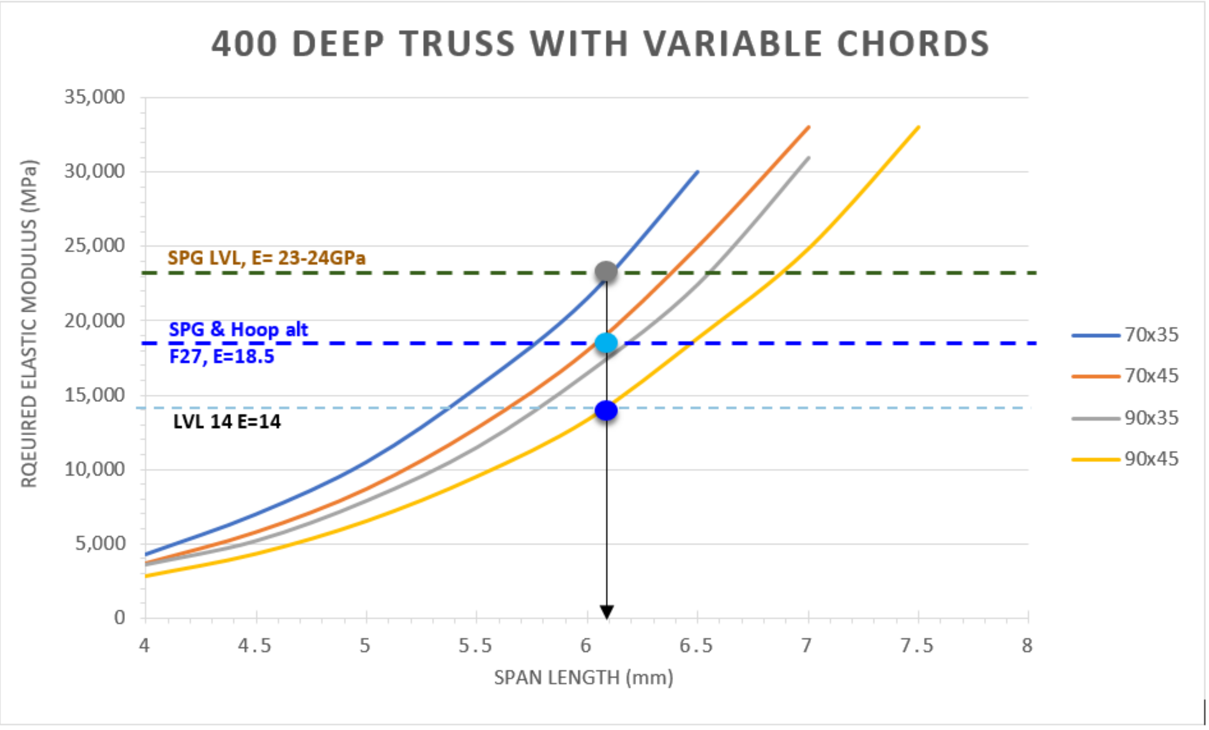


Figure 9.19. Effect of higher E grade materials on reduced cross section for a set span

It can be seen from Figure 9.19, that for 6.1m span, that the truss chord options for differing stress grades are as follows

- LVL14 (F17) 90x45mm

- LVL18.5 (F27)	90x35mm
- LVL 24	70x35mm

Using a higher E grade material can mean that a smaller dimensioned product could be used. The final determination here will be the relative price difference between the different available E grade materials.

Effect on design spans of increasing the chord member dimensions to improve stiffness (I)

As discussed, the critical design criterion for floor system floor truss members is vibration and dynamics and these design equations are dependent on the floor stiffness (EI) of the joists.

Whilst the previous sections have discussed the benefit of increased E values, it is also instructive to note the impact of varying the I-values for floor trusses.

Member stiffness (I) of a floor truss improves with increased depth, however another factor which effects the I-value is the dimensions of the actual truss chord members used.

Currently in Australia, floor truss chord feedstock is based predominately around the typically available softwood sawn sizes: 70x35, 70x45, 90x35 or 90x45mm. If LVL is utilised as chords, different width and thicknesses could be easily utilised.

Figure 9.20 illustrates the improvement in span for a 400mm floor truss (@ 450mm crs) for various truss chord dimensions and a range of different chord E values.

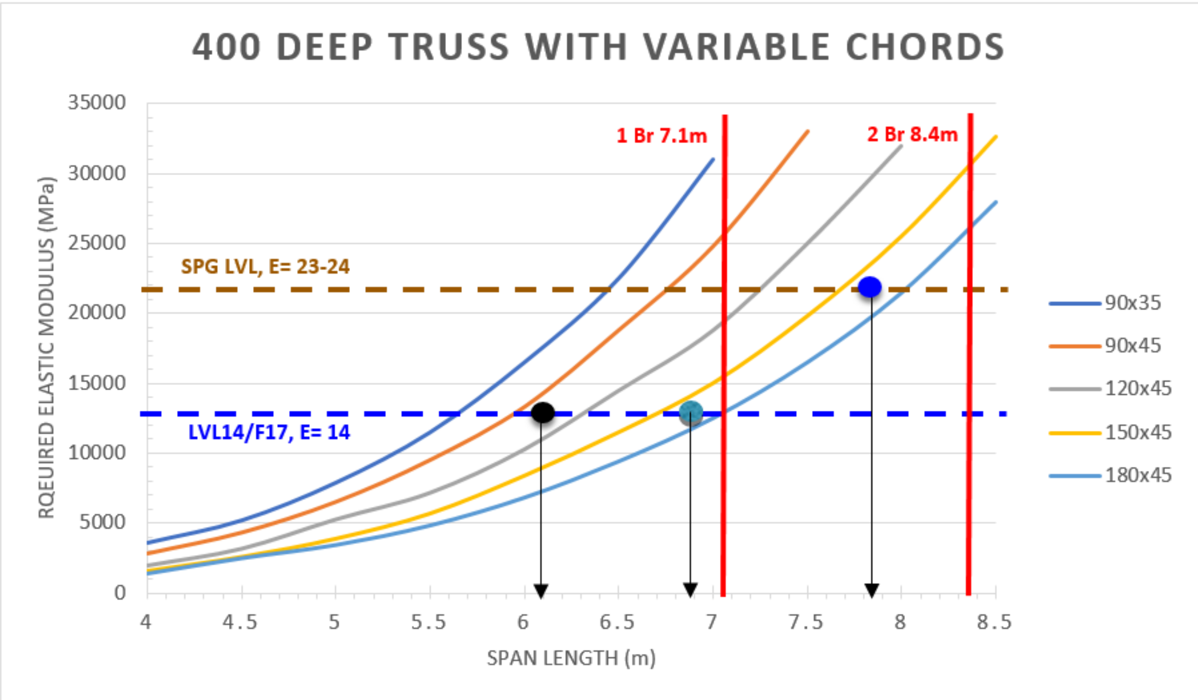


Figure 9.20. Comparison of spans for a 400mm deep floor truss with varying chord sizes and E

From Figure 9.20 it can be seen that:

- a floor truss made with 90x45mm LVL14/F17 chords (E14) will span approx. 6.1m ●
- a floor truss made with 150x45mm LVL14/F17 chords (E14) will span approx. 6.9m ●
    - *this equates to approx. 13% increase in span.*

Additionally, it can be seen that:

- a floor truss made with 150x45mm SPG LVL chords (E24) will span approx. 7.9m
    - *this equates to approx. 14.5% increase in span.*

Increasing the width of the truss chord provides an option for overall floor truss stiffness improvement. Again, the cost of materials will be a determining factor.

Discussion with F&T manufacturers indicates that current manufacturing plant would generally accommodate increased chord widths up to around 150mm. Often instead of increasing the width though, designs just double up the floor trusses, i.e. two 70mm chord width trusses, rather than one truss with 140mm width chords, this in theory though should be more costly due to the additional floor truss web materials required.

Improved nail plate holding capacity in LVL floor truss chords at 90°

Another potential design/performance consideration for new advanced hardwood EWP floor truss members could be improved nail plate tooth holding capacity.

When LVL top and bottom chords are oriented in a conventional manner then the teeth of the nail plates are pressed effectively into the 'side grain' of the horizontal LVL veneers and multiple gluelines.
To reduce the issue of nail plate teeth tearing out of LVL side-grain, alternative configurations, such as the following could be considered:

- utilise thicker LVL sections (70, 90mm thick); and
- manufacturing the floor trusses with the LVL chords turned at 90 degrees so the nail plate teeth are now penetrating the LVL face-grain.

With a new blended LVL in this application, the outer laminates of the LVL floor truss chord members could utilise higher density hardwood veneers, with improved joint group (JD) values which would further improve the web nail plate connector teeth holding capacity.

An important investigation would be to determine the capacity of the LVL laminate glue line and potential shear failure between the outer laminates pierced by the nail plate teeth and the central section of the truss chord.

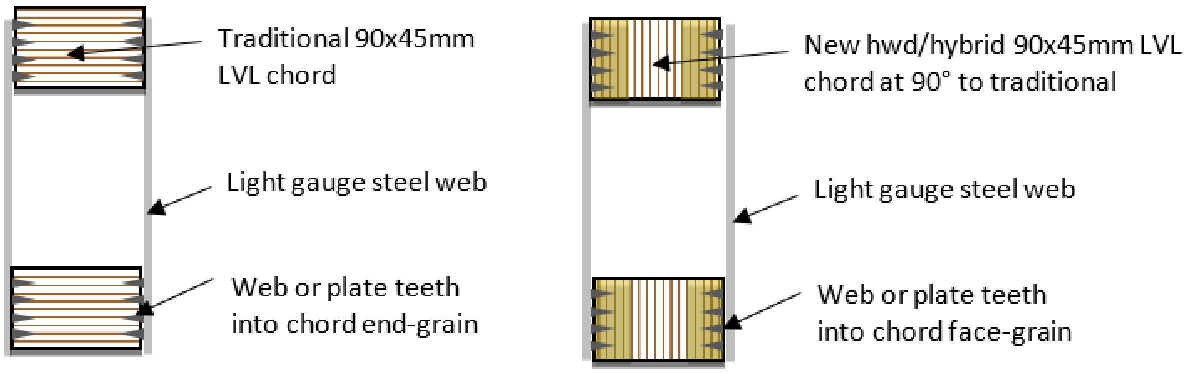


Figure 9.21. Floor truss chord orientation configurations

Floor truss chords: product dimensioning

For LVL floor truss chords the following dimensions are of note:

Widths: 70, 90mm typical, perhaps other widths up to 150mm

Thicknesses: 35, 45mm

Lengths 8.5m typical, LVL is valued for its longer lengths as it means frame and truss manufacturers do not have to splice chord members when long lengths are required.

12m likely, with floor trusses in mid-rise floor applications as floor cassettes will often be designed to span continuously across load bearing walls and double span cassettes up to 12m are (max length for unrestricted truck transport)

Floor truss chords: conclusions

In summary when examining opportunities for more advanced LVL type products in floor truss chord applications for mid-rise timber building the following is noted.

- For timber framed floors in mid-rise timber buildings, a max of 500mm is a suggested design target limitation for joist/truss depth, in order to maximise the number of floors that can be used with the NCC deem to satisfy 25m Effective Height limitations.
- Having the ability for floor systems to be able to ‘free-span’ between apartment walls is a significant advantage for apartment owners in terms of future alterations to their living spaces, and as such sets another design consideration.
- The key relevant design criteria for floor dynamic performance, is the floor stiffness (EI).
- Having additional advanced E grade options above the current industry softwood options would be very beneficial in floor truss chords providing additional improved design spanning options. Suggested targets for E for new manufactured advanced hardwood/hybrid LVL’s should be:
    - 14,000 MPa (F17 equiv.) - effectively the current softwood LVL grade
    - 18,500 MPa (F27 equiv.) - DAF prototype value SPG/Hoop LVL 18,500MPa
    - 21,500 MPa (F34 equiv.) - DAF prototype value SGL LVL 24,000MPa
- Using a higher E grade material can mean that a smaller dimensioned product could be substituted for a floor truss chord. The final determination here will be the relative price difference between the different available E grade materials.
- Increasing the width of the truss chord provides an option for overall floor truss stiffness improvement; again, the cost of materials will be a determining factor.

Advanced LVL wall framing opportunities for mid-rise timber buildings

Summary of mid-rise wall framing systems design considerations

Another new market opportunity for timber products in timber framed mid-rise construction, is ‘wall systems’.

Key ‘design considerations’ in this mid-rise application include the following:

- The physical wall configuration required to meet building acoustic regulations and performance targets.
- The thickness of the wall used, which can have a significant financial impact through reducing the effective nett saleable or rentable floor area.
- The material strength of the studs, essentially the greater the stud capacity, the more floors that can constructed from timber framed elements.

- The perpendicular-to-grain crushing strength of the wall frame top and bottom plates – which can be an issue in more highly loaded lower floors and which impacts on the vertical movement of the overall building.

Mid-rise timber framed wall system approaches and design considerations

Wall acoustic performance considerations

When designing and assembling lighter weight timber mid-rise buildings, achieving appropriate acoustic performance provides one of the most significant design challenges for the whole design team. Decisions on how best to achieve acoustic performance, effect not just the architectural but also the engineering solution. So, it is very important that the acoustic approach is discussed and agreed across the whole design team during the preliminary conceptual design phase.

The NCC sets a range of minimum acoustic performance requirements in terms of noise levels, and for some walls, separating particular types of room occupancies, how the wall must be constructed.

Three wall configurations typically used in timber framed mid-rise buildings to assist in meeting specific acoustic performance levels, are as follows.

Discontinuous double leaf stud walls: which utilise a pair of separated parallel single stud walls that are lined on the outer sides usually with fire-rated linings. The physical separation (20mm min) of the lined walls significantly reduces sound transmission, as the transmission of 'flanking' noise (physical vibration of the structure) is minimised or eliminated. The mass of the linings and acoustic insulation also assists in deadening sound.

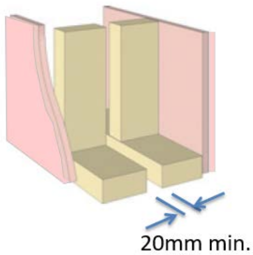


Figure 9.22. Discontinuous double leaf stud wall

Staggered stud walls: which utilise wall top and bottom plates wider than the studs, and wall linings each side are fixed to every second stud in the wall system, effectively providing a discontinuity of the wall faces. This is not as effective as a fully discontinuous wall as direct transmission of noise vibration will occur through the common wall plates. Acoustic insulation is utilised threaded between the gaps in the staggered studs and wall linings to improve airborne sound performance.

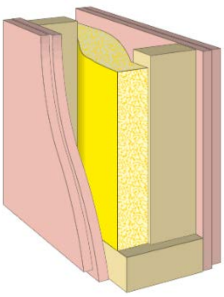


Figure 9.23. Staggered stud wall

<u>Single stud walls with resilient mounts:</u> which utilise channels that are fixed to the stud with acoustic separators to support the linings thereby enhancing acoustic performance. The most common types of acoustic separators are: rubberised resilient mounts or a channel fixed to the stud on only one leg of the channel.

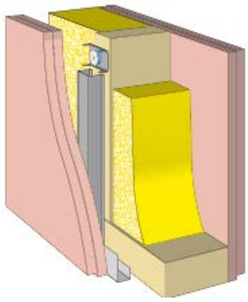
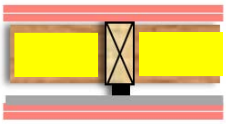
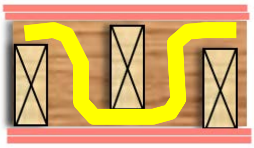
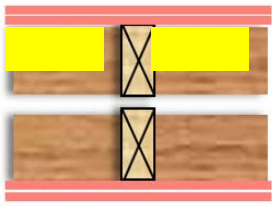


Figure 9.24. Single stud walls with resilient mounts

Figure 9.9 below provides a comparison of the three different wall system configurations using 90mm studs, their acoustic performance, and their application areas as set by the NCC.

Table 9.9. Comparison of wall systems: configuration thickness, acoustic performance

Wall Type	**Single Stud wall + Resilient Mounts**	**Staggered Stud Wall**	**Discontinuous Double Leaf Stud Wall**
Wall Configuration			
Wall Elements FRL 90/90/90	2 layers 13mm FR Pbd 90mm stud & plates Acoustic insulation 30mm resilient mount 2 layers 13mm FR Pbd	2 layers 13mm FR Pbd 90mm stud 120mm T&B Plates Acoustic insulation 2 layers 13mm FR Pbd	2 layers 13mm FR Pbd Wall 1: 90mm stud & plate Acoustic insulation 20mm gap Wall 2: 90mm stud & plates 2 layers 13mm FR Pbd
Wall Thickness	**172mm**	**172mm**	**252mm**
Min NCC reqmt Airborne Noise $R_w + C_{tr}$ (≥ 50)	**52** (with R1.5 insul - USGB) **53** (with R2.0 insul - USGB) 50 (with R2.0 insul - CSR)	**50** (with R1.5 insul - USGB) **51** (with R2.0 insul - USGB) 50 (with R2.0 insul - CSR)	**52** (with R1.5 ins 1 side - USGB) **53** (with R2.0 ins 1 side USGB) 54 (with R2.0 ins 1 side - CSR)
NCC Deemed to Satisfy Sound Insulation Requirements Class 2 & 3 Buildings			
SOU - Corridor	**OK: $R_w \geq 50$**	**OK: $R_w \geq 50$**	**OK: $R_w \geq 50$**
SOU HR – SOU HR	**OK**	**OK**	**OK**
SOU NHR – SOU KBTL	**OK**	**OK**	**OK**
SOU HR – SOU KBTL	System not allowed	System not allowed	OK
SOU – plant & Lift shaft	System not allowed	System not allowed	OK

SOU – Sole Occupancy Unit, *SOU KBTL – kitchen, bathroom, toilet, laundry,*
HR - Habitable room, means a room used for normal domestic activities includes a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room, home theatre and sunroom.
NHR - Non-habitable rooms, are bathroom, laundry, water closet, pantry, walk-in wardrobe, corridor, hallway, lobby, clothes-drying room, and other spaces of a specialised nature occupied neither frequently nor for extended periods. Refer NCC definition.

It can be seen from the above summary that:

- acoustically, any of the systems will meet the minimum NCC requirements: $R_w + C_{tr}$ (≥ 50);
- single stud resilient mount systems perform similarly to 2-leaf discontinuous wall systems for airborne noise, but discontinuous systems must be used under the NCC between SOU habitable rooms (HR) and adjoining SOU kitchens, bathrooms, toilet and laundries; and plant rooms or lift/stair shafts to minimize vibration and flanking impacts;
- single stud resilient mount systems perform slightly better acoustically than staggered stud systems (for same 172mm wall thickness).

As illustrated in Table 9.9, the acoustic requirements can determine the structural member configuration needed for specific walls between certain types of rooms; that is, whether a double leaf discontinuous wall must be used or if a single stud configuration is appropriate acoustically (either staggered studs or single stud with resilient mounts).

Wall thickness considerations

Designers also need to understand that the overall thickness of the wall systems used is also an important consideration in terms of the potential financial return of the building.

Wall thickness is influenced by both acoustics (as discussed in the previous section) and the depth of the wall stud designed by the engineer, which in turn sets the wall thickness. I.e. the engineer might choose to use a single 140mm deep stud because this structurally may be as efficient as triple 90mm studs, however the overall wall is now 50mm thicker, as illustrated in Figure 9.25.

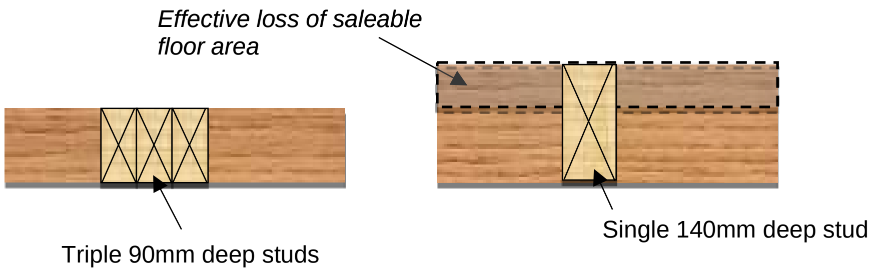


Figure 9.25. Using multiple smaller width stud instead of a deeper stud

This wall thickness consideration is particularly important for a project developer and their realtor perspective, as the *'thicker the wall system, the less net saleable or lettable floor area'*.

A recent internal Wood Solutions mid-rise team comparative study investigated the impact when different timber wall thickness systems are used in terms of lost net saleable area, using three different mid-rise apartment footprint layouts, over three different socioeconomic areas. The study found that the potential 'lost sales value' compared to a traditional 90 mm thick wall for a:

- 120 mm stud wall can range from 1.2 – 1.8% of the sellable area, and
- 140 mm stud wall can range from 2 – 3% of the sellable area.

The impact of these findings becomes much more significant when viewed with an overall project development perspective. Assuming a 6-level building, with 4 apartments per level, in a high-value land area, the potential effective loss of saleable area can be as high as:

- $240,000 when 120 mm thick walls are used instead of 90 mm, and up to
- $400,000 when 140 mm thick walls area used.

These are significant values by any one's measure. Consideration of the impact of wall thickness and lost opportunity needs to be understood by designers of mid-rise timber buildings.

Clearly it may, from an overall optimised project opportunity point of view, be more cost effective to utilise 'more - smaller studs', rather than 'less - deeper studs', even if the overall total dollar cost of the actual timber used in the project is higher (which is a good outcome anyway for the timber seller).

Mid-rise Timber Building Increasing Floor Level Stud Design Approach
When designing a mid-rise timber framed building, the general approach is to utilise traditional framed stud walls at each level (see Figure 9.26), and simply increasing the number of studs needed lower down the building as the loads get higher.

By example

- top two stories might be single studs at 450/600mm centers,
- next two floors, double studs at 450/600mm centers;
- lowest two floors, triple studs at 450/600mm centers.

Figure 9.26. Lightweight timber framed mid-rise apartments

At a certain point it will become more cost effective to switch over from multiple studs, to a mass-type wall configuration, i.e. laminated veneer lumber (LVL) panels or cross laminated timber (CLT).

The general 'rule of thumb' to date, has been that the limit for current lightweight framing products, is around six stories in height. Above this, it has been suggested that it is likely to be more efficient to use mass-type wall products in the lower levels, as the number of single timber framed studs required starts to get too high. Obviously, if new higher strength advanced LVL type products were available then it may be possible to use timber framed walls in the lower levels of taller mid-rise timber buildings, or less studs in the upper floors. The next section investigates this further.

Mid-rise timber building wall stud requirement assessment

To get a better feel for the types of wall stud configuration and sizes required for the different levels in a typical mid-rise apartment, a comparative analysis has been undertaken of a theoretical 8 storey timber framed apartment building with plan dimensions 30 x 26 m, utilising a CLT stair core, located in Melbourne, using the following design assumptions.

Loading Assumptions:

- Live Load: 2 kPa UDL – 1.8 kN point load (apartments)
- Dead Load: 3 kPa TOTAL (conservatively assuming an overlay topping slab may be used)
- Wall DL: SW, fire rated Plasterboard, 2 layers 13 mm Fyrchek)
- Bracing walls assumed (see Figure 9.27)

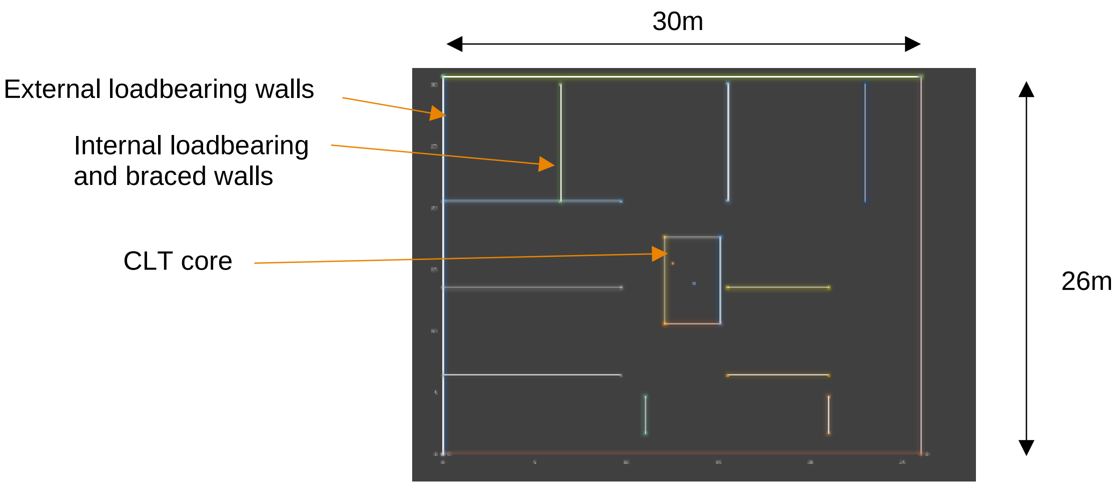


Figure 9.27. Analysis apartment plan of load bearing and bracing walls

Figure 9.28 provides a comparative summary of the results of the required wall stud configurations at each level within the eight storey building, for a range of different stress grade studs (MGP10, LVL14, LVL19, F27 and F34) and two different floor load width scenarios (FLW 3.5m, and 3.0m).

Table 9.10. Comparison of wall stud (90x45mm @ 450crs) requirements for a range of floor load widths and stress grades for an 8-storey apartment

FLW 3.5m, 7m Span Floor

	MGP10 (F'c 18) 90x45mm@ 450crs	Swd LVL (F'c 41) 90x45mm@ 450crs	Hwd LVL 19 (F'c 45) 90x45mm@450crs	Hwd F27 (F'c 51) 90x45mm@ 450crs	Hwd F34 (F'c 63) 90x45mm@ 450crs
Level 1	**1** stud	**1** stud	**1** stud	**1** stud	**1** stud
Level 2	**2** studs	**1** stud	**1** stud	**1** stud	**1** stud
Level 3	2 studs	**2** studs	1 stud	**1** stud	**1** stud
Level 4	**3** studs	**2** studs	**2** studs	**2** studs	**2** studs
Level 5	3 studs	**3** studs	2 studs	**2** studs	**2** studs
Level 6	4 studs	**3** studs	2 studs	**2** studs	**2** studs
Level 7	4 studs	**3** studs	**3** studs	**2** studs	**2** studs
Level 8	5 studs	**4** studs	3 studs	**3** studs	2 studs

FLW 3.0m, 6m Span Floor

	MGP10 (F'c 18) 90x45mm@ 450crs	Swd LVL (F'c 41) 90x45mm@ 450crs	Hwd LVL 19 (F'c 45) 90x45mm@450crs	Hwd F27 (F'c 51) 90x45mm@ 450crs	Hwd F34 (F'c 63) 90x45mm@ 450crs
Level 1	**1** stud	**1** stud	**1** stud	**1** stud	**1** stud
Level 2	1 stud	**1** stud	**1** stud	**1** stud	**1** stud
Level 3	2 studs	**1** stud	**1** stud	**1** stud	**1** stud
Level 4	**2** studs	**2** studs	**2** studs	**1** stud	**1** stud
Level 5	3 studs	**2** studs	**2** studs	**2** studs	**2** studs
Level 6	3 studs	**2** studs	**2** studs	**2** studs	**2** studs
Level 7	4 studs	**3** studs	2 studs	**2** studs	**2** studs
Level 8	4 studs	**3** studs	**3** studs	**2** studs	2 studs

As discussed previously the general advice has been that the limit for lightweight framing is approximately six stories. Above this, it is likely to be more efficient to use mass type wall products as the number of studs gets too high. The comparison provided in Figure 9.32 tends to support this contention for commonly available framing material such as MGP 10 (f'c 18) or LVL (f'c 41), particularly when larger floor load widths are required. It can be seen that:

- for an FLW of 3.5m, a floor cassette span of 7m, that
  - quadruple MGP10 studs (f'c=18) would be needed per 450mm crs at level 6, or
  - triple LVL studs (f'c =41).

The comparison provided in Table 9.10 also illustrates that for higher strength wall studs, particularly of an F27 (f'c 51) or F32 (f'c 63) grade, that the number of 90x45mm studs needed in the wall is significantly less.

New higher strength (F27 or better) LVL stud products would allow timber framed systems to be used in the lower levels of taller mid-rise timber framed buildings, or less overall stud numbers to be used in the wall systems.

Identification of critical wall system design criteria – wall stud capacity

Generally, wall studs carry compression loads from vertical dead and live load from the floor levels above; whilst external, and some internal braced stud walls, also carry lateral loads from wind forces. Studs are generally designed as compression members and checked for their performance under combined bending and compression actions.

The design compression capacity $N_{d,c}$ is given in AS 1720.1: $N_{d,c} = \emptyset\, k_1 k_4 k_6 k_{12} f'_c\, A_c$

$\emptyset$ - *Capacity factor*
k_1 – *Duration of load factor*
k_4 – *Moisture condition factor*
k_6 – *Temperature factor*
k_{12} – *Stability factor* used in calculating the capacity of studs
A_c – Area in compression
f'_c: compression parallel to grain – is the relevant material factor.

Compression parallel to grain (f'c) is the critical material design value for wall studs.

Figure 9.28 below provides a comparison of the maximum capacity (kN) of a 90 x 45 mm stud for a range of different stress grades (and their f'_c values).

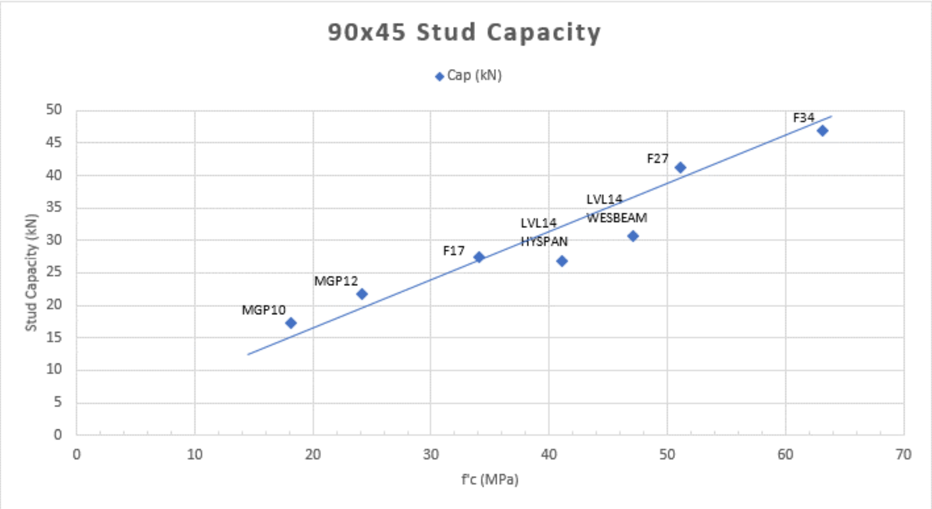


Figure 9.28. Capacity of 90 x 45 mm wall stud by stress grade for a 2.7 m wall stud fixed in the minor axis

It can be seen that as the stress grade of the stud material used increases, the capacity of the stud also increases (this is though, a non-linear relationship, as different grades will have different $\emptyset_c$ factors and may also have different $\emptyset$ factors).

Advanced LVL products of F27 or F34 grade could be utilised in higher strength mid-rise timber construction wall stud framing applications.

Target improved f'_c values suggest

- **f'_c = 51 MPa (F27 equiv.)**
- **f'_c = 63 MPa (F34 equiv.)**

Higher if possible

Identification of critical wall system design criteria – wall member crushing

With highly loaded lower storey stud walls in mid-rise timber framed buildings, another important material consideration is the capacity of timber members in regard to their resistance to crushing.

Elastic deformations due to compression loads are an issue of great interest with timber structures. Deformation of timber members loaded parallel to grain is generally small, in comparison to potential deformation (crushing) of members loaded perpendicular to grain. By example, studs loaded parallel to grain may show little deformation compared with the wall's top and bottom plates that they frame into, that can crush under high load (see Figure 9.29).

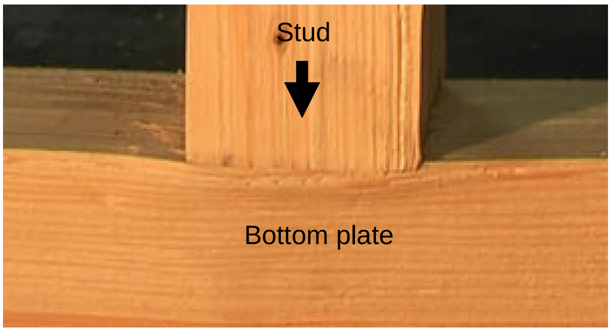


Figure 9.29. Illustration of perpendicular to grain crushing of bottom plate due to stud

AS 1720.1 requires two bearing capacity checks to be evaluated under Section 3.2.6:

- Bearing in the stud – parallel to grain; and
- Bearing in the top and bottom plates – perpendicular to grain.

In regard to the latter, the design bearing capacity for top and bottom plates loaded perpendicular to grain is given in Cl. 3.2.6.3 in AS 1720.1 Equation 9.1.

$$N_{d,} = \emptyset\ k_1\, k_4\, k_6\, k_7\, f'_p\, A_p$$

$k7$ is the length of bearing factor defined in Section 2.4.4 of AS 1720.1. It is only applicable to bearing perpendicular to grain and has the value 1.0 unless both:

- the bearing length is less than 150 mm; and
- the bearing is more than 75 mm from the end of the member.

$f'p$ - is the bearing strength perpendicular to grain given in Table H2.2 in AS 1720.1 and based on the Strength Group of the timber used. (Specific values for MGP grades are presented in Table H3.1 and LVL properties are available from the manufacturer.)

Ap - is the cross-section of the stud bearing on the surface of the top or bottom plate. In most cases for platform and semi-balloon framing, this is the full cross-sectional area of the stud

For platform framing, the bearing area at the end of the stud is used as the bearing area on the top or bottom plate (Ap).

Although the perpendicular to grain compressive strength of the plate is less than the parallel to grain compressive strength of the stud, the calculation of stud capacity must account for its ability to buckle, which significantly reduces its strength by a factor of three for a 2.7 m tall stud.

This means that for a smaller dimension stud, the grade of the plate can be less for the grade of the stud, and for a larger dimension stud, the grade of the plate may need to be greater.

It is noted that the lower storey studs of a mid-rise timber framed building could be over-sized to prevent perpendicular to grain failure in wall plates, i.e. the studs would be thicker (or more studs used) than required for stud compression, to prevent crushing perpendicular to grain in wall plates. This approach however could prove quite costly in major apartment projects. In this case, it is likely be more cost effective and structurally efficient to utilise top and bottom plates with a ‘higher’ compression perpendicular to grain performance.

A recent FWPA R&D study (TDA 2018) has investigated the influence of perpendicular to grain compression and creep in 4 to 8 storey lightweight timber framed buildings. The report concluded that if perpendicular to grain crushing of wall plates was an issue then design approaches that removed the wall plates out of the load path all together would be the best option.

However, if this is not possible, then the wall plates could be replaced with:

- alternative wall plate timbers with higher perpendicular to grain compressive strength such as higher-density hardwoods >800 kg/m^3

  (*interestingly, the study results for the cypress tests demonstrated a higher perpendicular to grain bearing value than that published in AS1720.1, almost double)*; or
- EWP’s with the majority of layers orientated with the parallel to grain timber in the load path, i.e. LVL or CLT wall plates.

In terms of perpendicular to grain bearing capacities of the timbers tested the study found that the

> *“AS1720.1 method to assign perpendicular to grain bearing capacities for various timber species by “strength group” or stress grade over predicted low to medium density timber species whilst under predicting high density timber species. From the research it was recommended that perpendicular to grain bearing capacity be assigned by timber density.”*

Improving the performance of wall top and bottom plates and the ‘compression perpendicular to grain strength’ is governed by the materials bearing strength perpendicular ($f'p$) which is related to the materials ‘Strength Group’. It is suggested that $f'p$ values of around 23 MPa should be targeted (F27 and F34 equivalent for SD2 Strength Group material – see Figure 9.30)

TABLE H2.2

CHARACTERISTIC VALUES FOR DESIGN RELATED TO STRENGTH GROUP

Strength Group		Characteristic values, MPa			
		Bearing		Shear at joint details	Tension perpendicular to grain
Unseasoned	Seasoned	Perpendicular to grain (f'_p)	Parallel to grain (f'_l)	(f'_{sj})	(f'_{tp})
	SD1	26	76	10	0.8
	SD2	23	67	8.4	0.8
	SD3	19	59	7.3	0.6

Figure 9.30. Table H2.2 from AS1720.1 defining $f'p$ values for different timber strength groups

Further investigation around material density improvement
Improved material density or 'pre-densification', is also an area for consideration for improving the crushing performance of top and bottom wall plates.

New research areas for densified wood laminates include:

1) pre-crushing,
2) heat treating,
3) resin filling, and
4) thermomechanical treatment.

Another manufacturing alternative could be to utilise stronger outer LVL laminate materials such as thin steel plate veneers, higher density veneers.

Another approach for highly loaded horizontal members such as wall plates or rim-boards to reduce perp-to-grain crushing issues could be to manufacture a new hardwood LVL or mass plywood billet, 90mm+ thick, with the grain oriented at 90 degrees to the conventional LVL direction and cut out appropriately thick plate products (see Figure 9.31). This would mean that the fibres with the strength parallel to grain (around three times the strength perpendicular to grain) would be aligned with the vertical wall loads, dramatically reducing the plate crushing effects.

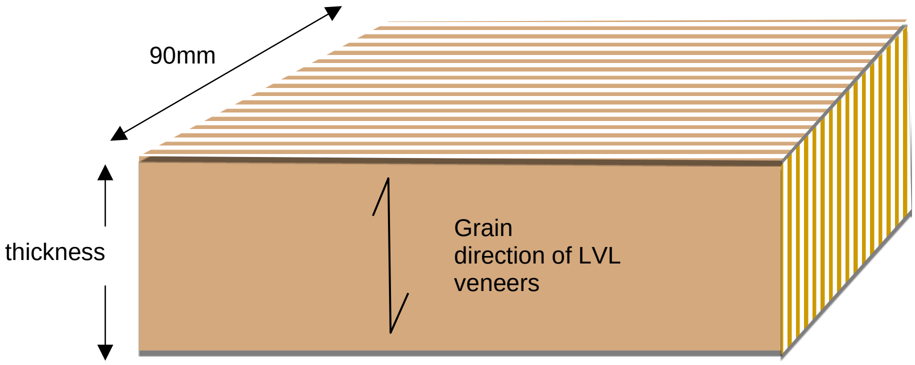


Figure 9.31. Possible new hardwood LVL/MPP product with grain orientated at 90 degrees

Some practical testing of these new products would be required to gauge how they performed in terms of nailing/fixing/potential splitting, etc.

Advanced LVL framing grade recommendations for mid-rise timber buildings

With current structural timber framing products, a significant practical market related issue is the overly large number of different types of timber members, stress grades, product dimensions, and species, produced and marketed by the wood products industry. This regularly provides confusion to building designers, engineers, architects and consumers. If the industry is seriously considering some new additional LVL timber framing options for the market, then this really needs to be pursued in a logical and considered way.

From an LVL perspective, a major focus by the LVL manufacturers active in the Australian markets since 2009 has been targeting the existing solid sawn hardwood F17 market with an LVL14 product, which provides in the main comparatively equivalent design properties (bar design joint group for some species).

With a new suite of advanced LVL framing products, it may be beneficial to:

1. work in alignment with the currently accepted structural timber product grade system, and

2. limit the additional grade market offerings with some logical grade-step improvements (so as not to add too many more products – and more market confusion).

Suggested targets for MoE for new manufactured advanced hardwood/hybrid LVL's could be:

- 14,000 MPa (F17 equiv. and effectively the current softwood LVL grade)

- 18,500 MPa (F27 equiv.)

- 21,500 MPa (F34 equiv.) grade.

The DAF initial prototype testing has indicated that

- a 100% *spotted gum* LVL can conservatively achieve an MoE of 24,000 MPa, so the upper F34 grade value appears achievable;
- a *spotted gum and hoop pine* alternate laminate LVL can conservatively achieve an MoE of 18,500 MPa, or an F27 equivalence.

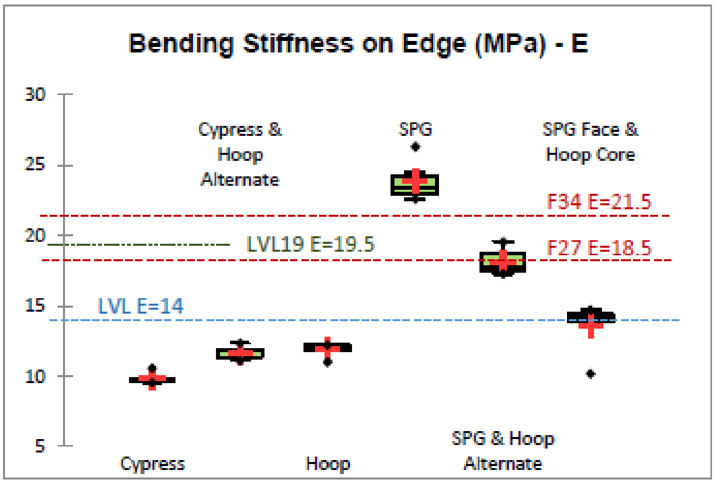


Figure 9.32. Initial prototype LVL testing results for MoE

This approach of targeting an F27 and F34 LVL product grade it is believed provides a real and significant potential opportunity for new hardwood and blended hardwood-softwood LVL products.

Reasoning:

- Australian produced LVL products with F27 and F34 equivalent performance does not currently exist – so it provides a 'market gap' (some tropical hardwood LVL19 (Keruing) has been imported in the past but some of its reported properties are less than F27).
- F27 is already well established and known structural product and for which markets already exist – F27 sawn timber is the core high strength structural product in NSW but also known in other states (so don't need to do a lot of new market development).
- F27 has demand and applications in the Class 1 market - so an established market already exists.
- F34 and F27 also have a great deal of potential opportunities as higher strength options to LVL14/15 in the emerging mid-rise timber framed market (truss chords, studs, plates, etc.) – this investigation has confirmed that in structural framing applications, it's hard to pin down on a specific application design scenario, to identify

a target MoE value. The fact really is that any higher MoE grade LVL materials above the current softwood maximum (E14/15) will definitely have mid-rise application. For example:

- o with wall studs – with higher stress grade material available – the higher buildings can be constructed in stud framed systems (not limited to 6-storeys),
- o with beams and truss chords - the higher the stress grade material available – the further members can span, or the smaller the beam/truss depth needed.

- Material cost will obviously be a significant factor in new product acceptance, however, the current pricing of F27 in the NSW market illustrates that in specific, more niche, high-strength applications where no other competing products exist, that good margins and returns can be achieved.

Advanced LVL 'heavy timber' elements for mid-rise timber buildings

Apartment and hotel type structures generally have many closely spaced walls, and are often used structurally as load bearing walls in a lightweight timber framed structural solution.

For office buildings (Class 5), an open-plan type layout with minimal structural elements is usually preferred by designers to allow the greatest flexibility with tenant fit-outs. As the majority of these type of buildings in the past have been constructed from concrete, a generally accepted and market expected column grid spacing is 9m x 9m; an optimum layout for post-tensioned concrete slabs. This market expectation provides a target grid-pattern for examination using timber floor elements and supporting beams and columns.

The most basic configuration would utilise primary support beams spanning 9m between columns with cassette floor panels spanning between these support beams as shown in Figure 9.33.

System / Product	Heavy timber framed members
Floors	• LVL floor-slab cassettes • LVL structural beams
Walls	• LVL structural columns
Roofs	• LVL rafters

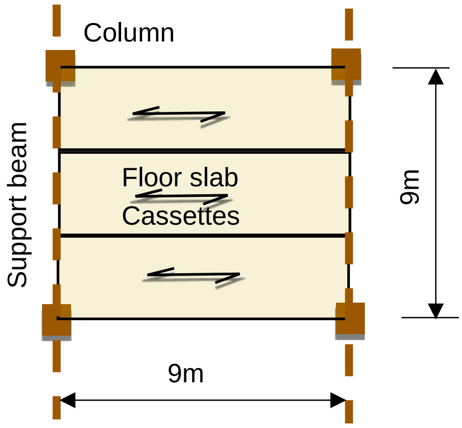


Figure 9.33. Typical office 9 x 9m grid

LVL rib-slab floor cassette

For longer spaning prefabricated floor cassette systems an approach of interest is the *LVL Rib-Slab Floor Cassette*, which is a prefabricated structural system constructed utilising thick LVL floor slabs rigidly connected by adhesives and screws to the supporting floor joist beams, see Figure 9.34.

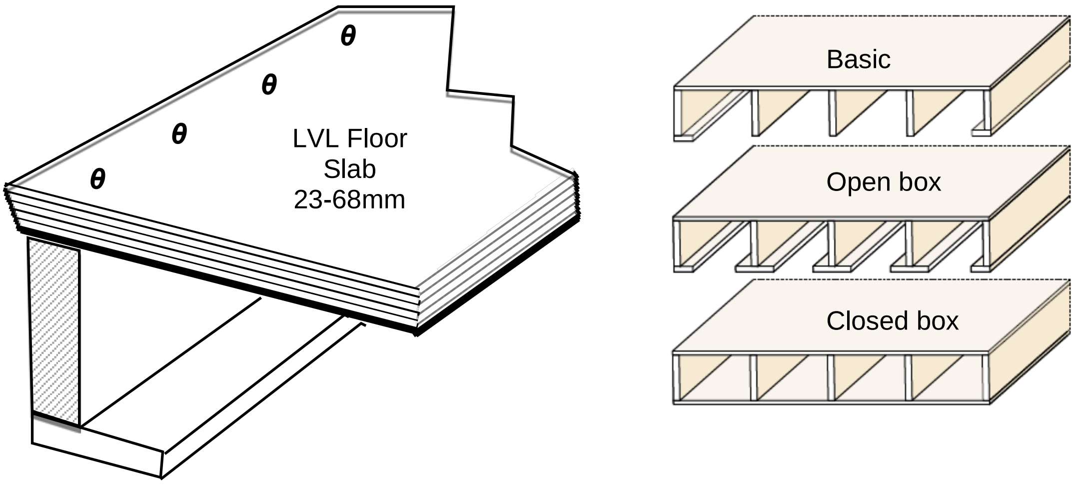


Figure 9.34. LVL Rib-Slab floor cassette module options

This approach allows a structurally optimised solution utilising composite action (bending and stiffness) of the thick LVL floor slab and supporting floor joist beams; providing a more material efficient solution than a solid CLT slab[15].

As shown in Figure 9.34, the cassettes could have three forms: basic, open box and closed box; each form providing respectively a more superior structural solution. The closed box form providing the most structurally effective approach.

The thick LVL floor slab as well as acting as the floor surface, also provides:

- an inherent acoustic performance improvement because of its greater mass (if the floor slab is greater than 40kg/m^2 and combined with other acoustic approaches, the floor system may not need an additional acoustic overlay topping),
- an improved dynamic (vibration) performance (greater flexural stiffness (EI) of cross members), and
- a stiff bracing floor diaphragm to assist in transferring lateral wind and seismic loads through the floor structure to the building core or bracing walls.

Optimal LVL floor slab dimensions would be:

- Thicknesses: from 45 – 75 mm, it is likely that some level of cross-banding would be required for LVL panel stability
- Widths: commonly produced 1.2m LVL billets could be used to form 2.4 m wide cassettes
- Lengths: current Australian made LVL billets available up to 13.5 m.

Eight different LVL rib-slab floor configurations were analysed as part of this report to assess the minimum depth required for a 9m span (G = 2.8 kPa, Q = 3kPa) and the results are summarised below in Figure 9.35 for an LVL14 product.

Type	Structural Depth
1. 63mm LVL floor slab open 100mm joists @500	543
2. 63mm LVL floor slab open 200mm joists @500	483
3. 150mm LVL floor slab open 100mm joists @500	530
4. 150mm LVL floor slab open 200mm joists @500	460

[15] Note: if acoustic performance required the use of a concrete slab overlay, this could also be designed as concrete timber composite member utilising the concrete to provided added structural performance along with its acoustic contributions; appropriate shear connectors would need to be provided to achieve composite action.

Type	Structural Depth
5. 63mm LVL floor slab top & bottom open 100mm joists @500	436
6. 63mm LVL floor slab top & bottom open 200mm joists @500	416
7. 150 mm top/63 mm bottom with 100mm joists @500	413
8. 150mm top/63mm bottom with 200mm joists @500	403

It can be seen from Figure 9.35, that utilising a 63 mm LVL floor slab and a basic cassette form, that a depth of 543mm would be required whereas a depth of 436mm would be required in a closed cassette form approach was adopted.

From a structural performance point of view the element stiffness (EI) again governs, so if higher MoE grade LVL was available, beam depths could be reduced.

Figure 9.35 illustrates this with plots for two LVL floor rib-slab forms, 1) a basic form using a single 63mm thick LVL floor panel (blue line), and 2) a closed box form using 63mm thick LVL panels top and bottom (orange line) of floor cassette depth vs modulus of elastic (MoE) of the cassette materials used.

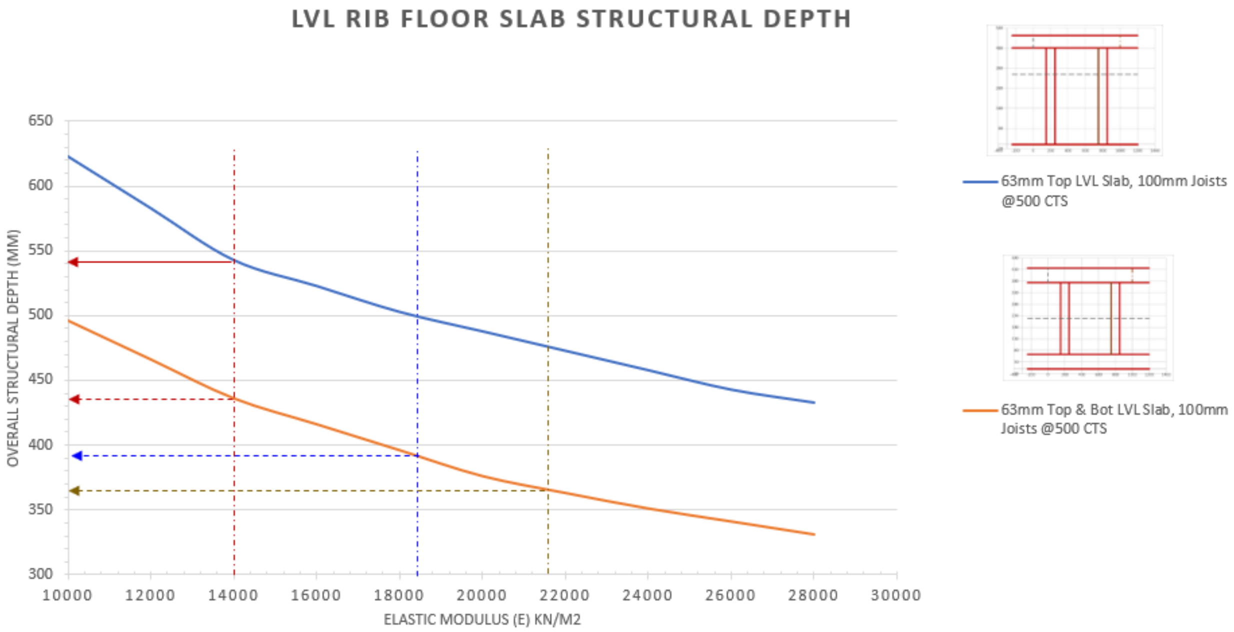


Figure 9.35. LVL rib-slab floors showing depth required for different modulus of elasticity material

From Figure 9.35, it can be seen that:

- using a closed box form and E14 material the rib-slab depth would be 436mm, however
- using and E18.5 (F27 equiv.) material would drop this depth to approx. 390mm, or
- using and E21.5 (F34 equiv.) material would drop this depth to approx. 365mm.

These depths, less than 500mm, are certainly encouraging for an optimally sized LVL rib-slab floor cassette solution for a 9m grid arrangement.

To achieve a 9m span with a conventional non-composite action floor truss arrangement would require truss depths around 660mm+ (see Figure 9.36 from Multinail's SteelWood brochure).

COMMERCIAL (Hebel Aerated Concrete Included)

SteelWood Size	Overall Depth	Timber Size	Maximum Spans for Commercial Floor Loads (3kPa / 2.7kN					
			300mm Centres			450mm Centres Timber Grades		
			MGP10	MGP12	MGP15	MGP10	MGP12	M
SWJ250	250	45x90	4600	5400	5600	4000	4800	5
SWJ300	300	45x90	5800	6000	6200	4600	5200	5
SWJ350	350	45x90	6000	6400	7000	4800	5800	6
SWJ400	413	45x90	6800	7600	8000	5600	6800	5
SWJ460	458	45x90	6800	8200	8800	5800	7600	7
SWJ560	560	45x90	7000	8600	9000	6400	8000	8
SWJ660	662	45x90	7600	9600	10400	6800	8600	9

Figure 9.36. Multinail's SteelWood Commercial floor truss spans

Using materials with higher modulus of elasticity, E18.5 or E21.5, the rib-slab floor depths for a 9m span could be brought down below 400mm. By reducing the secondary direction depth, services could run in the primary direction offering substantial value to architects

LVL support beams and columns

LVL support beams

Examining the floor support beam requirements for the 9 x 9 m grid configuration as shown in Figure 9.33 and assuming floor loadings of G = 2.8 kPa and Q = 3 kPa, Figure 9.37 provides a comparative summary of the overall depth required in the primary beams vs modulus of elasticity (MoE) of the materials used, for a range of different beam widths (135, 300, 600, 900 and 1,200 mm widths) for a 9m span and a 4.5m floor load width.

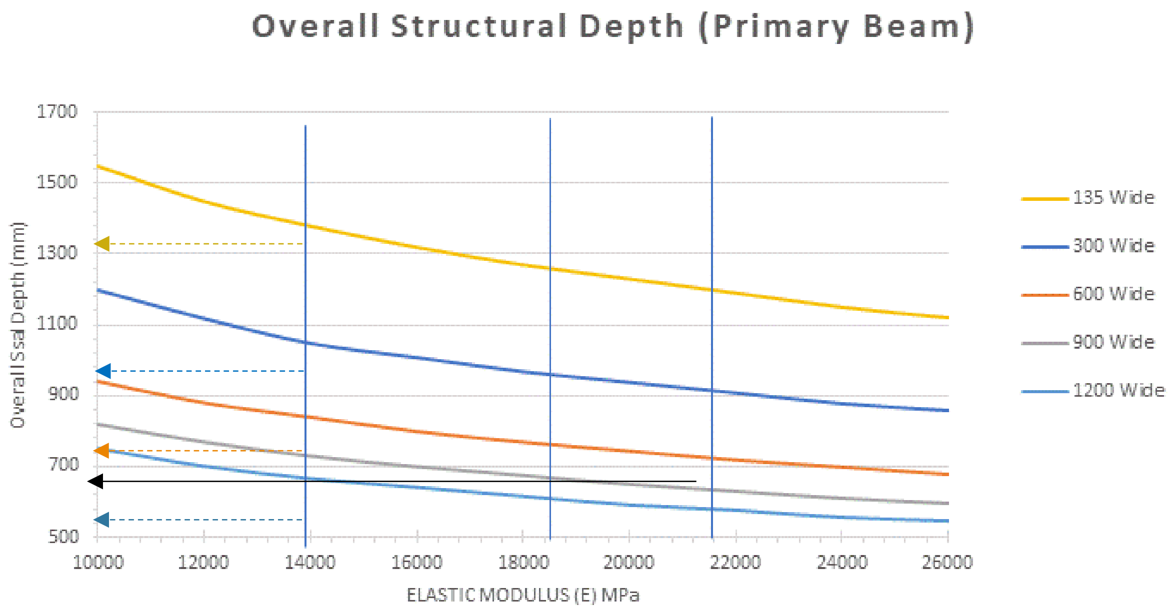


Figure 9.37. Primary beams for a 9m span grid, depth vs material E for various beam widths

It can be seen from Figure 9.37 that for a primary beam, if it was constructed using with E14, E18.5 or E21.5 materials, that the following approximate beam depths would be required for the different beam specified widths.

Table 9.11. Summary of required beam depths for a 9m span (4.5m FLW) for varying widths and MoE (E)

	Depth (and vol.) for Beam Material Modulus of Elasticity (MoE)		
Beam Width	**E14**	**E18.5**	**E21.5**
135mm	1,400mm (0.189m^3)	1,250mm (0.169m^3)	1,200mm (0.162m^3)
300mm	1,050mm (0.315m^3)	950mm (0.285m^3)	920mm (0.276m^3)
600mm	850mm (0.510m^3)	760mm (0.456m^3)	720mm (0.432m^3)
900mm	750mm (0.675m^3)	650mm (0.585m^3)	620mm (0.558m^3)
1,200mm	650mm (0.780m^3)	600mm (0.720m^3)	580mm (0.696m^3)

The figures above indicate that there is a significant opportunity to decrease the primary beam volume, for a similar depth, with improved beam material elastic modulus.

- For approximately 32% increase in MoE from E14 to E18.5, there is only approximately 10% decrease in span.
- For approximately 22% increase in MoE from E18.5 to E21.5, there is only approximately 4% decrease in span.

Using a higher MoE grade material can mean that a smaller dimensioned product could be used. The final determination will be the relative price difference between the different available MoE grade material.

LVL support columns

By improving the compressive strength of columns, the required surface area to carry the load reduces, and subsequently increases the sellable floor space for a given building. Figure 9.38 outlines the potential depth reduction for a square column for an improving compressive strength used in a 4, 7 and 10 storey building.

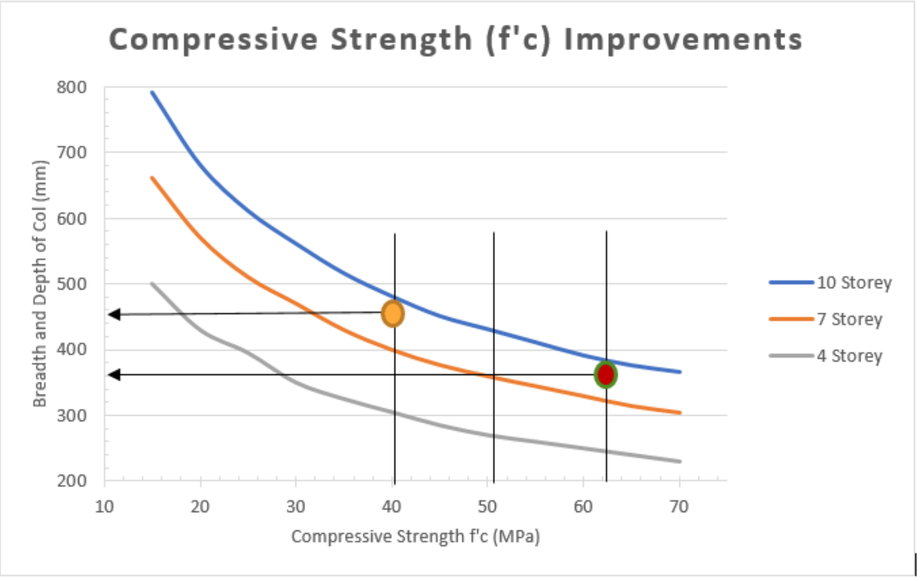


Figure 9.38. Square column dimensions with an improving compressive strength for a 4, 7 and 10-storey building with G =2.8kPa and Q = 3kPa

For the given geometry and applied loads, it can be seen that:

- A Hyspan "F17" (f'c 41 MPa) requires a structural depth of 480 mm (0.23 m^2).
- A F34 (f'c 63 MPa) column improves the depth to 390 mm. This grade improvement of 53% results in a reduction in depth of 14%, and reduces the column size by 26%.

Note the sellable floor space for an office building is approximately $10,000 per square metre. By improving the f'c from 41 MPa (Hyspan F17) to 63 MPa (F34) for a 10-storey building, there is an increased floor space of 0.08 m^2, improving the potential revenue by approximately $800 per column. There are potential market opportunities, if in this example, the increase in material cost is less than the $800 increase in sellable floor space.

New higher strength (F27 or better) LVL column products would increase the usable floor area as the column size is reduced. The final determination here will be the relative price difference between the different available f'c grade materials.

Structural beams – fire exposed

A further topic for consideration for large structural beams in mid-rise timber buildings is the fire performance.

Under the NCC provisions, all structural timber materials are required to be fully encapsulated with fire-rated linings to protect them against the required fire load. However, under the NCC Performance provisions, large timber elements can be left exposed if appropriately designed for the required fire load using the natural charring protection of the timber.

Market demand for exposed structural timber in buildings

There is an increasing desire by architects/building designers and developers with timber buildings to expose the timber structure and highlight the material's intrinsic natural appearance and sustainability attributes. The practice of Biophilic Design, or 'designing with nature' and natural materials, is currently very topical both here in Australia and internationally.

Recent research into biophilic design, *Workplaces, Wellness & Wood* (FWPA, 2018), has demonstrated that buildings designed on biophilic principles, including natural looking wooden surfaces in the workplace, are strongly associated with increased employee well-being and satisfaction; in turn enhancing engagement, creativity, innovation, retention and wellness - and all of which leads to improvements in productivity and personal and business success. Figure 9.39 illustrates the beauty of exposed fire-designed timber beams and columns at Library at the Dock in Melbourne.

Figure 9.39. Fire designed exposed timber beams and columns at Library at the Dock, Melbourne

Anecdotal reports on the rental returns for the new International House in Sydney has also indicated that rental clients are prepared to pay higher market rates for buildings with high biophilic attributes including exposed timber materials.

Fire design of exposed timber elements

If a beam or column is to be left exposed, then the practice is to design the members for the section size required structurally, and then to add a specific thickness of timber to all fire exposed surfaces dependant on the fire load the members needs to resist. This additional timber provides a sacrificial layer that will char during a fire, and once charred, will serve to protect the residual timber within required for the structural load resistance.

Figure 9.40 illustrates how this effective depth of charring can be “added” to the required structural section in order to provide adequate protection for the required fire resistance period.

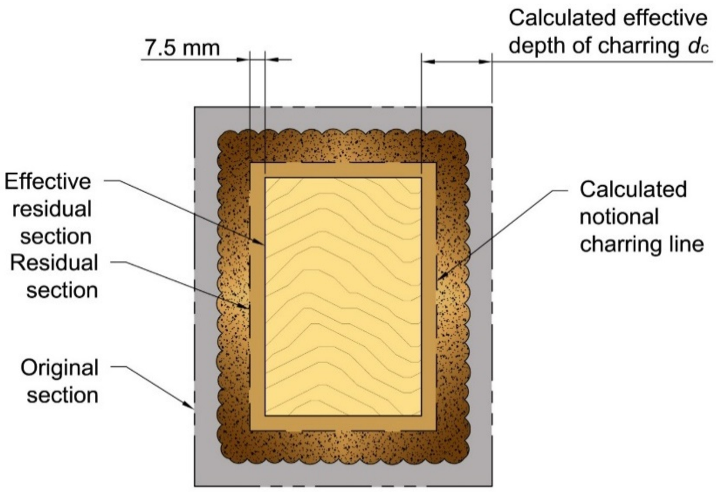


Figure 9.40 Loss of section due to charring

The effective depth of charring required for a timber member, for a specific fire-resistance period, is based on the timber species density and can be calculated using AS 1720.4 (Standards Australia, 2006).

Table 9.12 shows this calculation for specific time periods and demonstrates the desirable relationship between increasing wood density the decreasing effective depth of charring.

Species	Density
Radiata pine	550 kg/m^3
Victorian ash	650 kg/m^3
White cypress	700k g/m^3
Shining gum	700 kg/m^3
Jarrah	800 kg/m^3
Blackbutt	900 kg/m^3
River red gum	900 kg/m^3
Karri	900 kg/m^3
Spotted gum	1000 kg/m^3
Blue gum	1000 kg/m^3

Table 9.12. Effective depth of timber charring in relation to timber species density

Species Density (kg/m^3)	Notional Char Rate (mm/minute)	Time Period (minutes)					
		30	60	90	120	180	240
		Effective Depth of Charring (mm)					
550	0.66	28	48	67	87	127	166
650	0.59	26	43	61	78	113	149
800	0.52	24	39	55	71	102	133
1000	0.48	22	37	51	65	94	123

So, for a fire resistance time period required for offices of 120 minutes, it can be seen that:

- the effective charring rate for a 550 kg/m^3 species (e.g. radiata pine) is 67mm,
- whilst for a high-density species at 1,000kg/m^3 (e.g. spotted gum), the effective depth of charring is reduced to 55mm.

Opportunities for improved fire performance from advanced LVL products

With the potential manufacture of advanced engineered hardwood products, a beam or column could be manufactured using different higher density outer laminates to improve the notional charring capacity of the element.

As an example, in the design for a 90 minute structural fire adequacy period (FRL 90/–/–) of an LVL beam or column, it could be designed and manufactured with the outer 51mm of laminations utilising spotted gum or similar (density: around 1000 kg/m^3) to achieve the required fire-char resistance while the encapsulated structural member could be of a similar or different material (see Figure 9.41). The effectiveness of the fire performance is dependent on the adhesive type used.

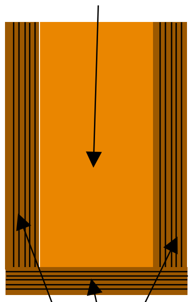


Figure 9.41 Fire protected timber with higher density outer laminates

Table 9.13 illustrates the percentage of timber that could be "saved" with increasing timber density across all the relevant time periods; in accordance with AS 1720.4. This "saving" can be used to offset any higher material costs.

Table 9.13 Percentage timber saving in relation to timber species density

Species Density (kg/m3)	**Notional Char Rate (mm/minute)**	**Time Period (minutes)**					
		30	**60**	**90**	**120**	**180**	**240**
		Percentage material saving compared to 550 kg/m^3 (%)					
550	0.66	0	0	0	0	0	0
650	0.59	7.1%	10.4%	9.0%	10.3%	11.0%	10.2%
800	0.52	14.3%	18.8%	17.9%	18.4%	19.7%	19.9%
1000	0.48	21.4%	22.9%	23.9%	25.3%	26.0%	25.9%

It can be seen from the figures above that there is a real potential to take advantage of the advantages of higher density hardwood species in relation to the fire performance of exposed structural timber members. For new EWP's, these potentially could be either single species or a blend of different species. Species such as spotted gum and blue gum with densities of 1,000 kg/m^3 could therefore be particularly attractive for higher performance product manufacture.

For a 90min fire performance level, the saving in material using a 1,000 kg/m^3 density species over a 550kg/m^3 structural core product is approximately 24%.

Using higher density hardwood timber would enable smaller cross-sections to be used due to the inherent structural strength and slower charring rate.

Simply based on charring rate, a hardwood timber column would be at least 30-66 mm less in each cross-sectional dimension compared to a lower density softwood column.

Other fire related considerations – glue types

In Australia, the manufacturing of EWPs such as plywood, LVL and Glulam have predominately used phenol, resorcinol, phenol-resorcinol and poly-phenolic glues. These adhesives are thermosetting glues and are deemed not affected by fire; therefore, they do not impact on the fire-resistance of the structural member and the product's fire-resistance can be determined in accordance with AS 1720.4.

Other glue types such as polyurethanes (PUR), Emulsion Polymer Isocyanate (EPI), Melamine-Urea Formaldehyde (MUF) can impact on the product's fire performance, and therefore require certification for use via fire testing. These "newer" adhesives provide greater flexibility for the manufacture of EWPs (e.g. glue setting times, feedstock moisture content); but from a 'fire resistance perspective', these adhesive types do not perform as well as Phenol/Resorcinol type adhesives and new design approaches have been developed by the product manufacturers based on fire testing.

New EWPs using the non-thermosetting glues are likely to have to undergo specific fire testing in Australia to demonstrate their expected performance.

Recommendations and suggestions for product manufacture investigation

An opportunity exists to utilise the slow charring rate of the higher density hardwoods in fire-designed exposed timber elements with manufacturing of the LVL product focusing on using the LVL:

- as the sole material for the entire (whole) beam and/or column element; or
- as the sacrificial fire-protective covering to the main structural beam and/or column element.

The species selection, product composition and glue types used would be influenced by the end use application as described below.

Considerations and Approaches

a) Entire beam/column element
When using glued-laminated timber products, the impact of the glueline on the fire performance of the glued products is a major consideration. If adhesive systems other than phenolic or resorcinol-based systems (as permitted by AS 1720.4) are to be used (e.g. polyurethane), then fire tests in accordance with AS 1530.4 are required to determine the effective char-rate and any delamination potential of the LVL product.

b) Fire-protective covering
If using the LVL as a 'fire-protective covering', the connection of the LVL to the main structural element will be via metal connectors, glue or a combination of both. Fire testing should be undertaken to investigate key aspects of the installation including fastener spacing and protection (e.g. plugs), glue types, junction and corner joint detailing and protection (e.g. fire mastics).

Advanced LVL 'massive timber' elements for mid-rise timber buildings

The interest from building professionals in 'mass timber elements' such as cross laminated timber (CLT) is currently extremely high in Australia. However, one of the inhibitors to more rapid take up is the lack of local supply. The commencement of operations by XLam Australia at Wodonga in May 2018 as Australia's first commercial CLT manufacturing facility will go some way to reduce this impediment, but it is expected that the future local demand for mass timber products will still mean supply pressures. Alternative solutions for massive timber products are therefore of high interest to the timber and building sectors.

System Product	Massive timber panels
Floors	• LVL mass floor panels
Walls	• LVL mass wall panels
Roofs	• LVL mass roof panels
Lift & Stair Shafts	• LVL mass shaft panels

The NCC defines massive timber as:
"an element not less than 75mm thick as measured in each direction formed from chemically bonded laminate timber and includes:

a) Cross Laminated Timber (CLT),
b) Laminated Veneer Lumber (LVL), and
c) Glued laminated timber (Glulam).

LVL is an obvious alternative for CLT in mass panel products in mid-rise timber construction such as floors, walls, roofs and shafts. In terms of Australian production, Wesbeam announced (Wesbeam, 2018) in August 2018 that they have available two new 'made to order' mass panel LVL products to target the mid-rise market as part of their *Tall Timber Building Systems* program activities.

e-slab

- an Australian made, high strength to weight ratio solid engineered timber panel
- Width – 1.2m
- Thickness range – 28mm, 35mm, 45mm, 63mm, 75mm
- E2S treated
- No blue e-seal applied
- Produced from certified Australian plantation timbers.

e-slab [architectural]

- an Australian made, high strength to weight ratio solid engineered timber panel with an expressed natural high feature natural timber surface on the top and bottom faces
- Width - 1.2m
- Thickness range – 28mm, 35mm, 45mm, 63mm, 75mm
- Closed scarf joints on the face
- No blue e-seal applied
- E2S treated
- Produced from certified Australian plantation timbers.

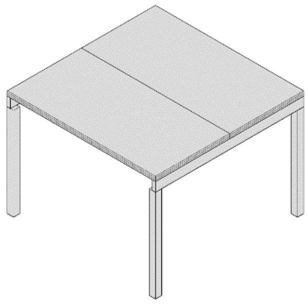
Wesbeam have announced that these products will be targeted at:

- Horizontal applications: LVL floor cassettes, LVL box-beams, LVL mass floors, LVL mass beams, and
- Vertical applications: LVL Box columns, LVL Mass Columns, LVL mass walls and LVL post tensioned mass walls.

LVL mass floor panels

For mass timber floors, LVL, glulam or CLT mass panels might be used. For CLT floor panels in mid-rise multi residential apartment applications, spans range from approx. 3.0 m for 100 mm thick panels to up to around 6.5 m for 300 mm deep panels (see Figure 9.42).

LVL or glulam floor panels



CLT floor panels

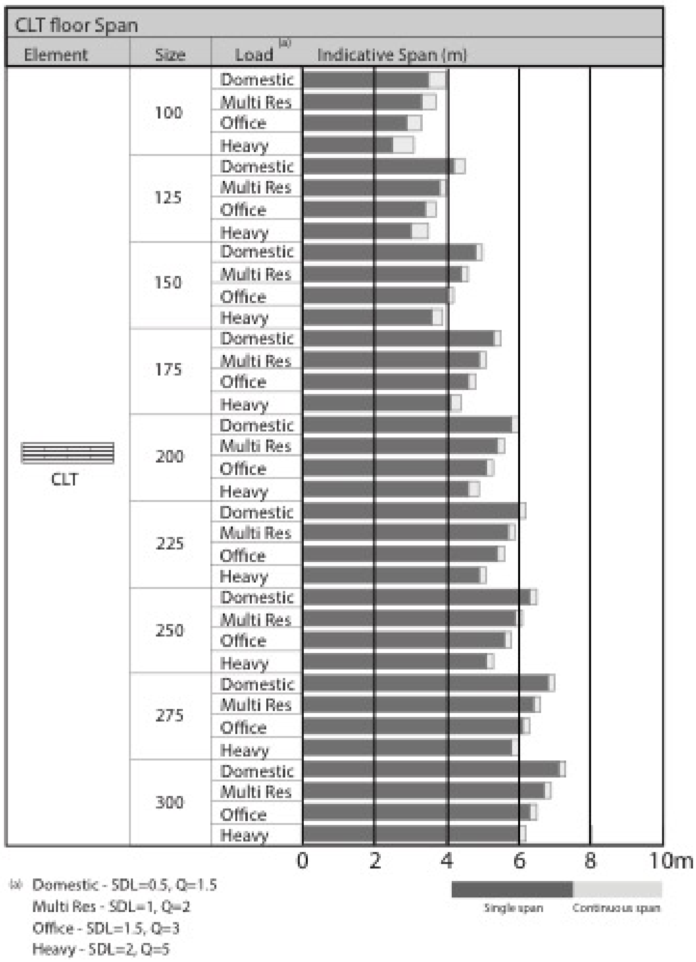


Figure 9.42. Indicative CLT floor panel spans – from WS Tech Guide #? 2018

With CLT in floor panel applications, the laminates with the grain running in the span direction provide most of the structural resistance, particularly the two outer most laminations; the top laminates in compression and the bottom laminates in tension. The cross-lamination layers can, depending on the panel lamination, provide some two-way spanning action as well as transferring shear forces within the element.

With LVL floor panels, all of the grain (unless there are some cross-bands) is running in the span direction. So LVL panels used with a one-way spanning action will, assuming a consistent MoE value, have a moderate improvement in bending and deflection performance.

Also, if an LVL with a higher material MoE value could be utilised, spanning capabilities could be increased or panel depths reduced.

Figure 9.43 illustrates the different depths required for both CLT (E- 8,000MPa) and LVL mass floor panels (E's of 14,000, 18,500, 21,500MPa) for spans 5.0m and 5.5m

(Loading: G = 1.6 kPa, Q = 1.5 kPa (Class 2 building loads), and the dynamic check governs design, based on frequency of structure).

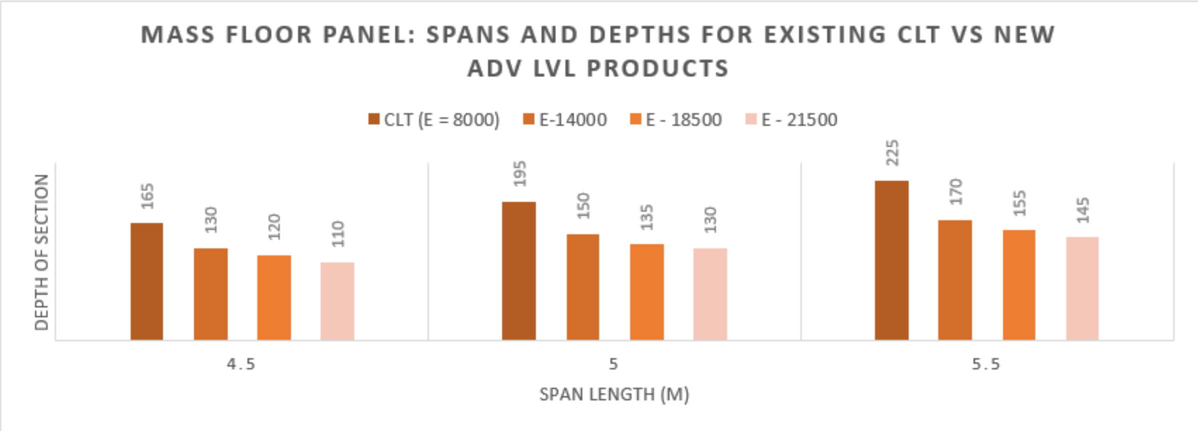


Figure 9.43. Floor panel depths of CLT and LVL of different E values for 5.0 and 5.5m spans

It can be seen from Figure 9.43 that:

- An LVL mass floor panel using standard LVL17 products will be around 20-25% thinner than a CLT panel (E-8,000MPa)
- Using higher E grade LVL panels also results in thinner panels around 10% difference between the current LVL14 (equivalent to F17) products and an F27 LVL.

LVL mass floor panels are a major product segment of interest for Wesbeam's new 'e-slab' product, particularly the 63 mm and 75 mm billets. The plan would be for fabricators to build up in-factory mass product elements utilising a number of panel thicknesses, screwed and glued together using polyurethane based glues, see Figure 9.44.

These mass floor panels could then be installed on site using a number of different construction techniques. Figure 9.45 shows both a 'stepped assembly' which effectively gives a 1.8m wide coverage, and a 'block assembly' which gives a 1.2m wide coverage; this approach also utilises an infill strip installed on-site between the panels to provide panel linkage and fire protection by minimising airflow through the joint.

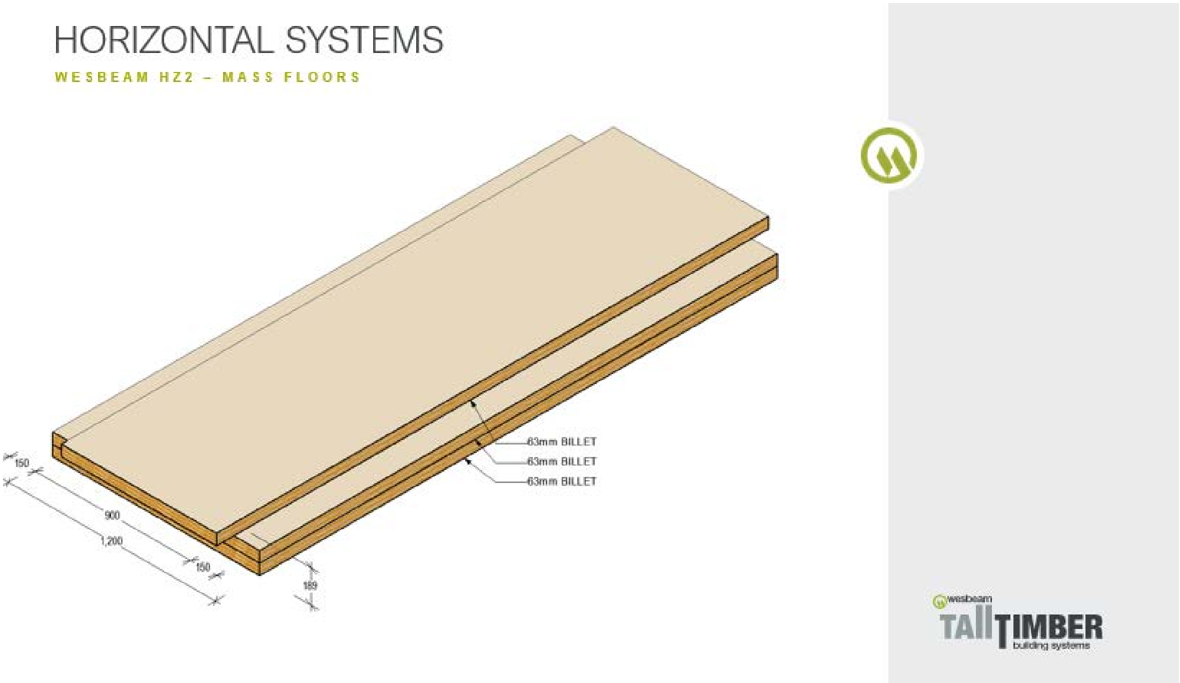


Figure 9.44. Wesbeam e-slab used in mass floor panels (image: David Bylund Wesbeam)

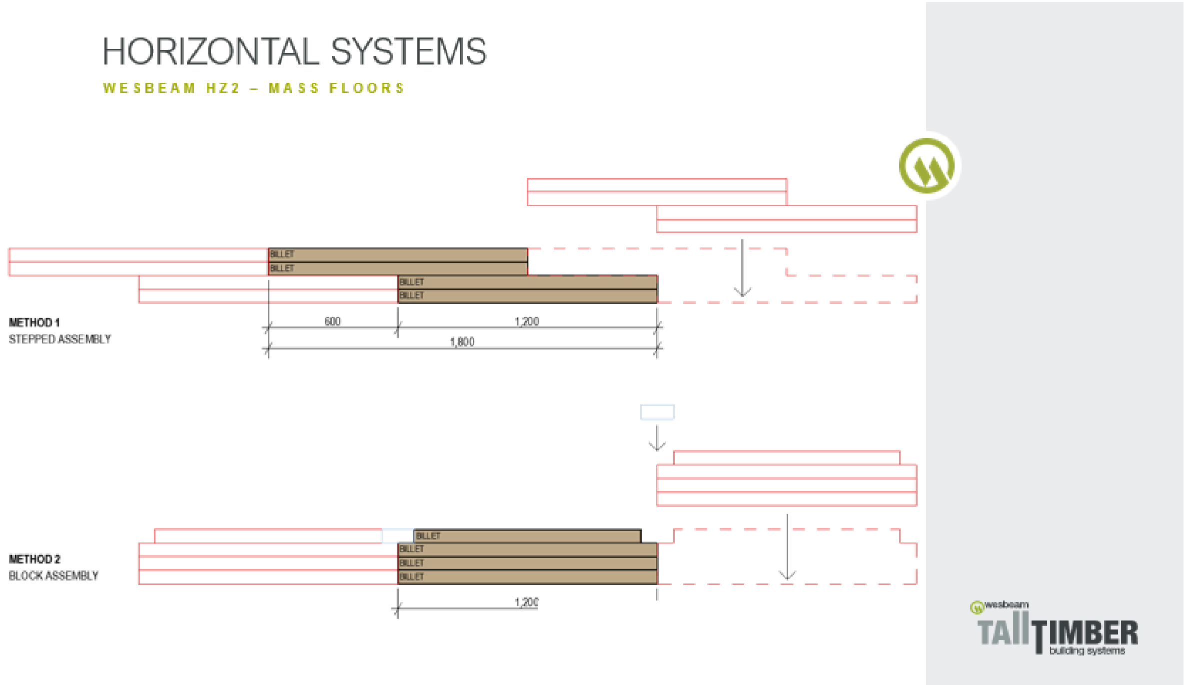


Figure 9.45. Possible joining arrangements for mass floor panels (image: David Bylund Wesbeam)

LVL mass wall panels

LVL also makes for a very effective mass wall panel type product compared to CLT. This is due to the fact that with LVL all the grain in the laminates is running parallel to the vertical load (unless cross-bands are included) and as such contributes to vertical load resistance. With CLT, by comparison, the cross laminations do not contribute to vertical load resistance.

LVL provides a simple alternative to CLT in mass wall applications. The 1.2 m wide panels can be easily handled by prefabricators and again thicker, or longer mass wall panel sections can be built up by screwing and gluing. Typically, the length of these wall panels would be around 2.1 – 3.6 m if the floor / wall joint was to use a platform approach where the floor cassettes sit directly in bearing on top of the wall. If desired, another alternative could be to use longer wall panels over two stories (so panel lengths of around 7.2m would be required) and a semi-balloon framing approach for the floor/wall joint, where the floor cassettes are fitted between the walls bearing on ledger plates fixed to the wall.

Figure 9.46 illustrates a vertical application for Wesbeam's new e-slab mass wall panel.

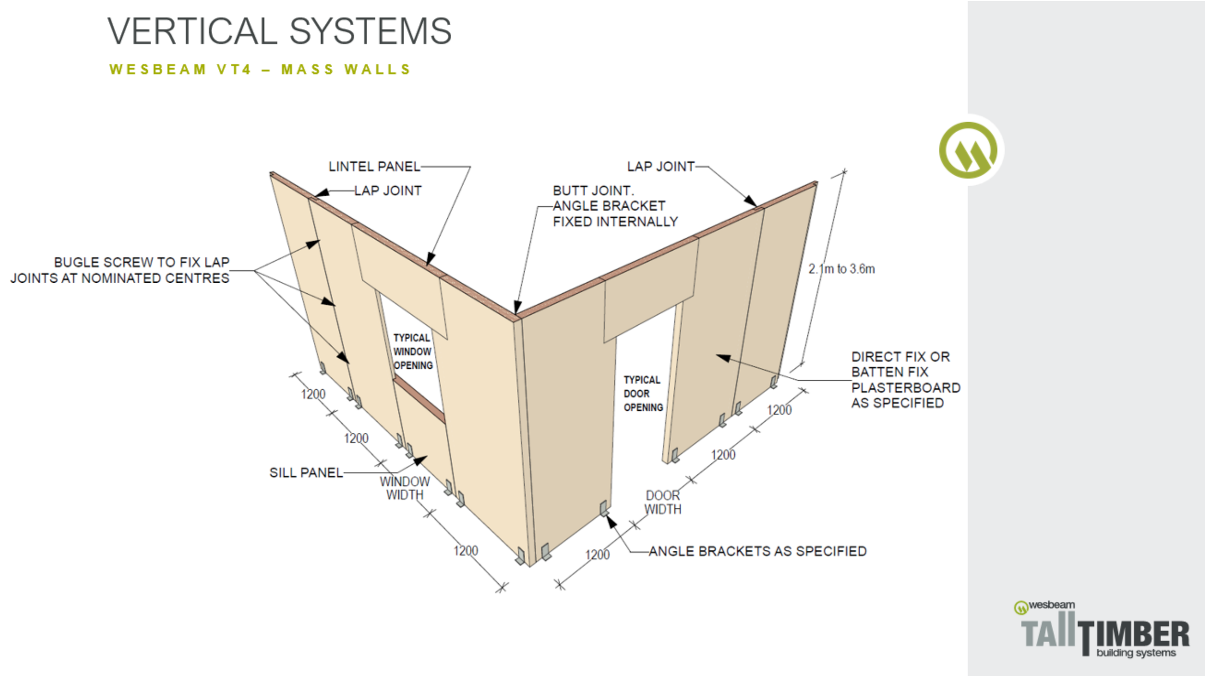


Figure 9.46. Wesbeam e-slab used as a mass wall panel (image: David Bylund Wesbeam)

LVL mass shaft panels

The limiting factor for tall timber buildings is typically the inter-storey drift, which is the amount of horizontal movement per floor under wind or earthquake forces, and is reduced for an improved stiffness, EI. By improving the Elastic Modulus and/or the geometric properties of the cores within a building, the overall horizontal movement can be reduced enabling additional floors and sellable floor space. Currently, timber buildings typically require concrete cores above certain heights to improve the overall stiffness of the building for an acceptable movement.

A demonstrative example that shows the total inter-storey drift for a range of E values is shown in Figure 9.47.

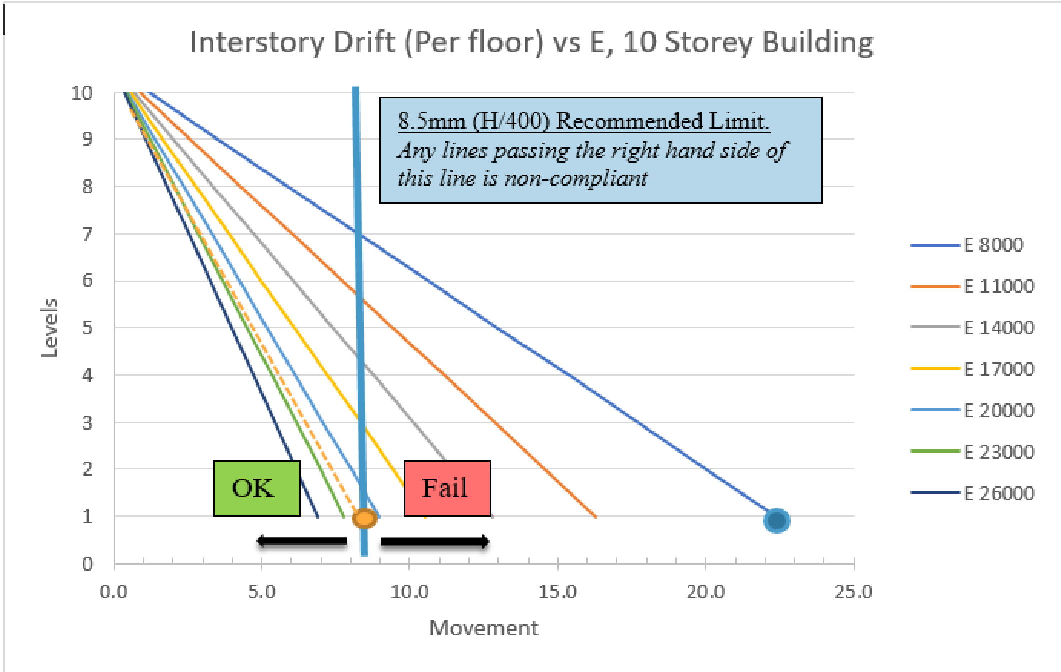


Figure 9.47. 'Back of the envelope calculation' indicating the improvements for an increasing elastic modulus

For the given geometric properties, from Figure 9.47 it can be seen that:

- The elastic modulus of existing CLT products may not be able to reduce the horizontal movement (inter-storey drift) to acceptable limits.
- An MoE value of approximately 21,500 MPa (equivalent to F34) can increase the stiffness and reduce the horizontal movement to within the acceptable limit of 8.5mm.

Using materials with higher modulus of elasticity, E18.5 or E21.5, the total height of timber buildings that are limited by horizontal movement, could be extended. **By enabling the additional building height, and extra floors with sellable floor space, high value products with F34 properties could offer significant value to building designers.**

Opportunities for exposed LVL stair elements

The NCC provides a concession for stairways allowing timber treads, risers, landings and associated supporting framework to be used within both non-fire-isolated and fire-isolated stairways/passageways subject to several conditions.
The conditions specific to timber products are that the timber treads, risers, landings and associated supporting framework:

(i) have a finished thickness of not less than 44 mm; and

(ii) have an average density of not less than 800 kg/m^3 at a moisture content of 12%.

Some timber species that would meet this density requirement include [*species (density kg/m^3)*]: spotted gum (1,000), red ironbark (1,050), river red gum (900), turpentine (945), blackbutt (900), silver top ash (850), kwila or merbau (850).

Higher density advance LVL's could be manufactured to service the demand for timber stairways for use in mid-rise timber buildings as they are easier to pre-fabricate, erect on site and speed up overall building construction.

This NCC Stair Concession opens some specific and unique opportunities for higher density hardwoods and for potential new specialist stair products.

There is an immediate opportunity for the manufacture of high density (min. 800 kg/m^3) LVL for use in commercial stair construction in accordance with the NCC fire provisions. These higher density stairs are required for both non-fire-isolated (internal) and fire-isolated stairways (fire exits). As these stairs would be in accordance with the fire provisions, they would be Deemed-to-Satisfy and no further 'investigation' would be required depending on the adhesive used.

If, however, a hybrid LVL product was preferred e.g. high-density outer veneers with lower density inner veneers, a fire test would be required to demonstrate equivalency of performance to the DtS stairs.

A typical product specification would be as follows:

Cross-sections	250 x 45 mm (stair treads, landing) 300 x 45 mm (stringers)
Lengths	0.9-2.4 m
Density	Average 800 kg/m^3 (minimum)

Mid-rise timber buildings - market potential

It should be noted that the Class 2, 3 and 5 mid-rise timber building sector is an emerging and dynamic market development area in Australia at present where new architectural and engineering design approaches are still being explored, determined and developed.

As the mid-rise sector is not an established market, rather an active new market development, the information reported here on possible market size should be treated as purely hypothetical, based on many assumptions and opinions.

It is proposed that the following process to estimate market potential be considered to give some estimates of potential product volumes.

1. An assessment has been undertaken of two types of buildings with four types of product-variable construction approaches:
   1) a Class 2 apartment building of 6 levels with a 34 x 22 m footprint, constructed from
      - Lightweight floor trusses and wall studs with a concrete core,
      - Lightweight floor trusses and wall studs with a massive timber core, and
      - Massive panel timber floors, lightweight wall studs with a concrete core.

   2) a Class 5 office building of 6 levels with a 30 x 45 m total footprint, constructed from timber cassette floors, primary beams and massive timber core.
2. A calculation can then been made of the approximate volume (in m^3/m^2 of floor area) of timber products in the different products / applications and a comparison made of the different systems and the percentage of timber used in the different applications.
3. The anticipated floor area for apartments to be constructed in Australia per year is estimated using data from ABS 2018. Using this data, a percentage-timber market share value can be assumed to provide an indication for different potential levels of market size (in m^2).
4. The results from stage 3 can then be combined with those of stage 2 to get some range-estimates for potential market size for different products.

5. Also, with the results of stage 4, a %-sensitivity analysis can be used to get a feel for how much volume might end up in different potential advanced LVL applications (F27 or F34).

This proposed process and the assumptions that might be used are now explained in further detail

Building assessment process and assumptions to determine volumes

To provide an indicative and comparative feel, the volume of each structural element, per unit in m^3/m^2 has also been calculated for two building construction types and four construction methodologies

- Class 2 apartment building of 6 levels with a 34 x 22m footprint (as indicated in Figure 9.48), constructed from
  - Lightweight floor trusses and wall studs with a concrete core,
  - Lightweight floor trusses and wall studs with a massive timber core, and
  - Massive panel timber floors, lightweight wall studs with a concrete core.
- A Class 5 office building of 6 levels with a 30 x 45m total footprint, constructed from timber cassette floors, primary beams and massive timber core

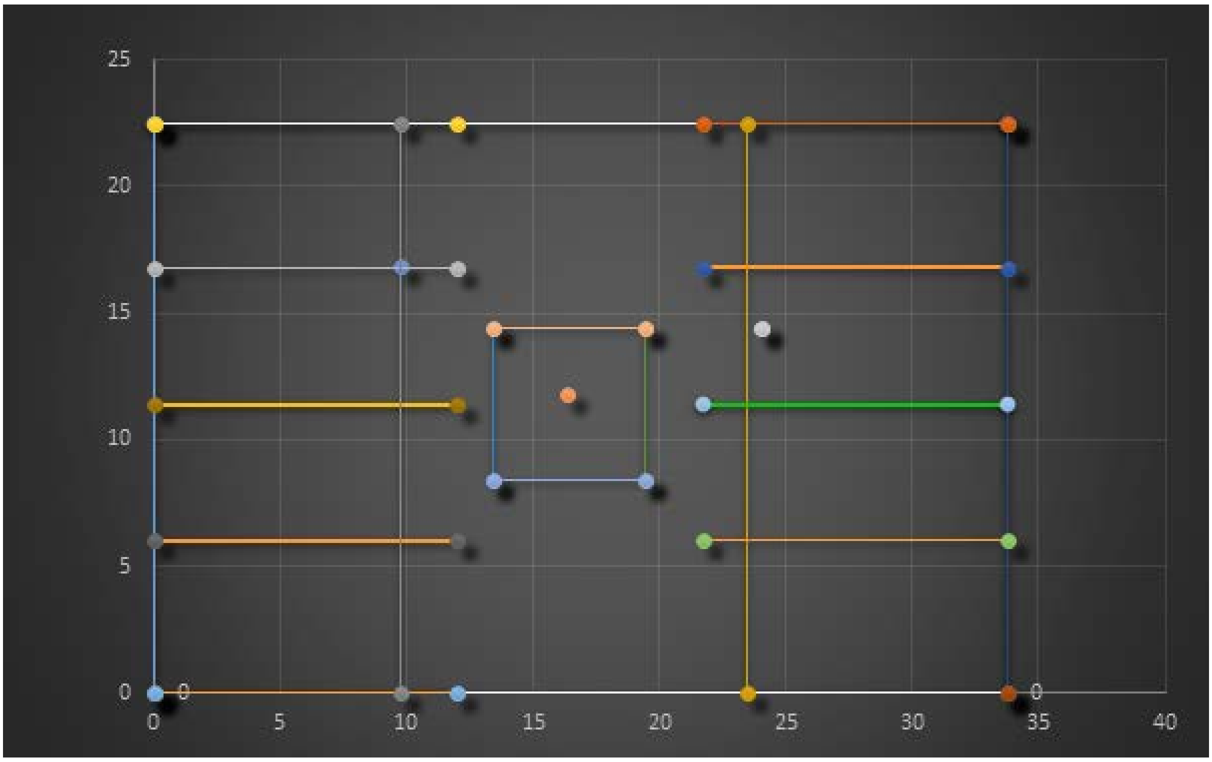


Figure 9.48. Class 2 apartment building used in product volume estimate analysis

With the two buildings the following product use assumptions have been used.

Table 9.13. Assumptions around materials used in product volume estimate analysis

Application	Timber product sizes assumed
Lightweight truss floors:	floor trusses at 450mm crs comprising 2 x 90 mm x 45 mm chords
Lightweight stud walls:	90 mm x 45 mm studs at 450 mm crs assume single studs top 3 floors, double studs bottom 3 floors (as per Fig 3.32, FLW 3.0 m LVL)
Wall top & bottom plates:	90 mm x 45 mm
Mass timber core	190 mm thick mass timber floor
Mass timber core	190 mm thick mass timber
Primary beams	2x 300mm x 900 mm beams
Columns	450 mm x 450 mm

Calculation and comparison of volumes of timber used in different products

Table 9.14 summarises the volume of timber used in each of the products in m^3/m^2 for the four construction methodologies.

Table 9.14. Volume of timber used for products in the four construction methodologies (m^3/m^2)

		Lightweight (m3/m2)			Mass Timber, Post and Beams (m3/m2)				
		Plates	Studs	Floor Truss	lassive Timb	Cores	Columns	Cassettes	rimary Beam
Class 2 Buildings	Class 2	(m3/m2)	(m3/m2)	(m3/m2)	(m3/m2)	(m3/m2)	(m3/m2)	(m3/m2)	(m3/m2)
	1. Lightweight Trusses and Studs, Concrete Core	0.0031	0.0123	0.0180	0.0000	0.0000	0.0000	0.0000	0.0000
	2. 190mm Massive Floor Slabs, Studs, Concrete Core	0.0000	0.0123	0.0000	0.1890	0.0000	0.0000	0.0000	0.0000
	3. Lightweight Truss and Studs, LVL Core	0.0031	0.0123	0.0180	0.0000	0.0040	0.0000	0.0000	0.0000
Class 5 Buildings	4. Columns, Cassettes and Beams	0.0000	0.0000	0.0000	0.0000	0.0045	0.0038	0.1880	0.0900

The total volume of timber for each construction methodology per unit m2 is presented in Table 9.15.

Table 9.15. Total volume of timber for each construction methodology

		m3/m2 (total)
Class 2 Apartment Buildings	1. Lightweight Floor Trusses and Studs, Concrete Core	0.06
	2. 190mm Massive Floor Slabs, Studs, Concrete Core	0.20
	3. Lightweight Floor Truss and Studs, Mass Timber Core	0.06
Class 5 Buildings	4. Floor Cassettes, Primary Beams and Columns	0.29

The total volume of timber for each construction as a percentage is illustrated in Figure 9.49.

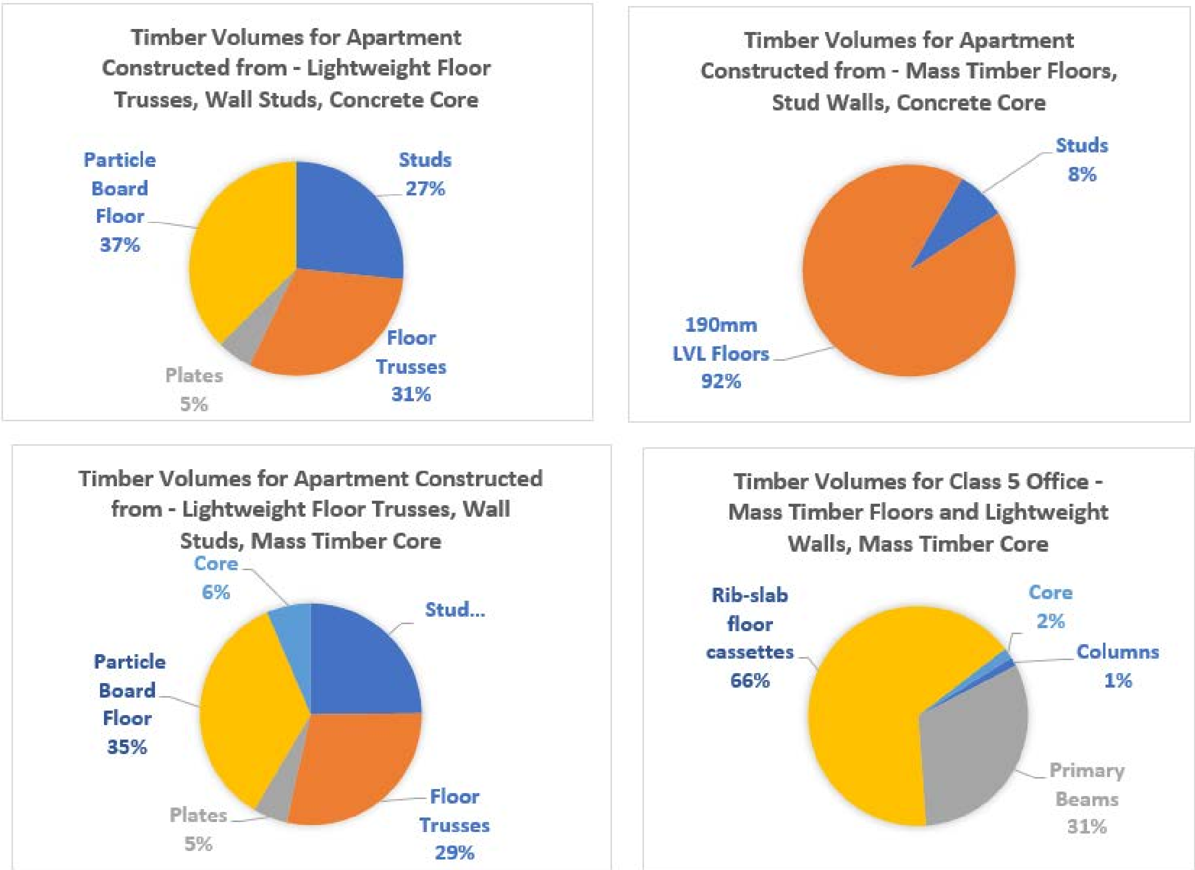


Figure 9.49. Total volume of timber by percentage for each construction methodology

It can be noted that significantly more timber is required for massive timber project applications, particularly for Class 5 buildings due to the increased floor depths required to meet the increased spans. The proportion of each element within each construction type can give indication of where most potential for new products by volume is held.

Estimate of total square meterage of apartments and proportions of timber

Statistics for the total number of apartments (Australia) according to ABS 2018 are as follows:

Table 9.16. Statistics for apartments (Australia) according to ABS 2018

Building storey height	No. of projects	% of projects	Total apartments		Apartments per project	Avg m^2 per apartment	Total m^2
4 storey	793	37.0%	22,200		28	109	2,419,800
5 storey	372	27.9%	16,740		45	163	2,728,620
6 storey	166	18.5%	11,100		67	84	932,400
7 storey	74	8.7%	5,220		71	95	495,900
8 storey	47	7.9%	4,740		100	101	478,740
Projects	1,451	100%	**60,000**		62.2	110.4	7,055,460

It can be seen from Table 9.16 that there is around 7 million m^2 of apartment floor area built annually, with around 6 million of this being apartments up to 6 storeys.

Estimate of potential market sizes for different products

Using the above national apartment square meterage figures and 1) applying, a total percentage timber market share assumption (possible new market gained from existing alternative products such as steel and concrete), and 2) a percentage share assumption for each of the construction methodologies discussed in this report – or new ones if necessary, some upper and lower bound scenarios can be undertaken to get an estimate of product volume opportunities.

Estimate of potential volumes of new advanced LVL applications (equivalent to F27 or F34)

Table 9.17 allows for some assumptions to be added around potential volumes of new advanced hardwood products that might be used in new F27 or F34 equivalent grades. The following comments are made on how this sensitivity section might be used based on the findings in this report.

Table 9.17 Structural element market potential

Structural Element	F27	F34	Justification (as outlined in report)
Plates	0%	0%	*Minimum f'p can be supplied by market already*
Studs	10%	5%	*Increase height of light frame buildings 6 - 8 storeys*
Floor Truss	10%	5%	*Marginal cases where structural heights need to be minimized*
Massive Timber	0%	0%	*TBC*
Cores	5%	3%	*TBC*
Columns	10%	5%	*TBC*
Cassettes	8%	4%	*Improves structural depth significantly*
Primary Beams	4%	2%	*Improves structural depth, minor improvement*

The following provides two examples (Figure 9.50 and Figure 9.51) that investigate different scenario assumptions and associated volume estimates.

Mid-rise Timber Construction Product Volume Estimate Tool

		m2 of Timber Buildings	Assumption on Constuction Methodology	Total Apart m2	Assumption of Apts in Timber
1. Input m2 of Development	1. Apartment Buildings - Lightweight Trusses and Studs, Concrete Core	705,546	100%	7,055,460	10%
	2. Apartment Buildings - Lightweight Truss and Studs, LVL Core	0	0%		
	3. Apartment Buildings - 190mm Massive Floor Slabs, Studs, Concrete Core	0	0%		
	4. Office Buildings - Columns, Cassettes and Beams	0	100%		
		705,546			

		F27	F34	Justification
2. Input % of Product to be F27 and F34	Plates	0%	0%	Minimum f'p can be supplied by market already
	Studs	10%	5%	Lower levels of mid-rise buildings >6 storeys
	Floor Truss	10%	5%	Marginal cases where structural heights need to be minimized
	Massive Timber	0%	0%	Unlikely to have big impact
	Cores	5%	3%	Higher properties enable taller buildigns
	Columns	10%	5%	Lower levels of buildings > 8 storeys
	Cassettes	10%	5%	Special products with high grade material on outer fibres
	Primary Beams	10%	5%	Special products with high grade material on outer fibres

		Total Volume (Entire Market)	F27 (m3)	F34 (m3)	Other Grades
3. Outputs	Plates	2,211	0	0	
	Studs	11,005	1,100	550	
	Floor Truss	12,700	1,270	635	
	Massive Timber	0	0	0	
	Cores	0	0	0	
	Columns	0	0	0	
	Cassettes	0	0	0	
	Primary Beams	0	0	0	
		25,915	2,370	1,185	

ABS Apartments

Building Height	Total m2
4 storey	2,419,800
5 storey	2,728,620
6 storey	932,400
7 storey	495,900
8 storey	478,740
	7,055,460

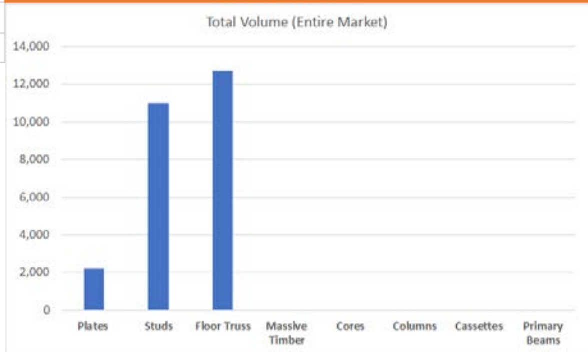


Figure 9.50. Example 1 Assume 10% Market share for timber and 100% to construction methodology 1

Mid-rise Timber Construction Product Volume Estimate Tool

		m2 of Timber Buildings	Assumption on Constuction Methodology	Total Apart m2	Assumption of Apts in Timber
1. Input m2 of Development	1. Apartment Buildings - Lightweight Trusses and Studs, Concrete Core	352,773	**50%**	7,055,460	**10%**
	2. Apartment Buildings - Lightweight Truss and Studs, LVL Core	0	**0%**		
	3. Apartment Buildings - 190mm Massive Floor Slabs, Studs, Concrete Core	352,773	**50%**		
	4. Office Buildings - Columns, Cassettes and Beams	0	**100%**		
		705,546			

		F27	F34	**Justification**
2. Input % of Product to be F27 and F34	Plates	0%	0%	**Minimum f'p can be supplied by market already**
	Studs	10%	5%	**Lower levels of mid-rise buildings >6 storeys**
	Floor Truss	10%	5%	**Marginal cases where structural heights need to be minimizec**
	Massive Timber	0%	0%	**Unlikely to have big impact**
	Cores	5%	3%	**Higher properties enable taller buildigns**
	Columns	10%	5%	**Lower levels of buildings > 8 storeys**
	Cassettes	10%	5%	**Special products with high grade material on outer fibres**
	Primary Beams	10%	5%	**Special products with high grade material on outer fibres**

		Total Volume (Entire Market)	F27 (m3)	F34 (m3)	Other Grades
3. Outputs	Plates	**1,105**	0	0	
	Studs	**11,005**	1,100	550	
	Floor Truss	**6,350**	635	317	
	Massive Timber	**66,674**	67	67	
	Cores	**0**	0	0	
	Columns	**0**	0	0	
	Cassettes	**0**	0	0	
	Primary Beams	**0**	0	0	
		85,134	**1,802**	**934**	

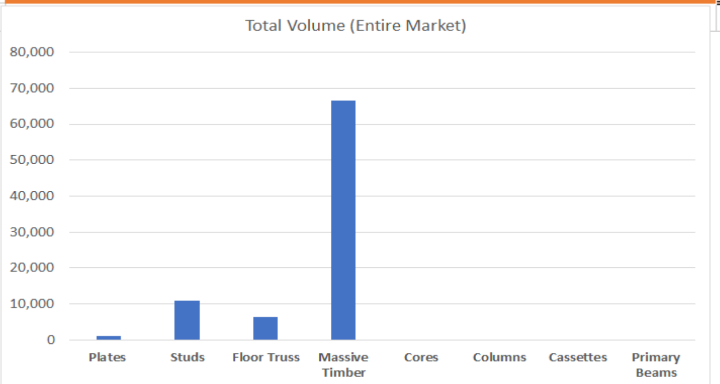


Figure 9.51. Example 2 Assume 10% Market share for timber and 50% to construction methodology 1 and 50% to construction methodology 3 (mass floors)

References:

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Wesbeam. (2018). Wesbeam Tall Timber Building Systems Inaugural Timber Fabricators Workshop. Melbourne.

Chapter 10: Key mechanical properties of cross-banded laminated veneer lumbers manufactured from blending spotted gum and hoop pine veneers

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Introduction

From sustainably managed native Australian forests, a volume of small-diameter (less than 30 cm in diameter at breast height) spotted gum (*Corymbia citriodora* - SPG*)* hardwood logs is potentially available. However, this resource is currently considered sub-optimal in quality due to incompatibility with traditional converting techniques, and therefore attracts minimal or no value. This has resulted in the resource not been fully utilised (McGavin and Leggate 2019). This species is known for its high mechanical properties and durability (Bootle 2005), and therefore could be used for structural applications. To process such small diameter logs, relatively new spindle-less rotary veneer technology has been demonstrated to be efficient means to convert this log type, recovering up to 70% of the log into veneers which have properties well suited to structural veneer-based products (VBP) (McGavin and Leggate 2019; McGavin *et al*. 2014a).

While the volume of the above SPG logs is limited, a large volume of hoop pine (*Araucaria cunninghamii* - HP) softwood plantation logs are available, with HP being one of the well-established commercial plantation trees in Queensland. A potential commercialisation opportunity for the small quantity of rotary-peeled veneers from small-diameter native SPG logs is currently being investigated through a strategy of blending SPG and HP veneers to produce laminated veneer lumbers (LVL) and cross-banded laminated veneer lumbers (LVL-C) (McGavin and Leggate 2019; Nguyen *et al*. 2019). It has been proven that mixing these two species into LVL and LVL-C results in products with structural characteristics which are comparable or superior to currently commercialised VBP (McGavin *et al.* 2019; Nguyen *et al.* 2019). However, the number and grade of SPG and HP veneers used to manufacture the products in these studies were chosen to provide benchmark performance data using generic product construction strategies and identified opportunities for further optimisation. To further pursue this opportunity, Nguyen *et al.* (2019) developed a tool to optimise the use of given resources while targeting final grades of products. Yet, the optimum LVL-C products resulted from this optimisation tool were not fully tested. Although in Nguyen *et al*. (2019), dynamic Modulus of Elasticity (MOE)-based veneer grading was adopted to optimise the products, visual grading is still widely accepted for veneer-based products in Australia (McGavin and Leggate 2019; McGavin *et al.* 2014b) and research is still needed to understand the relationship between MOE-based veneer grading for the SPG veneers and the visual grading method.

Consequently, the key objectives of this work are to: (i) evaluate the difference between visual-grading and MOE-grading methods when applied to SPG veneers rotary peeled from small-diameter logs; (ii) examine the mechanical properties (density, edgewise and flatwise bending static MOE and Modulus of Rupture (MOR), tension and compression strength perpendicular to the grain, and longitudinal-tangential shear strength) of optimised LVL-C products manufactured by blending SPG and HP veneers and (iii) compare the measured properties to LVL manufactured from SPG and HP veneers or commercially available LVL-C.

LVL-C was targeted in this study to overcome the low mechanical properties perpendicular to the grain typically encountered in LVL, resulting in the possibility of premature splitting failure in structural connections (Kobel et al. 2014). Especially, relevant to this study, low tension perpendicular to the grain capacity (about 1-1.5MPa) were reported for veneer-based products manufactured from small-diameter plantation-grown SPG logs (Gilbert et al. 2018a).

This paper is part of various Australian projects aiming at developing a market for forest resources with sized and qualities considered inadequate to be efficiently processed, see McGavin *et al.* (2013); Gilbert *et al.* (2014);Gilbert *et al.* (2018b) and McGavin *et al.* (2019) for instance.

Methodology

Timber used

As part of a collaborative project between the timber industry and the Queensland government, aiming at transforming lower-value logs into high-performance engineered wood products, small diameter native forest SPG and commercial plantation HP logs were rotary peeled using spindle-less rotary veneer lathes into nominal 3.0 mm thick veneers. In total 60 SPG logs were peeled and produced the feedstock for the LVL manufacturing. A sub-set of 163 SPG veneer sheets of 1.5 m × 2.6 m were taken from the recovered veneers, whereas 246 HP veneer sheets of 1.5 m × 2.6 m were selected from the production line of a commercial veneer manufacturer. The details (age of the trees, breast height diameter, number of trees, etc.) of the SPG resource and processing information has been previously reported by McGavin and Leggate (2019). Resource information was not available for the HP as the veneers were collected from within a commercial process. After peeling, the veneer sheets were dried to a target moisture content of 8%.

Veneer grading

The dried SPG veneers were visually graded first and their dynamic MOE was then measured. For the HP veneers, only their dynamic MOE was measured.

Visual grading of each 1.5 m × 2.6 m SPG veneers was undertaken in accordance with Australian and New Zealand Standard AS/NZS 2269.0 (2012). This standard separated veneers into the following grades: A (high-quality appearance), B, C, D and reject F-grade, based on the presence and severity of defects. This grading process is well accepted by the Australian veneer industry and similar systems exist internationally (Leggate *et al.* 2017; McGavin and Leggate 2019; Wang and Dai 2013).

To measure the dynamic MOE parallel to the grain (E_{L_Veneer}) of the SPG and HP veneers, a 200 mm (tangential direction) x 1,200 mm (longitudinal direction) strip was cut from each veneer sheet. An acoustic natural-vibration method (Brancheriau and Baillères 2002; CIRAD 2018) was used to measure the dynamic MOE of each strip, following the procedure as detailed in McGavin *et al.* (2019). The longitudinal natural frequency of the strip were recorded and analysed using the software Beam Identification by Non-destructive Grading (CIRAD 2018). For each species, three grades, referred to as Low, Medium and High, were determined and equally divided the veneers into three bins. The MOE cut-off values between grades were the 33rd and 66th percentile values of the cumulative distributive function of each species. The MOE cut-off values and the grade notations for the two species followed the methodology reported by Nguyen *et al.* (2019), and given in Table 10.1.

To assess the correlation between MOE-based and visual grading, the distribution of MOE-based grades (*i.e.* “Low”, “Medium” and “High”) in each visual grade (*i.e.* A, B C, D and F) is compared.

Table 10.1. Veneer MOE grading

Species	Grade	MOE threshold
Spotted Gum	SPG_L	MOE < 20,340
	SPG_M	20,340 ≤ MOE<23,750
	SPG_H	MOE ≥ 23,750
Hoop Pine	HP_L	MOE < 11,300
	HP_M	11,300≤ MOE <13,100
	HP_H	MOE ≥ 13,100

Construction strategies and LVL manufacturing

Two different construction strategies for both the reference 12-ply LVL and optimised 12-ply LVL-C were investigated and are shown in Figure 10.1. They consist of one single-species reference HP LVL, one mixed-species reference LVL and two mixed-species LVL-C. The construction strategies are detailed as follow:

- Strategy LVL_1 consisted of a reference LVL manufactured from HP veneers only. All veneers have a dynamic MOE greater than 13.1 GPa (High grade).
- Strategy LVL_2 consisted of a reference LVL with eight HP veneers of different grades (6 × Low grade (MOE < 11.3 GPa) and 2 × High grade (MOE > 13.1 GPa)) in core and two SPG veneers (one High grade (MOE ≥ 23.7 GPa) and one Low grade (MOE < 20.3 GPa)) on each face. In the optimisation process (Nguyen et al. 2019), this strategy aimed at targeting a final product with an edgewise bending MOE greater than 14 GPa while maximising the use of Low-grade HP veneers and minimising the use of High-grade SPG veneers.
- Strategy LVL-C1 consisted of mixed-species LVL-C with eight HP veneers of different grades (6 × Low grade and 2 × Medium grade (11.3 GPa ≤ MOE < 13.1 GPa) in core and two High-grade SPG (MOE > 23.7 GPa) veneers on each face. Two out of the six Low-grade HP veneers were rotated 90^o (cross-banded veneers). LVL-C1 aimed at minimising the use of High-grade SPG veneers while targeting average edge bending dynamic MOE greater than 14 GPa (Nguyen et al. 2019).
- Strategy LVL-C2 consisted of mixed-species LVL-C which were manufactured from the exact same veneer sheets used in the manufacture of LVL_2, but with two HP veneers rotated 90^o. This allows a direct comparison between the two products.

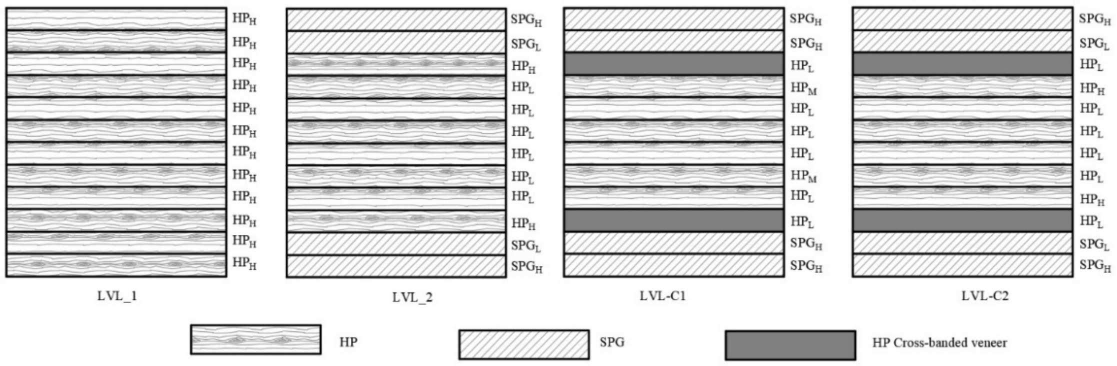


Figure 10.1. Construction strategies of LVL and LVL-C

Panel manufacturing

Three panels per construction strategy, *i.e.* total of 12 panels with a targeted thickness of 36 mm, were manufactured. The veneers were bonded with a commercial melamine urea formaldehyde (MUF) adhesive with a glue spread level of 400 g/m^2 per glue line. This adhesive was selected to achieve a B-bond glue line as outlined in Australian Standard AS/NZS 2754.1 (2016). The panels were pre-pressed with an open assembly time of 22 minutes (measured from adhesive application to the first veneer to when pressure was applied in the press) and hot-pressed at 1.1 MPa and at a temperature of 135^{o}C during 26 minutes. After hot-pressing, the panels were stacked for two weeks for post curing.

Two panels (one for Strategy LVL-C1 and one for Strategy LVL-C2) experienced gluing problems during the manufacturing process and were discarded.

Test samples and test set-up for mechanical properties

After manufacturing, samples were cut from each panel to experimentally assess their (1) static edgewise bending MOE (E_{b_e}), (2) static flatwise bending MOE (E_{b_f}), (3) edgewise bending MOR (f_{b_e}), (4) flatwise bending MOR (f_{b_f}), (5) tension perpendicular to grain strength ($f_{t\_\perp}$), (6) compression perpendicular to grain strength ($f_{c\_\perp}$) and (7) longitudinal-tangential shear strengths (f_s) following the cutting patterns reported by McGavin et al. (2019).

The samples were conditioned at 20°C and 65% relative humidity before being tested, following the recommendations in the Australian standard AS/NZS 4357.2 (2006). Compression and tension samples tested perpendicular to the grain were weighed immediately after being tested to calculate the moisture content of the timber at the time of testing, following the over-dry methodology in the Australian and New Zealand standard AS/NZS 1080.1 (2012). Similarly, for bending samples, a 25 mm long piece was cut from each sample and weighed immediately after testing to determine the moisture content of the samples.

For all LVL and LVL-C samples, the thickness (t_{LVL}) of each panel was measured by averaging the thickness of all the test samples cut from the same panel. The same calculation was applied for density and moisture content (MC).

Note that due to the nature of rotary peel veneers the perpendicular direction to the grain corresponds to the tangential direction of the wooden material. The testing methodology for each test are described in the following subsections.

Edgewise and flatwise bending strength and static MOE

The static bending tests were conducted in accordance with the Australian standard AS/NZS 4357.2 (2006) using a four-point bending test set-up. From each panel, two 60 mm (height) × 1,200 mm (long) samples were tested in the edgewise bending and two 100 mm (wide) × 800 mm (long) samples were tested in flatwise bending in a Shimadzu Universal Testing Machine (AG-100X) at a stroke rate of 5 mm/min to reach failure between 3 and 5 minutes. The apparent static MOE was determined from the measurement of the mid-span vertical displacement, measured with a digital camera (Figure 10.2(a-c)), of the samples as,

$$MOE = \frac{23 \times L^3}{108 \times b \times d^3} K_{elas} \quad \text{[eq. 10.1]}$$

where L is the total span, d and b are the measured depth and width of the samples, respectively, and K_{elas} is the elastic stiffness of the load-displacement curve, calculated herein by performing a linear regression on the linear part of the curve.

The MOR of the samples is calculated as:

$$MOR = \frac{F_{ult} \times L}{b \times d^2} \quad \text{[eq. 10.2]}$$

where F_{ult} is the ultimate load.

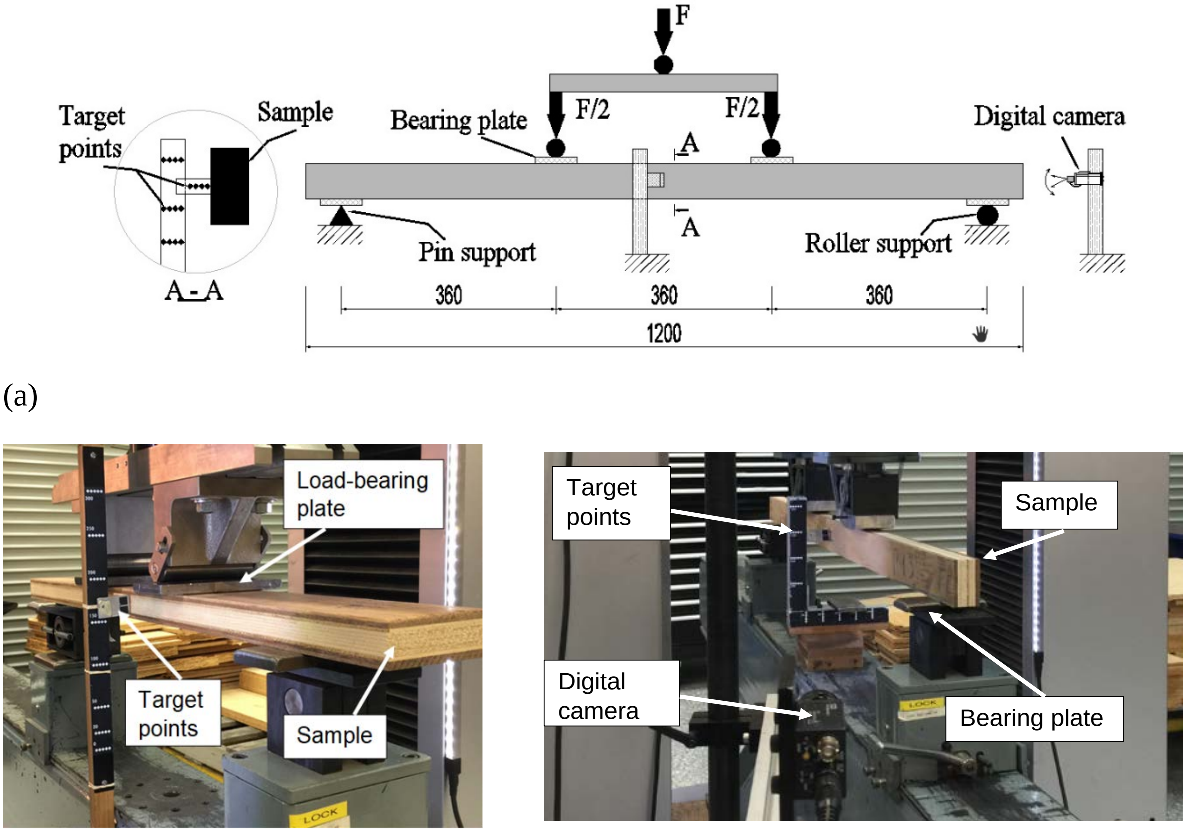


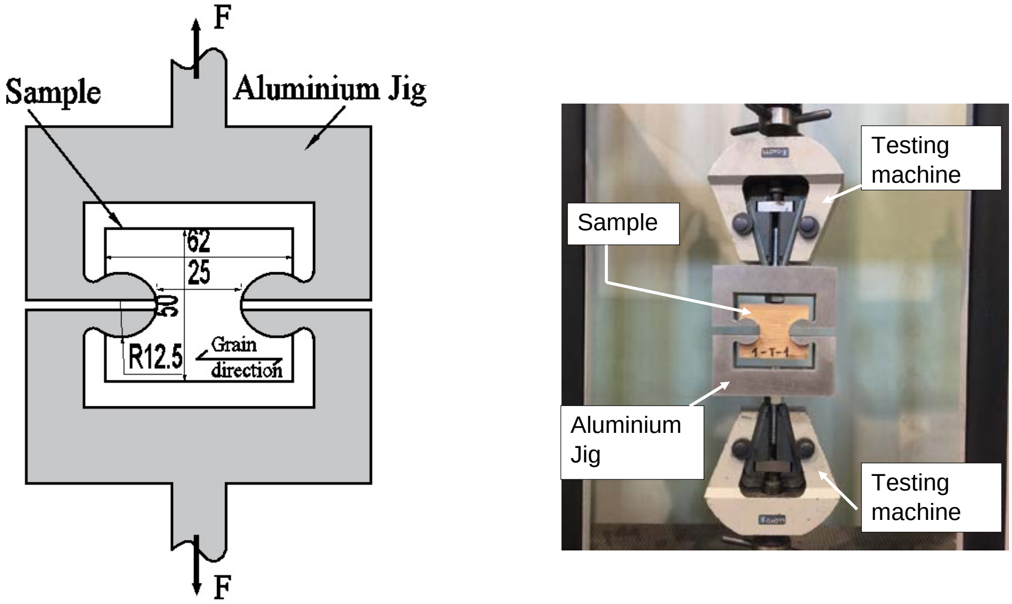
Figure 10.2. Static bending test set-up, (a) schematic and (b-c) photos

Tensile strength perpendicular to the grain

The tensile strength perpendicular to the grain was determined following the configuration in the ASTM D143-14 (2014) that was developed for solid timber specimens. The procedure was successfully adopted in the literature to LVL samples (Ardalany et al. 2011; Gilbert et al. 2018a). Three samples were cut per panel to the dimensions given in Figure 10.3a. The samples were then inserted into an aluminium jig as shown in Figure 10.3b. The jig was gripped in the jaw of a 30 kN capacity Lloyd universal testing machine which was driven in displacement control, at a stroke rate of 2.5 mm/min, to reach failure between 1 and 3 minutes. The tensile strength perpendicular to grain $f_{t\_\perp}$ of the samples is calculated as,

$$f_{t\_\perp} = \frac{F_{ult}}{w \times t} \qquad \text{[eq. 10.3]}$$

where F_{ult} is the ultimate applied force, and *w* and *t* are measured width and thickness of the sample, respectively. *w* is measured at the minimum cross-sectional width in Figure 10.3, with nominal *w* equal to 25 mm.



(a) (b)

Figure 10.3. Tension perpendicular to grain test set-up, (a) schematic and (b) photo

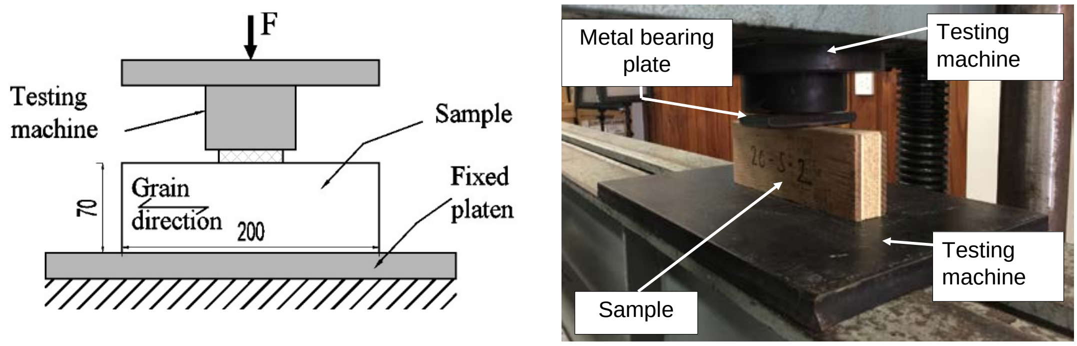
Compression strength perpendicular to the grain

Compressive strength (or bearing strength) perpendicular to the grain was determined using the bearing strength test method from Australian Standard AS/NZS 4063.1:2010 (2010). Two 70 mm (height) × 200 mm (long) test samples were cut from each panel. The tests were conducted in a Shimadzu Universal Testing Machine and the load was applied at a speed rate of 1.0 mm/minute to reach failure between 2 and 5 minutes. The load was transferred to the samples through a metal bearing plate of 50 mm in width placed across the upper surface of the samples at equal distances from the ends of the sample (Figure 10.4).

The compressive strength perpendicular to the grain $f_{c\_\perp}$ is calculated from the following equation:

$$f_{c\_\perp} = \frac{F_p}{50 \times b} \qquad \text{[eq. 10.4]}$$

where F_p is the value of applied load corresponding to a 2.0 mm deformation, b is the breadth of the test piece. Note that the displacement of the stroke of the testing machine was taken as the deformation of the testing sample.



(a) (b)

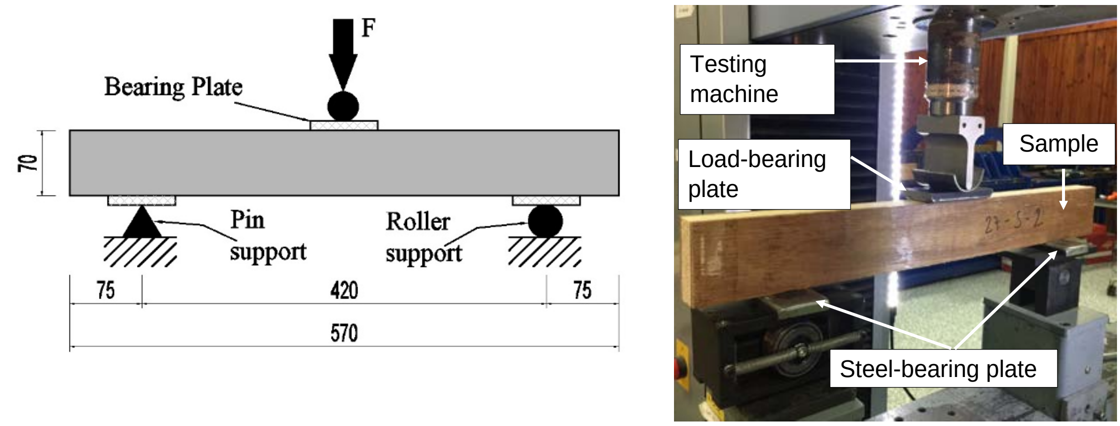
Figure 10.4. Compressive perpendicular to grain test set-up, (a) schematic and (b) photo

Longitudinal-tangential shear strength

Longitudinal-tangential shear strength testing was conducted in accordance with Australian Standard AS/NZS 4063.1 (2010). Two 70 mm (height) x 570 mm (long) samples were cut per panel and tested using a three-point bending test set-up, as shown in Figure 10.5. The shear strength f_s of a sample is calculated from the following equation:

$$f_s = \frac{0.75 \times F_{ult}}{b \times d} \qquad \text{[eq. 10.5]}$$

where F_{ult} is the ultimate value of the applied load, b and d are the measured width and depth of the cross-section, respectively.



(a) (b)

Figure 10.5. Longitudinal-tangential shear test set-up, (a) schematic and (b) photo

Commercial LVL-C used for comparison

The mechanical properties of the investigated LVL-C are compared in this paper to product literature for commercially available 11-ply LVL-C products, namely Kerto-Q and STEICO LVL *X* manufactured from Metsä wood company (Metsä Wood company 2019), and STEICO company (STEICO group 2019), respectively. These LVL-C products included two cross-banded veneers and were manufactured from spruce (*Picea abies*) or pine (*Pinus sylvestris*) veneers of nominal thickness 3 mm.

Results and discussion

Veneer grading

Figure 10.6 presents the visual-grading distribution of SPG veneers with 3%, 6% and 70% of veneer sheets being classified into B-grade, C-grade and D-grade, respectively. The remaining veneers were classified into F Reject. No veneers were graded into A-grade.

Figure 10.7 plots the distribution of MOE-based grades for each visual grade and indicates that there is limited correlation between visual-grading and the MOE-based grading, especially for C-grade and below. Veneers visually graded as B-grade were all graded as having high MOE, while C-grade, D-grade and F-grade had a relatively uniform distribution of Low, Medium and High dynamic MOE graded veneers. This suggests there is limited opportunity for a commercial product manufacturer to utilise a visual grading system to target veneers with specific veneer stiffness properties.

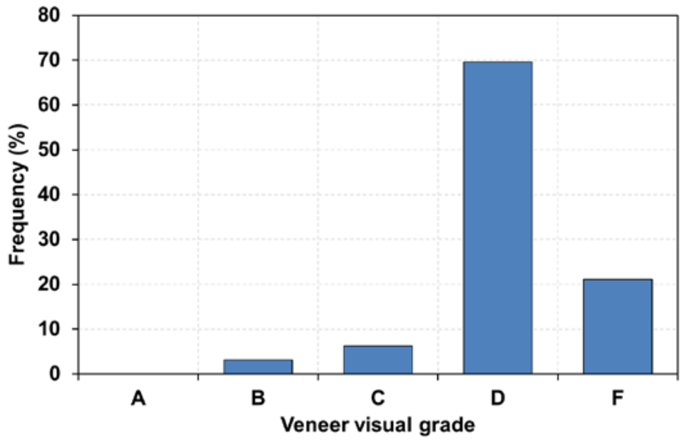


Figure 10.6. SPG veneer visual grade distribution

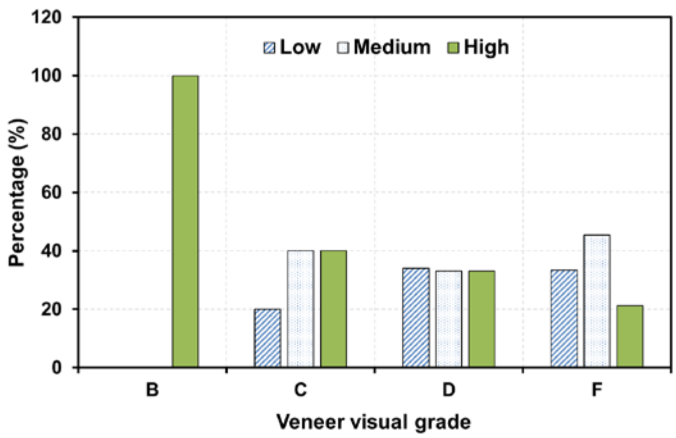


Figure 10.7. Correlation between visual grading and MOE grading of SPG veneers

Panel thickness and moisture content

The average thickness, density and moisture content at the time of testing for all panels are summarised in Table 10.2. The mean oven-dry moisture content at the time of testing for all investigated products ranges from 11.5% to 13.6%.

Table 10.2. Physical properties of LVL-C and LVL

Types	Panel	Thickness t_{LVL}		Moisture content		Density	
		Average (mm)	**CoV (%)**	**Average (%)**	**CoV (%)**	**Average (kg/m^3)**	**CoV (%)**
LVL_1	1	33.2	3.05	12.7	2.26	629	1.55
	2	33.7	2.47	13.1	2.30	658	1.40
	3	33.0	1.69	13.6	5.27	637	2.60
	Ave.	**33.4**		**13.1**		**648**	
LVL_2	1	34.8	2.24	11.8	2.23	779	2.32
	2	34.5	1.15	12.5	2.88	805	2.10
	3	34.4	0.67	12.2	2.26	780	2.09
	Ave.	**34.5**		**12.2**		**788**	
LVL-C1	1	35.0	3.60	12.3	1.31	766	2.85
	2	34.9	1.44	11.8	4.20	793	1.40
	Ave.	**35.0**		**12**		**780**	
LVL-C2	1	34.4	3.80	12.1	2.07	746	2.80
	2	33.8	0.88	11.5	1.97	756	2.30
	Ave.	**34.1**		**11.8**		**751**	

Edgewise and flatwise bending test results

Table 10.3 shows the calculated static MOE and MOR for both flatwise and edgewise bending for all investigated products. Due to LVL_2, LVL-C1 and LVL-C2 construction strategies which use high MOE veneers as face veneers, their static flatwise bending MOE E_{b_f} was found to be 20% higher on average than the corresponding static edgewise bending MOE E_{b_e}. The average flatwise and edgewise bending MOE value of the single-species HP LVL_1 was up to 29% and 12% lower, respectively, than the mixed-species LVL and LVL-C. Despite sharing the same veneers in the manufacture, LVL_2 had an edgewise and flatwise bending MOE 12% and 24% higher, respectively, than LVL-C2. This indicates a relatively large contribution of the two cross-banded Low MOE HP veneers on the stiffness of the products. Due to the High MOE SPG face veneers, LVL-C1 showed higher MOE values than LVL-C2.

On average, the MOR of the investigated products was significantly higher for flatwise bending than edgewise bending, as shown in Table 10.3. Due to the strategic positioning of higher MOE veneers on the faces than in the core, LVL_2 had the average highest flatwise MOR value of 144 MPa, followed by LVL-C1 with the value of 126.4 MPa. However, both the edgewise and flatwise bending MOR values of single-species HP LVL1 were observed to be higher (up to 8.2%) than the cross-banded LVL-C2. LVL-C2 also showed an edgewise and flatwise MOR about 20% lower than LVL_2, as detailed in Table 10.3. These results compare to previous studies on single-species LVL-C (Kawazoe et al. 2006; Kobel et al. 2014).

When compared to commercial LVL-C products (see Table 10.3), the average flatwise bending MOE and MOR, of the two investigated LVL-C were found to be up to 72% and 251% higher than the single cross-banded Kerto-Q LVL, with thickness of 27 to 69 mm, (Metsä Wood company 2019) and single cross-banded STEICO *LVL-X* (STEICO group 2019). The values for edgewise bending were up to 44% (MOE) and 191% (MOR) higher than the commercialised LVL_C products.

Table 10.3. Mechanical properties of investigated products versus commercial LVL-C products

Type	**Panel**	**Flatwise bending**		**Edgewise bending**		**Tension strength** ($f_{t\_\perp}$) *(MPa)*	**Compressive strength** ($f_{c\_\perp}$) *(MPa)*	**Shear strength** (f_s) *(MPa)*
		MOE (E_{b_f}) *(MPa)*	**MOR** (f_{b_f}) *(MPa)*	**MOE** (E_{b_e}) *(MPa)*	**MOR** (f_{b_e}) *(MPa)*			
LVL_1	1	13,911	94.7	14,233	89.1	2.72	14.05	9.6
	2	14,481	112.6	14,314	84.9	2.92	15.85	12.2
	3	14,433	120.6	14,094	81.7	2.56	18.56	10.7
	Ave.	**14,274 (4%)**	**109.3 (11.4%)**	**14,213 (1.2%)**	**85.2 (6.4%)**	**2.74 (11.6%)**	**16.15 (13.6%)**	**10.8 (22.6%)**
LVL_2	1	20,575	131.1	16,411	92.5	3.66	19.83	16.9
	2	20,214	155.5	15,431	95.2	2.97	19.98	9.3
	3	19,605	146.6	16,764	93.4	3.15	18.29	10.1
	Ave.	**20,131 (5%)**	**144.4 (9.5%)**	**16,202 (4%)**	**93.6 (2.87%)**	**3.26 (12.14%)**	**19.13 (4.8%)**	**12.1 (31.5%)**
LVL-C1	1	18,870	138.7	14,404	85.0	7.31	23.50	10.3
	2	17,387	114.0	15,956	101.9	9.84	23.37	9.2
	Ave.	**18,128 (6.2%)**	**126.4 (11.5%)**	**15,180 (6.08%)**	**93.4 (11.4%)**	**8.58 (19.4%)**	**23.44 (2.41%)**	**9.8 (7.7%)**
LVL-C2	1	16,250	104.3	14,866	84.6	9.34	23.50	7.7
	2	16,318	103.1	13,777	72.9	10.42	23.11	9.2
	Ave.	**16,284 (5.4%)**	**103.7 (13.2%)**	**14,321 (4.5%)**	**78.7 (9.5%)**	**9.88 (14.35%)**	**23.30 (3.12%)**	**8.4 (13.2%)**
Kerto® -Q	**-**	10,500	36	10,500	32	6.0	9.0	-
STEICO *LVL X*	-	10,600	36	10,600	36	5.0	9.0	-

Tensile strength perpendicular to the grain

Table 10.3 shows the tensile strength perpendicular to the grain ($f_{t\_\perp}$) for all the investigated products. On average, the tensile strengths of LVL-C products (LVLC-1 and LVL-C2) was observed to be about 3 times higher than that of single-species HP LVL and mixed-species LVL. This is explained by the positive effect of the cross-layer veneers in LVL-C products that results in a significant improvement in tensile strength. Specifically, LVL-C2 had the highest tensile strength value of 9.88 MPa, whereas the lowest value of 2.74 MPa was found for single-species HP LVL. There is no significant difference in $f_{t\_\perp}$ between the mixed-species LVL and the single-species HP LVL.

When compared to commercial cross-banded LVL-C in Table 10.3, the average $f_{t\_\perp}$ of the investigated LVL-C were up to 97% superior to the cross-bonded Kerto-Q LVL and STEICO *LVL-X*.

Compression strength perpendicular to the grain

Table 10.3 depicts the compression strength perpendicular to the grain ($f_{c\_\perp}$) for all the investigated products. There is a difference by up to 45% between LVL-C products and LVL products in the average $f_{c\_\perp}$, but no significant difference between the two mixed-species LVL-C products. The average $f_{c\_\perp}$ was found to be 17.2 MPa, 19.1 MPa, 23.4 MPa and 23.3 MPa for LVL_1, LVL_2, LVL-C1 and LVL-C2, respectively. In addition, the average compressive strength value for LVL-C2 was observed to be 21% superior to that of mixed-species LVL_2, which was manufactured from the exact same veneer sheets.

When compared to commercial cross-banded LVL-C (see Table 10.3), the average $f_{c\_\perp}$ of the investigated LVL-C were up to 160% greater than the one of either cross-bonded Kerto-Q LVL or STEICO *LVL- X* .

Longitudinal-tangential shear strength

All three-point bending test performed to investigate the longitudinal-tangential shear strength failed in bending. The maximum shear stresses reached during the tests are conservatively reported in Table 10.3 and therefore represents lower band values of the shear strengths.

LVL_2 had the highest shear strength with an average shear strength greater than 12 MPa, followed by single species HP LVL_1 with 10.8 MPa. The shear strength of LVL-C1 (9.7 MPa) was higher than that of mixed-species LVL-C2 (8.4 MPa). Due to the presence of the cross-layered veneers, one would expect the shear strength value of the LVL-C to be higher than the one of the LVL. This counter-intuitive result is likely due to the observed bending failure and to the bending MOR of LVL-C being lower than that of LVL (see Table 10.3). Bending failure likely occurred in the LVL-C significant before shear failure would have occurred.

Conclusions

The work investigated selected mechanical properties of 12-ply LVL-C and LVL manufactured from blending native forest SPG and commercial plantation-grown HP veneers. The correlation between visual grades and MOE grades was also considered. The following conclusions can be drawn:

1. D-grade was the dominant grade for the SPG veneers and accounted for around 70% of the veneers recovered from the peeling process. 21% of the veneers were graded as F-grade (reject). Limited correlation between visual grading and dynamic MOE-based

grading was found meaning that visual grading may not be the most appropriate method to guide the manufacture of veneer-based products of targeted MOE from the native forest SPG veneers.

2. For both edgewise and flatwise bending, the average MOE and MOR values of cross-banded LVL were found to be (i) up to 19% (MOE) and 28% (MOR) lower than the investigated LVL but (ii) up to 72% (MOE) and 251% (MOR) higher than commercially available LVL-C.
3. The average compression strength perpendicular to the grain of LVL-C was found to be 23% and 160% higher than the investigated LVL and commercial LVL-C, respectively. The tensile strength perpendicular to the grain of the investigated LVL-C products was observed to be approximately 3 times higher on average than the other investigated LVL products.
4. Regarding the longitudinal-tangential shear strength, all the samples were observed to fail in bending rather than shear. The maximum shear stress reached was reported and showed that the LVL-C showed a shear strength of at least 8.4 MPa.
5. In view of the reported characteristic, mixed-species LVL-C manufactured from native forest SPG and plantation HP veneers show mechanical properties superior to commercially available LVL-C and could represent a market for the studied veneers.

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Chapter 11: Blended species laminated veneer lumber (LVL) resistance to subterranean termites

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Introduction

The heartwood of white cypress pine *Callitris glaucophylla* is known to be resistant to termite and fungal attack due to the presence of extractives in the heartwood, though this resistance does not extend to the sapwood. These extractives include e.g. thujaplicin, nootkatin, dolabrin, thujaplicinol and pygmaein. The extractives have been investigated as potential natural preservative treatments (in preference to chemical preservatives) for timber to prevent termite attack.

Previous studies (Evans, P.D. *et al.* 2000 and Evans, P.D. *et al.* 1997) looking at blends of durable e.g. cypress pine and non-durable e.g. radiata pine or hoop pine in both particleboard and MDF have shown enhanced resistance to termite attack when compared to those composed entirely of a non-durable species. The greater the ratio of durable to non-durable veneers in a panel then the greater the termite resistance. Similarly, the biological durability of LVL (laminated veneer lumber) made from durable and non-durable species was tested against decay fungi and shown to have enhanced durability when two faces and one core were from a durable species. Both of these studies were performed in the laboratory and not in the field.

A study (Faraji *et al.* 2009) looking at such a mix in plywood (*Cupressus sempervirens* and Beech / Poplar / Scots pine) was evaluated against *Reticulitermes santonensis* in laboratory trials in France. Enhanced durability (i.e. of the hoop plys) was found where the face and back veneers were:

- Cypress pine heartwood and,
- where 60% of the veneers consisted of cypress pine heartwood.

Integration of the layers (durable / non-durable) was found to be extremely important, whereas the percentage of durable vs. non-durable was less so. Having the durable layers as a face and back veneer is a necessary condition for a plywood panel to achieve resistance to termite attack. Similar trials with basidiomycete fungi (Faraji *et al.* 2008) showed that the ratio of exposed durable surfaces versus non-durable surfaces in plywood is the determiner of resistance rather than the volume of durable vs. non-durable plys.

Previous durability studies with termites in the laboratory hint at the need for field tests to rigorously confirm these results and test the theory that the durability of face and back veneers are the key factor in natural resistance of plywood panels to attack by subterranean termites. The use of LVL in outdoor applications is limited by several durability issues, such as dimensional stability and biological degradation (termites and fungi).

Work by Nzokou *et al.* (2005) assessed laboratory manufactured LVL, using veneers from decay- resistant and decay-susceptible species in order to evaluate changes in the durability as a result of the LVL manufacturing process, and to test if the mixing of decay resistant species and decay susceptible species can improve durability against biological degrade. It is hypothesized that the use of durable species will yield durable LVL, and mixing veneer from durable wood species and non-durable species may increase the durability of the resulting LVL because of the diffusion of extractives. To test this hypothesis, a non-durable species (red maple) was mixed with durable species (sassafras, black locust, and European larch) in the manufacture of LVL boards, and their durability was assessed. A laboratory soil block test (against fungi) and a field test (against termites – species unknown) were conducted. The durability (against decay fungi) of mixed LVL consisting of two or three-plies from black locust and two or three plys from maple was superior to that of LVL made of five sassafras veneers. For LVL made using veneer from durable and non-durable wood species, durability was improved when two faces and one core veneer were from decay resistant species. However visual evaluation (to rate termite attack) of the LVL samples revealed that mixed LVL was more vulnerable to termite attacks than LVL made with five veneers of black locust or sassafras. Termites were able to selectively colonize the non-durable maple veneer layer even in the core of the LVL.

To further investigate the termite resistance or susceptibility of a blended species (cypress pine and spotted gum – durable, hoop pine – non-durable) LVL, test blocks from six different LVL construction types were exposed to feeding by the subterranean termite *Coptotermes acinaciformis* in a field trial at Esk S.E. Queensland. The results are outlined in this report.

Materials and methods

LVL – construction types

Spotted gum (*Corymbia citriodora,* SPG), white cypress pine (*Callitris glaucophylla,* CYP) and hoop pine (*Araucaria cunninghamii*, HP) were included in the trial. The spotted gum and white cypress pine veneers were sourced from the processing trials undertaken during the project (McGavin and Leggate, 2019) and represent two different resources commercially available to the timber industry from Australia's native forests. These species represent a high density, durable hardwood and mid-high density, durable softwood. Hoop pine was also included to represent a plantation softwood resource. The hoop pine veneers for the trial were recovered from approximately eight logs peeled by a commercial veneer producer during standard commercial operations.

Each of the construction types was comprised of 12 veneers. A total of 3 LVL panels measuring approximately 1200 x 1200 x 36 mm, for each construction type was targeted.

The strategy that guided the selection of veneers and their placement within the LVL panels had the following main objectives:

1. To minimise the within-species variation of veneer structural quality (MoE) of veneer selected for the panel manufacture.
2. To target 'average' structural quality veneers.
3. To ensure individual veneers were in the optimum position within the allocated panel to maximise the panel mechanical properties.
4. To minimise the within-species veneer and veneer location variation between panels of the same construction type.

Six different LVL construction types were selected and included:

1. White cypress pine – 100%
2. Hoop pine – 100%
3. Spotted gum - 100%
4. Spotted gum face veneers and hoop pine core
5. Spotted gum and hoop pine – alternating with spotted gum faces
6. White cypress pine and hoop pine – alternating with white cypress pine face

Sample preparation

A total of 18 LVL panels were manufactured with three panels for each construction type. A melamine urea formaldehyde (Hexion M8188) was selected aimed at achieving a B-bond glue line as outlined in Australian Standard *AS/NZS 2754.1:2016 Adhesives for timber and timber* *products, Part 1: Adhesives for manufacture of plywood and laminated veneer lumber (LVL).* The formulation was comprised of the following additives:

- 90.4% resin,
- 2.1% of a formic acid solution (25% concentration), and
- 7.5% plain flour.

The adhesive was applied to each face of the veneers targeting a total spread rate of 400 gsm (grams per square metre) per glue line. The assembly stage included an open assembly time of approximately 22 minutes (measured from adhesive application to the first veneer to when pressure was applied in the press). Pre-pressing was undertaken at 1 MPa for a duration of 8 minutes. At the completion of pre-pressing, the panels were transferred to the hot press and pressed at 1.1 MPa, for a duration of 26 minutes at 135°C. After pressing was complete, the panels were removed from the hot press, both panel surfaces misted with water and panels block stacked to cool.

LVL test blocks (130 x 110 x 36 mm) were cut from the 18 panels so there were 20 replicates of each construction type (1 - 6). Pine (predominantly sapwood) feeder blocks were also cut from material obtained from Bunnings hardware. The dimension of the feeder blocks was 135 x 70 x 20 mm. The total number of pine sapwood blocks was 140. There were 20 exposure boxes each containing six LVL test blocks (configurations 1 to 6) and 7 pine sapwood feeder blocks i.e. 11 blocks per exposure box. The pine feeder blocks (termite susceptible timber) were included to encourage on-going termite foraging in the exposure box and provide an indicator of termite vigour (based on mean % mass loss of the pine feeder) within each box.

Test block configuration in exposure box

In each exposure box LVL blocks were interspersed with pine sapwood blocks with corrugated cardboard separating all samples (Figure 11.1). LVL blocks were randomly assigned to each exposure box such that the same LVL construction type did not sit in the exact same position for every exposure box. This was done to account for any position effects (with regards termite feeding) in each box. The exposure box was a plastic container with lid purchased from Bunnings. Each set of blocks (LVL and pine sapwood) was wrapped in corrugated cardboard and taped to form an enclosed package ready for exposure to termites (Figure 11.1). The corrugated cardboard was used to provide a series of runways for the termites once they had entered the box. This aided the movement of termites throughout the exposure box. All the blocks were weighed prior to the packages being constructed. This enabled mass loss data to be calculated for each block post-exposure to termites, as well as allowing for a comparison with the visual termite damage score previously assigned to each block.

Figure 11.1. LVL test blocks and pine sapwood feeder blocks prior to placement in a termite exposure box

Field exposure

The 20 exposure boxes were placed on concrete besser blocks sitting atop a trench which had earlier been filled with termite susceptible feeder material (pine off-cuts) at the Esk trial site where *C. acinaciformis* was known to be active. Pine feeder stakes, driven into the ground within the holes in the concrete blocks and touching lengths of pine stud buried just below the surface of the trench, were used to facilitate termite entry into the boxes (Figure 11.2). Once the exposure boxes were in place the entire trench was liberally doused with water using a watering can and then covered with black plastic to maintain a dark, humid environment conducive to sustained termite foraging (Figure 11.3). The boxes were inspected after one month to ensure termites had entered all the boxes and then left un-disturbed for a further 16 weeks culminating in a 20-week exposure period.

Figure 11.2. Timber previously placed atop the aggregation trench was heavily infested with *C. acinaciformis*

Figure 11.3. The exposure boxes were placed atop the aggregation trench and covered with black plastic

Results and discussion

After a 20-week exposure period the boxes were retrieved from the field and returned to the laboratory at the Salisbury Research Facility for assessment of the LVL test blocks and pine feeder. The cardboard enclosed bundle was removed from each box and the LVL and pine blocks separated and cleaned (using a brush and thin metal spatula) to remove any dirt, debris and termites. Live termites were found in the majority of the 20 exposure boxes at this time (Figure 11.4).

Figure 11.4. Live termites were found in the majority of the termite exposure boxes when assessed in the lab

Initially each block was examined for termite damage and assigned a visual termite damage rating based on the following numbered rating system: The numbering system is arbitrary and has been modified slightly for this study.

- **1** - Sound
- **2** - Superficial damage or grazing by termites
- **3** - Slight surface damage by termites/up to 5mm in depth core veneers
- **4** - Damage (slight) - 5 - 25% mass loss/ > 5mm in depth core veneers
- **5** - Damage (moderate) - 25 - 50% mass loss
- **6** - Damage (severe) - 50 - 75% mass loss
- **7** - Damage (destroyed) - 75 - 100% mass loss

Secondly each block was weighed to determine the mass loss due to termite attack and subsequently the percentage mass loss (this will help to substantiate the visual rating) to assess the degree of termite damage to each block. Note was made of whether face/back veneers and/or core veneers were damaged by termites and to what degree. Mass loss in itself was not a true indicator as to the extent of termite damage to an individual LVL block. Significant damage could be sustained by individual veneers in a block without a significant loss in mass. Examples of this were seen with SPG/hoop core and SPG/hoop alt. where a visual damage rating of 4 was assigned to some blocks but the average mass loss was only 9.1g and 8.4g respectively.

The majority of the pine sapwood feeder blocks were severely damaged by termites (Figure 11.5) indicative of strong termite vigour.

Figure 11.5. The majority of the pine feeder blocks were severely damaged by termites

Mean mass losses per exposure box ranged from 19% (boxes1&2) up to 74% (box 14) (Figure 11.6). Visual termite damage ratings ranged from 2 through to 7 (destroyed) for these blocks. Some feeder blocks were reduced to a series of individual pieces such was the termite damage sustained. Figure 11.7 indicates the minimum, mean and maximum % mass loss of the seven pine feeder blocks per exposure box. While some boxes had only small minimums (<10%) the maximum per exposure box was always in excess of 35%, again a good indicator of strong termite vigour per box.

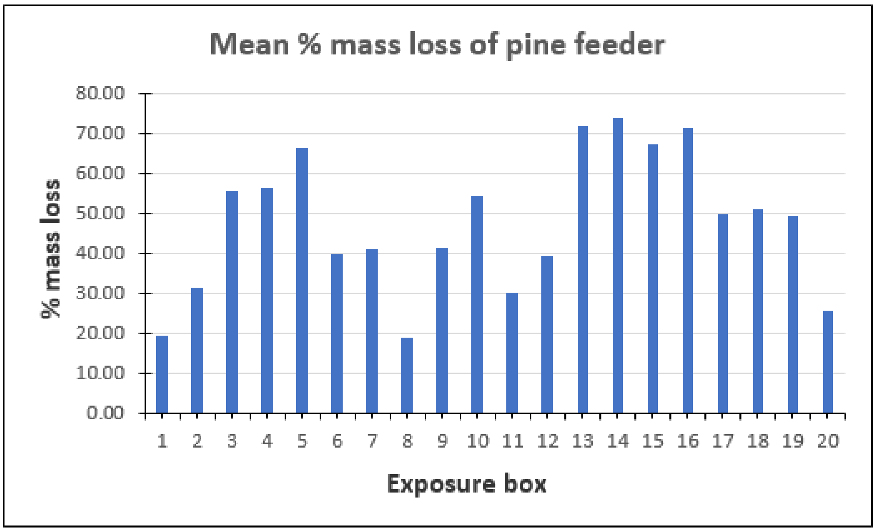

Figure 11.6. Mean % mass loss of pine feeder blocks per exposure box

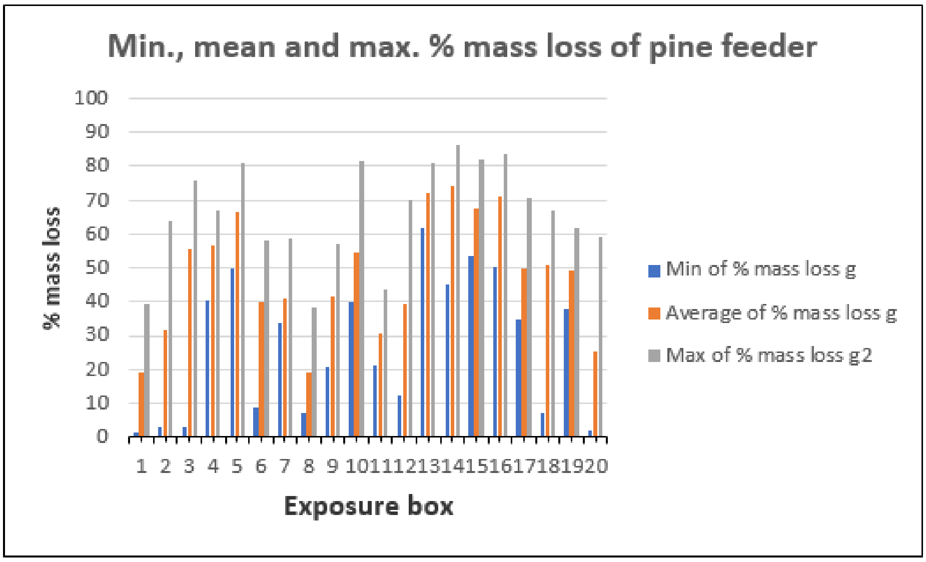

Figure 11.7. Minimum, mean and maximum % mass loss of pine feeder blocks per exposure box

The nominated control (full hoop) LVL blocks were all damaged by *C. acinaciformis* with mass losses ranging from 4% up 21% for individual blocks. The mean mass loss across all 20 boxes was 13%. In 15 of the blocks the face, back and inner plys were damaged to some degree and in some blocks the termites had also eaten through the glueline (Figure 11.8). Some blocks had close to 100% of the face and back veneer damaged by termites. All 15 blocks had a visual damage rating of 4. The remainder of the blocks, apart from block 10_4, only sustained damage to the face or back veneer and in a couple of cases the inner plys were not damaged by termites. Block 10 4 sustained only minor damage to the inner plys at one end (this consisted of a series of small drill holes) (Figure 11.9). This was the only block that had a visual rating of 2. The visual damage rating for all blocks ranged from a 2 (superficial damage) to a 4 (5 - 25% mass loss/ > 5mm in depth core veneers).

Figure 11.8. Fifteen of the 100% hoop pine LVL blocks were severely damaged by *C. acinaciformis*

Figure 11.9. Block 10_4 was the least damaged of all the 100% hoop pine LVL blocks

The 100% cypress LVL blocks performed best when exposed to *C. acinaciformis* feeding with 18 of the 20 blocks not damaged by termites (visual rating 1) (Figure 11.10) with the remaining two blocks sustaining only superficial damage (visual rating 2) on an inner ply (Figure 11.11).

This was to be expected as the heartwood of cypress pine is regarded as resistant to termite attack. Mass loss for these two blocks was 0.9% and 1.5% with a mean mass loss of 0.12%.

Figure 11.10. Eighteen of the 100% cypress LVL blocks were sound (visual rating 1)

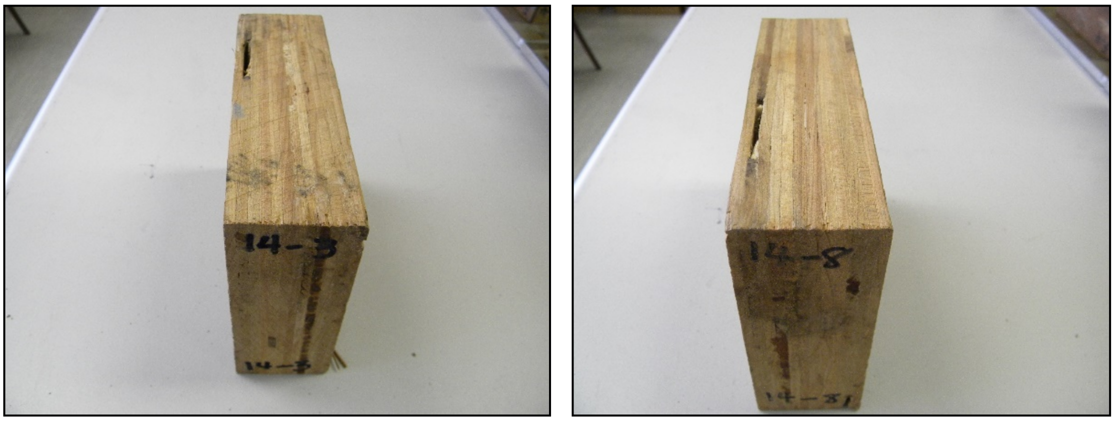

Figure 11.11. Two of the 100% cypress LVL blocks sustained minor damage to one of the inner plys

Four of the 100% spotted gum LVL blocks were not damaged (visual rating 1) by *C. acinaciformis* while 15 of the blocks sustained some minor grazing (visual rating 2) to the face and/or back veneer while occasionally one or two inner plys were slightly grooved (Figure 11.12). Only block 3_4 received a visual rating above 2 (in this case 3) due to a > 5mm depth damage to some of the inner plys (Figure 11.13). Mass losses per individual blocks ranged from 0.27% up to 1.25% with a mean mass loss across the 20 boxes of 0.6%. The visual termite damage rating ranged from 1 (sound) through to 3 (slight surface damage by termites/ up to 5mm in depth core veneers).

Figure 11.12. Fifteen of the 100% SPG blocks had minor damage to the face and/or back veneers and inner plys

Figure 11.13. Block 3_4 sustained damage to the face and back veneer and inner ply with a visual rating of 3

Eleven of the cypress/hoop alternating LVL blocks were sound (visual rating 1) while seven of the remaining blocks sustained nil damage to the face and back veneer (cypress) but significant damage to some of the hoop plys, with up to 25mm in depth damage (six blocks with a visual rating of 3 and one with a rating of 4) (Figure 11.14). Block 16_5 was the only block to sustain face damage (Figure 11.14). The two remaining blocks (16_1 and 16_7) had a visual rating of 2 with only a slight nibble on an individual hoop ply. Mass losses per individual blocks ranged from 1.26% up to 6.24% with a mean mass loss across the 20 boxes of 1.8%. The visual termite damage rating ranged from 1 (sound) through to 4 (damage (slight) - 5 - 25% mass loss/ > 5mm in depth core veneers). The inner cypress plys were not damaged by termites.

Figure 11.14. The cypress/hoop alt. LVL blocks sustained significant damage to some of the hoop plys

Seven of the SPG/hoop core LVL blocks were sound (visual rating 1) but the remaining 13 blocks all sustained damage to the hoop plys, though to varying degrees. Four blocks had a visual rating of 4 with significant damage to the hoop core with up to 35mm in depth damage to some hoop plys (Figure 11.15). Four blocks also had slight grazing on the face and/or back veneer. Mass loss per individual blocks ranged from 1.1% up to 9.6% with the majority of the mass loss attributed to damage to the hoop core. The mean mass loss across the 20 boxes was 3.3%. The visual damage rating ranged from 1(sound) through to 4 (damage (slight) - 5 - 25% mass loss/ > 5mm in depth core veneers).

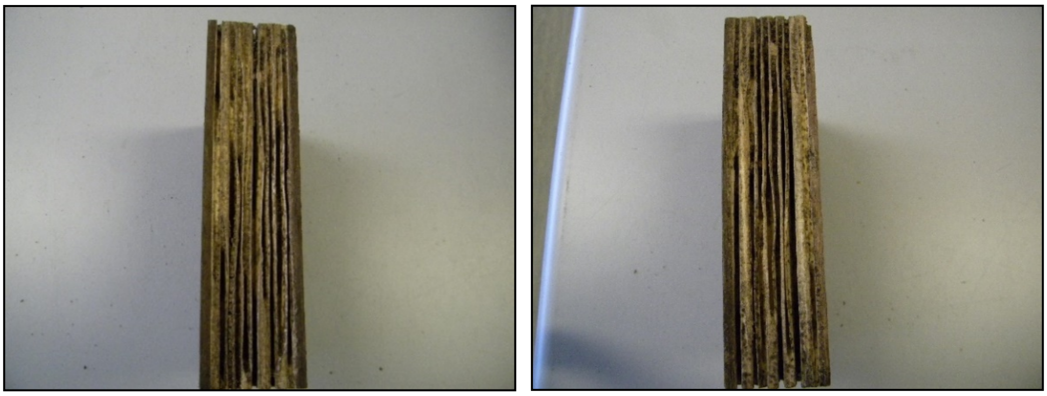

Figure 11.15. There was significant damage to the hoop core in some blocks

Seven of the SPG/hoop alt. LVL blocks were sound (visual rating 1) and 10 blocks sustained damage to the hoop plys though to varying degrees. None of the SPG inner plys were damaged by termites. Five of these ten blocks sustained significant damage to the hoop plys with up to 25 mm in depth damage to some plys (visual rating 3 or 4) (Figure 11.16). The remaining five of these blocks had only minor damage or nibbling to the hoop plys with a visual damage rating of 2. The remaining three blocks had only slight grazing on the face and/or back veneer with no damage to the hoop plys. Nine blocks overall had damage to the face and/or back veneer. There were two blocks where the face damage could be considered significant (8_6 and 8_9) where up to 25% of the face had been damaged by termites (Figure 11.17). Mass loss per individual blocks ranged from 1.5% up to 6.3% with the majority of the mass loss attributed to damage to the hoop plys. The mean mass loss across the 20 boxes was 2.8%. The visual termite damage rating ranged from 1 (sound) through to 4 (damage (slight) - 5 - 25% mass loss/ > 5mm in depth core veneers). A rating of 4 was attributed to one block only viz. 8_6.

Figure 11.16. There was significant damage to the hoop plys in some of the blocks

Figure 11.17. Two blocks sustained significant damage to the face veneer

The mean % mass loss per construction type is shown in Figure 11.18. Figure 11.19 shows the same information but with the pine feeder material included.

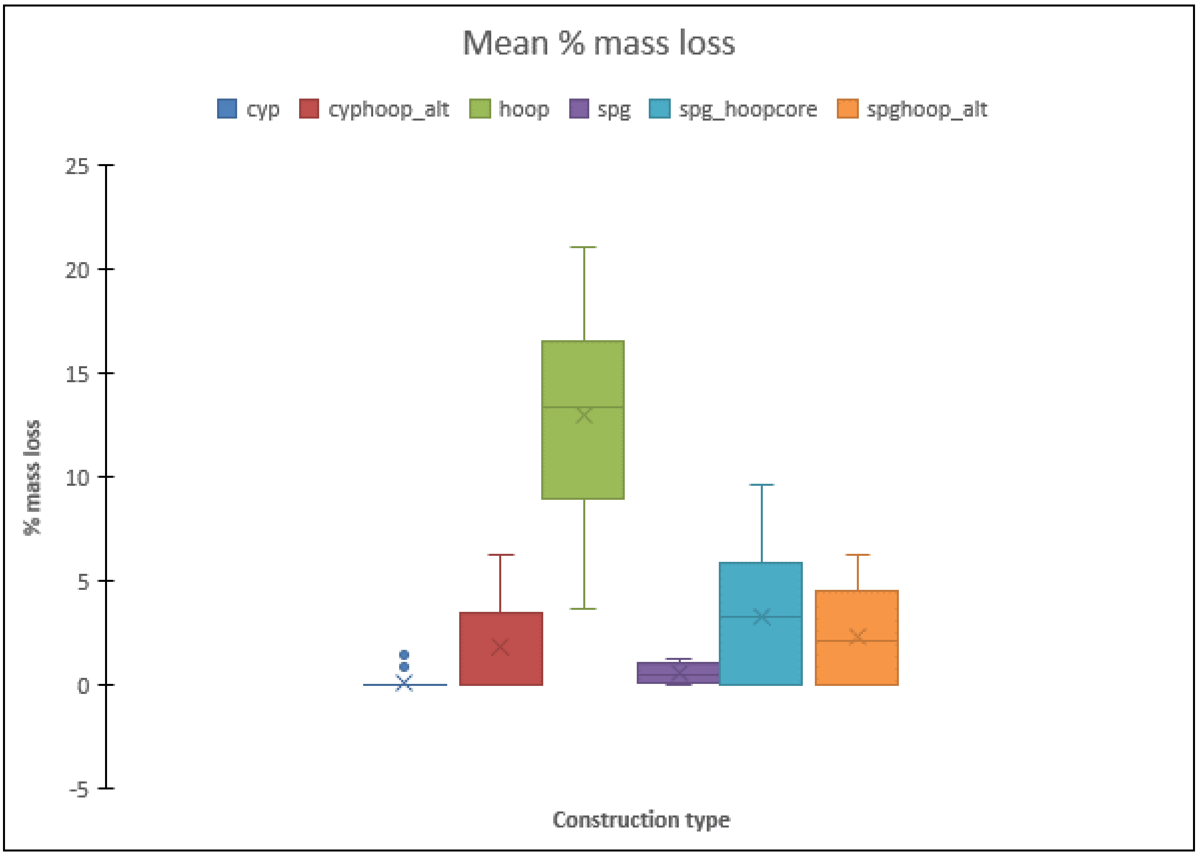

Figure 11.18. Mean % mass loss due to termite feeding per construction type

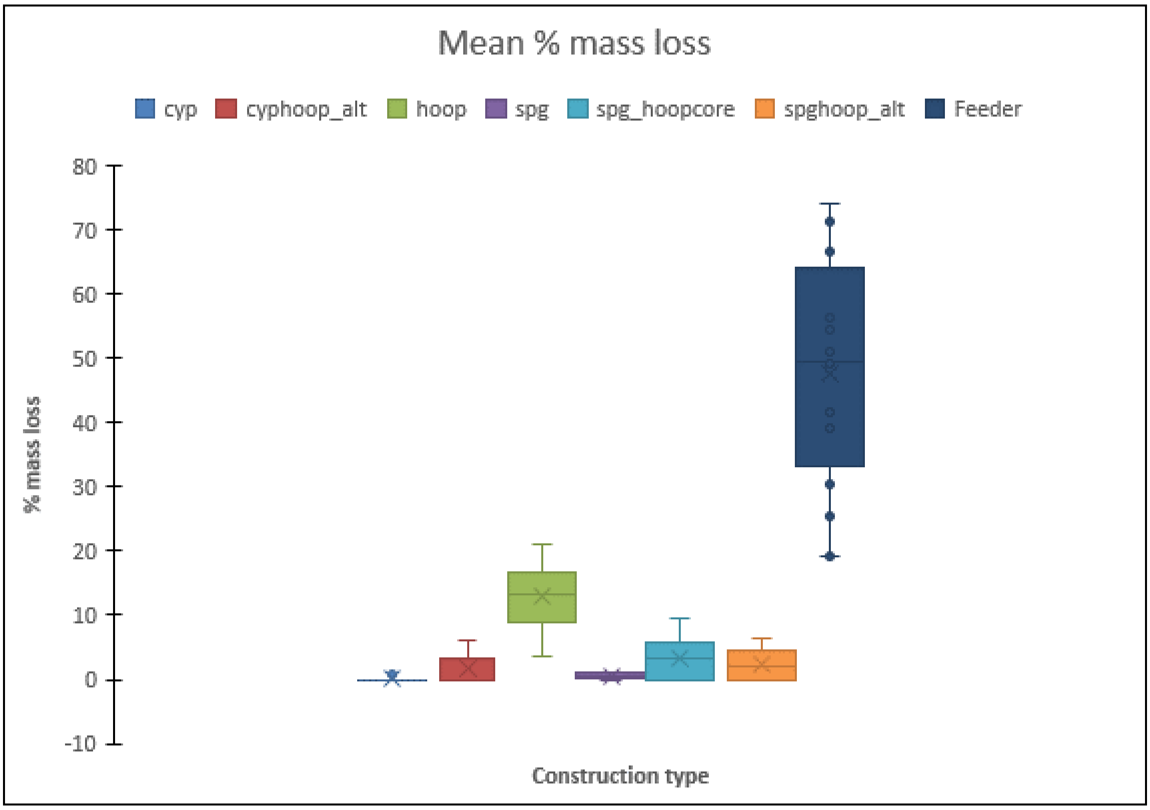

Figure 11.19. Mean % mass loss due to termite feeding per construction type including pine feeder

Analyses were performed using GenStat v19. Percentage_mass_loss was analysed using an ANOVA with Construction Type as a treatment effect, Box_no as a block effect and FeederAverage%ML as a covariate. Means, adjusted for the covariate, were calculated (Figure 11.20).

Termite Damage Rating was converted into a binomial damaged rating (Rating Binomial) where a rating of 1 or 2 was negative (0; sound-mostly sound) and 3, 4 or 5 was positive (1; damaged). This was analysed using a Generalised Linear Model (GLM) with a binomial distribution and logit link fitting Box_no and Treatment. The predicted mean proportion of wood blocks damaged were calculated (Figure 11.21). For both analyses pairwise comparisons were performed using Fisher's protected least significant difference with a 5% significance level where means with the same letter are not significantly different.

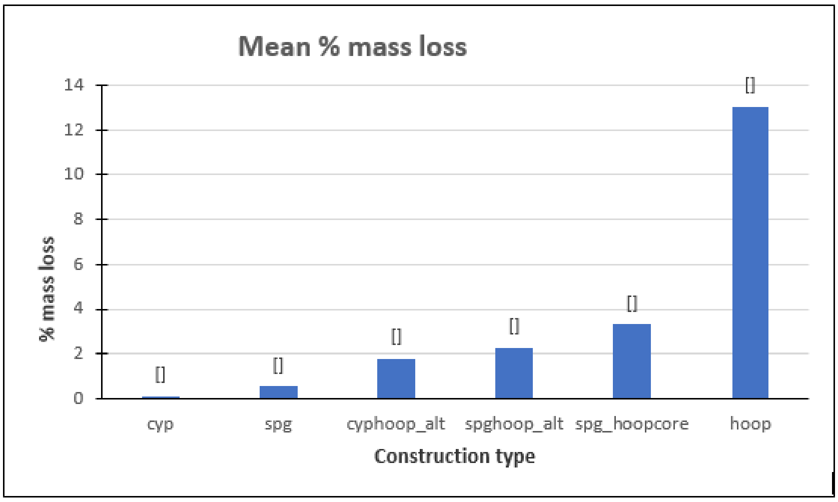

Figure 11.20. Mean % mass loss due to termite feeding per construction type

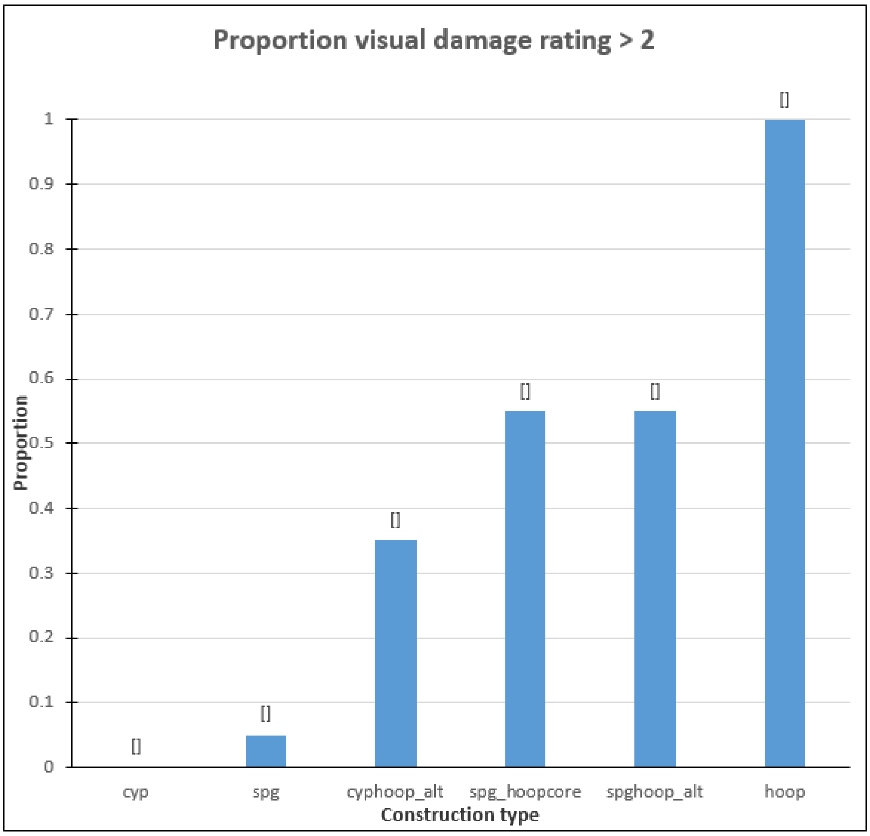

Figure 11.21. Average percentage mass loss due to termite feeding per construction type

Figure 11.22 shows the mean mass loss of each replicate group (cut from one of three LVL panels) within the six construction types. Replicate 15 (full cypress) sustained nil damage.

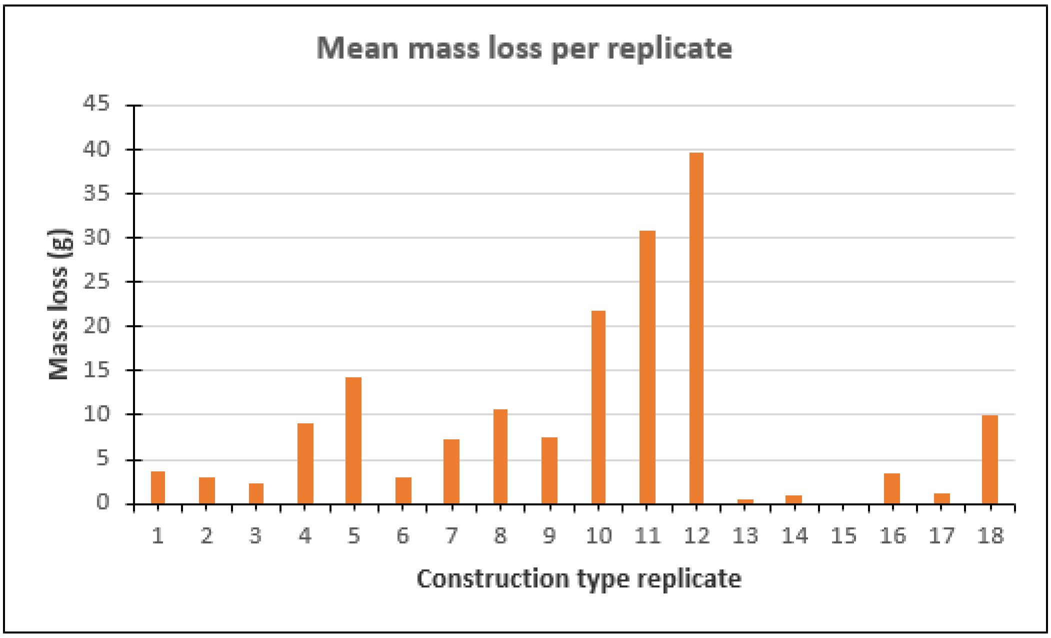

Figure 11.22. Mean percentage mass loss per replicate per construction type

Note:

- ***1-3** 100% SPG*
- ***4-6** SPG/hoop core*
- ***7-9** SPG/hoop alt.*
- ***10-12** 100% Hoop*
- ***13-15** 100% Cypress*
- ***16-18** CYP/hoop alt.*

The results from above incorporating the visual termite damage rating and the mean % mass loss for the 6 LVL construction types and the pine feeder blocks are outlined in Table 11.1.

Table 11.1. The visual termite damage rating and mean mass loss (20 test blocks) for 6 LVL construction types and pine feeder blocks spread across 20 exposure boxes

Construction type	Face veneer	Back veneer	Inner plys	Visual damage rating	Mean mass loss (g)
SPG	+	+	+	1 - 3	2.94
SPG /Hoop core	+	+	+	1 - 4	9.07
SPG/Hoop alt.	+	+	+ hoop only	1 - 4	8.35
Hoop	+	+	+	2 - 4	29.85
Cypress	-	-	+ very slight	1 - 2	0.4
Cyp/Hoop alt.	+	-	+ hoop only	1 - 3	5.08
Pine feeder	n/a	n/a	n/a	2 - 7	33.75

(+) termite damage (-) no termite damage

The 100% hoop pine LVL blocks (nominated control) were all damaged by *C. acinaciformis* to varying degrees with a mean mass loss across the 20 boxes of 13.1% (range 4% - 21% for individual blocks). The visual termite damage rating ranged from 2 through to 4 but only one block (10_4) had a rating of 2, with a slight nibble on the face veneer, while 15 of the blocks had a visual damage rating of 4 (5 - 25% mass loss/ > 5mm in depth damage) with significant damage to the face, back and core veneers and glueline penetration. In some blocks the entire surface of the face and back veneer had been eaten by termites. These blocks were susceptible to attack by *C. acinaciformis,* as expected.

The 100% cypress LVL blocks were virtually untouched by *C. acinaciformis* with nil damage to the face and back veneers and only very slight damage (nibble and a single drill hole) in two of the blocks. Notwithstanding this minor damage 100% cypress LVL can be regarded as resistant to *C. acinaciformis*. This was not unexpected as cypress pine heartwood is known to be resistant to termite attack.

While spotted gum (SPG) is listed as a Durability Class1 (above-ground) hardwood and known to be termite resistant only four of the blocks were not damaged by termites. The remaining 16 blocks sustained termite damage to the face and/or back veneer and to some of the inner plys but in all cases, with the exception of block 3_4, the visual termite damage rating was 2 (superficial damage). Block 3_4 had minor grooves on the face and back veneer but one of the inner plys had a 5mm depth damage representing a visual damage rating of 3. Interestingly this block was sitting in Box 14 which had the highest mean mass loss of feeder material i.e. 74.2% indicating strong termite vigour. Overall due to the minor nature of the termite damage in most blocks there is nothing to suggest that full SPG LVL is not resistant to termite attack.

There were eleven blocks in the cypress/ hoop alternating LVL construction type that had a visual damage rating of 1 (sound) and there were seven blocks that sustained damage to the hoop plys, some with up to 25mm in depth damage (visual rating of 4). One of these blocks (16_5) also sustained some minor nibbles to the cypress face veneer. The two remaining blocks had a visual damage rating of 2 with only a slight nibble on an individual hoop core ply. While the mean mass loss across the 20 boxes was just 1.8% there was sufficient damage to some of the hoop core plys (block 18_7, 6.3% - mass loss of 17.9g) to deem this construction type susceptible to attack by *C. acinaciformis*.

With the SPG/ hoop core LVL construction type there were seven blocks that had a visual damage rating of 1 (sound) but in this instance the remaining 13 blocks all sustained damage to the hoop plys to varying degrees. There were 5 blocks with a visual damage rating of 4 with up to 35mm in depth damage to some of the hoop plys. While the mean mass loss across the 20 boxes was just 3.3% there was sufficient damage in some of the blocks (block 5_4, 9.6% - mass loss 26g) to deem this construction type susceptible to attack by *C. acinaciformis*.

When SPG was alternated with hoop pine (SPG face and back) the results were somewhat similar with seven blocks also with a rating of 1 (sound) and a further 10 blocks with damage to the hoop plys to varying degrees. None of the SPG core plys were damaged by termites. One of these ten blocks (8_6) had a visual damage rating of 4. Eight of the 10 blocks had visual damage rating of 3 and one a rating of 2. The remaining three blocks sustained only light grazing on the face or back veneer with nil damage to the hoop plys. However nine blocks overall had damage to the face and/or back veneer. While the mean mass loss across the 20 boxes was just 2.3% there was sufficient damage to some of the blocks (block 8_6, 6.3% - mass loss of 23g) to deem this construction type susceptible to attack by *C. acinaciformis.*

In this trial only the 100% cypress and 100% SPG LVL constructions could be considered resistant to termite attack i.e. against *C. acinaciformis* in a field trial. The four remaining LVL construction types were susceptible to termite attack due to the severity of damage to the hoop core plys and, in the case of the full hoop LVL construction, to the face and back veneers as well. Neither the cypress as a face and back veneer (cypress/ hoop alt. construction) or SPG as a face and back veneer (SPG/ hoop core and SPG/ hoop alt. construction) could protect the inner hoop plys, in not all (except for full hoop), but in enough instances to regard the LVL construction types susceptible to attack by *C. acinaciformis*. With the cypress/ hoop alt. construction type the results differ from Report 1 where the cypress (in a 7-ply plywood configuration) inhibited termite attack on the inner hoop plys. In this instance there were four cypress veneers to three hoop veneers. This was not the case with the similar LVL construction (six cypress veneers and six hoop veneers) where seven blocks had significant damage to some of the inner hoop plys. There was no damage to the core cypress plys in this LVL construction. Similarly with the SPG/ hoop alt. construction type there was nil damage to the core SPG plys. However the termites had been able to selectively colonize and feed on the hoop veneer layer in the core of the LVL. A visual damage rating of 4 (5 - 25% mass loss/ >5mm depth damage) was assigned to some of the blocks in these four construction types.

With mixed plywood (durable and non-durable veneers) Faraji *et al* 2009 found that having a durable veneer (cypress pine heartwood) as a face and back veneer was the primary necessary condition for the plywood block to be resistant to termite attack, but secondarily the cross bands must be cypress pine as well. A contributing factor also to imparting termite resistance was that at least 60% of the plys in the construction should be cypress pine. This was close with the resistant plywood construction (cypress face/ back/ long bands – hoop cross bands) in Report 1 with 57.2% cypress and less (but not markedly so) with the LVL construction with 50% cypress veneers. Interestingly the hoop veneers in the LVL construction are approximately twice as thick as those used in the plywood configuration in Report 1. This greater exposed surface area may have contributed to the termite attack on the hoop plys in the LVL constructions where a durable species (cypress or SPG) was used as a face and back veneer, especially where the hoop veneers were alternated with durable species. An additional trial (currently waiting assessment) will look at the termite susceptibility or resistance of mixed species plywood with varying thicknesses of hoop veneer.

While the mean mass losses in cyp/hoop alt., SPG/hoop core and SPG/hoop alt. were 1.8% (mean mass loss 5.1g), 3.3% (mean mass loss 9.1g) and 2.3% (mean mass loss 8.4g) respectively and this suggests only superficial damage or nibbling, it is the fact that termites have damaged the face, back and inner hoop plys (sometimes considerably) that is the significant factor in deeming these LVL construction types unsuitable for use in termite prone situations.

Cypress pine and spotted gum were considered durable species for the purpose of the blended species LVL construction. While there was more visible termite damage on the 100% SPG blocks compared to 100% cypress there was no significant difference between the mean % mass loss of cypress compared to hoop. SPG/hoop alt., SPG/hoop core and SPG/cyp alt. construction types were not significantly different from one another with regards mean % mass loss. Mean % mass loss for the 100% hoop LVL was significantly different from all other construction types which is not unexpected with hoop pine representing the non-durable species.

Conclusions

1. An LVL construction type comprising either 100% cypress or 100% SPG can be considered resistant to termite attack by *C. acinaciformis*; there was no significant difference between the mean % mass loss of cypress compared to SPG.
2. No other LVL construction type in this study could be deemed suitable to prevent attack by *C. acinaciformis* to a degree that would be acceptable if the end-use involves exposure to possible subterranean termite attack.
3. Having a durable species (cypress or SPG) as a face and back veneer in the LVL construction type did not provide protection for the inner hoop (non-durable species) plys though this was not the case with all 20 test blocks and the hoop plys were attacked to varying degrees.
4. While the mean % mass loss for all LVL construction types (other than 100% hoop) was < 5% it was the degree of damage to some of the inner hoop plys that was the significant factor in assigning susceptibility to termite attack of individual blocks.
5. SPG/hoop alt., SPG/hoop core and SPG/cyp alt. construction types were not significantly different from one another with regards mean % mass loss; mean % mass loss for the 100% hoop LVL was significantly different from all other construction types.

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Chapter 12: Effect of veneer thickness on susceptibility to attack by the subterranean termite *Coptotermes acinaciformis*

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Introduction

In Australia, the demand for veneer-based engineered wood products (EWPs) including plywood and laminated veneer lumber (LVL) continue to grow as building products for both structural and non-structural applications, and in both interior and weather-exposed situations. Despite the economic downturn, which resulted from the global financial crisis in 2008, there has been little evidence of any slowdown in the global production of either plywood or veneer (Hughes, 2015). With ever improving manufacturing technology and continued advances in building manufacture and design, the use and popularity of EWP's is expected to increase.

Veneer-based engineered wood products provide an opportunity to improve the utilization of forest resources compared to traditional sawn products. This is coupled with the potential to use currently under-used, small-diameter native forest log resources (with the advent of spindleless rotary veneering technology) to produce useful veneer-based products. McGavin *et al.* (2018) suggested that a suitable pathway for the use of small-diameter native forest resources would be to blend the rotary veneers recovered from peeling operations with existing commercial plantation softwood veneers such as hoop pine (*Araucaria cunninghamii*). Blending resources can provide a number of benefits including efficient resource utilisation, compatibility with modern building design and enhanced product performance.

One component of enhanced product performance is the ability to resist biological degrade (termites and fungi) through heightened natural durability *i.e.* without the requirement for chemical preservation. Enhanced product durability can potentially be achieved by blending durable and non-durable timber species in an EWP such as plywood or LVL. The key proviso is that the non-durable species can only be used as a core veneer (typically integrated with the durable species) and not as the exposed face or back veneer (Faraji *et al.* 2009).

White cypress pine (*Callitris glaucophylla*) (from here on referred to as CYP) is a softwood which is widely distributed within Australia's inland native forests (McGavin and Leggate 2019). The heartwood of this species is known to be resistant to termite and fungal attack due predominantly to the presence of extractives (natural preservatives) in the heartwood, though this resistance does not extend to the sapwood. These extractives include thujaplicin, nootkatin, dolabrin, thujaplicinol and pygmaein. The extractives have been investigated as potential natural preservative treatments (as alternatives to chemical preservatives) for other non-durable timbers to prevent termite attack. The extractives can be either toxic or repellent to termites (Evans *et al.* 2000).

Previous studies (Behr and Wittrup 1969; Kamden and Sean 1994; Evans *et al.* 1997; Evans *et al.* 2000 and Kartal and Green 2003) looking at blends of durable (*e.g.* CYP) and non-durable (*e.g.* radiata pine, *Pinus radiata* or hoop pine) in either particleboard or medium density fibreboard (MDF) have shown enhanced resistance to termite attack when compared to those composed entirely of a non-durable species.

Faraji *et al.* (2009) demonstrated that the greater the ratio of durable to non-durable veneers in a plywood panel, then more enhanced was the termite resistance. The improved durability was also found to be influenced by the number of veneers, veneer thickness and the veneer lay-up strategy (*i.e.* the veneer positioning within the panel). Similarly, Nzokou *et al.* (2005) reported the biological durability of LVL made from blending durable black locust (*Robinia pseudoacacia*) and non-durable red maple (*Acer rubrum*) species demonstrated enhanced durability when the face and back veneer and at least one core veneer were from the durable species.

The study reported by Faraji *et al.* (2009) included plywood made from blends of the durable heartwood of cypress pine (*Cupressus sempervirens*) and the non-durable sapwood of Scots pine (*Pinus sylvestris*), beech (*Fagus sylvatica*) and poplar (*Populus* sp.), which were evaluated against the subterranean termite *Reticulitermes santonensis* in laboratory trials. Plywood blocks included both 5-ply and 9-ply configurations and consisted of a mix of 2.6 mm and 1.3 mm thick veneers for various blends of durable and non-durable species, as well as single species controls. Resistance to termite attack in a blended plywood was only achieved where the face and back veneers were cypress pine heartwood. Of the four panels that were deemed termite resistant, three of them consisted of 60% durable plies with an integration of durable and non-durable plies in the core of the plywood block as well.

The percentage mass loss in the 5-ply configurations was always higher than for the 9-ply configurations (where all the veneers in both configurations were of non-durable species). The authors suggested this could be related in part to veneer thickness. The 5-ply configurations comprised only 2.6 mm veneers while the 9-ply configurations consisted of eight 1.3 mm veneers and a center veneer of 2.6 mm. Termites indiscriminately attacked the thicker veneers in both configurations but preferentially only the outermost 1.5 mm veneers in the 9-ply configuration. The remaining six 1.5 mm veneers were not attacked. The test block dimensions were 50 x 25 x 15 mm and were exposed to 250 termite workers in a laboratory trial.

Trials assessing resistance against basidiomycete fungi, in addition to termites, reported by Faraji *et al.* (2008) showed that the ratio of exposed durable surfaces vs. non-durable surfaces in plywood is the determiner of resistance rather than the volume of durable vs. non-durable veneers.

Nzokou *et al.* (2005) assessed LVL manufactured using veneers from decay-resistant black locust (*Robinia pseudoacacia*) and decay-susceptible red maple (*Acer rubrum)* to determine the durability impact of the LVL manufacturing process, and to test if the blending of decay-resistant and decay-susceptible species can improve resistance against biological degrade. A laboratory soil block test (against fungi) and a field test (against termites – species unknown) were conducted. The study concluded that durability against decay was shown to improve when the two faces and at least one core veneer were from decay-resistant species. However, the blended LVL was vulnerable to termite attack and it was concluded that the termites were able to selectively colonize the non-durable red maple veneers even if positioned in the core of the LVL.

In this study, a termite exposure trial was established to investigate the effect of veneer thickness (of both durable CYP and non-durable hoop pine) on enhancing termite resistance in blended-species plywood panels all consisting of a CYP face and back veneer but half with a full hoop pine core and the remainder having a CYP long band integrated with a hoop pine cross band. The study aimed to determine, in what plywood panel lay-up configurations, can the durable CYP enhance the protection of the non-durable hoop pine from termite attack.

Materials and methods

Veneer source and test sample matrix

CYP and hoop pine were the two species included in the study. CYP represents a mid-high density, durable softwood that is sourced from sustainably managed native forests, while hoop pine represents a plantation softwood resource and is non-durable (DAF 2018). Both of these species are commercially available to the Australian timber industry.

The CYP veneers were sourced from small-diameter (< 25 cm) native forest logs which were processed using a spindleless rotary veneering system. The hoop pine veneers were recovered from approximately eight logs peeled by a commercial veneer producer during standard commercial operations. There were three dry-veneer thicknesses of CYP (1.8, 2.8 and 3.0 mm) and hoop pine (1.0, 1.5 and 3.0 mm). Four different groups of 7-ply plywood were manufactured with different thickness variations represented within each group. This resulted in a total of 24 plywood configurations (Table 12.1).

Table 12.1. Eighteen blended plywood configurations and six same species configurations were manufactured and tested.

Plywood Configuration	CYP veneer thickness (mm)				Hoop veneer thickness (mm)			No. of test blocks
	1.8	2.8	3.0		1.0	1.5	3.0	
1	√				√			8*
2	√					√		8*
3	√						√	16
4		√			√			16
5		√				√		16
6		√					√	16
7			√		√			16
8			√			√		16
9			√				√	16
10	√				√			8*
11	√					√		8*
12	√						√	8*
13		√			√			8*
14		√				√		8*
15		√					√	8*
16			√		√			16
17			√			√		8*
18			√				√	16
19					√			16
20						√		16
21							√	16
22	√							16
23		√						16
24			√					16
								Total - 312

* These configurations had only 8 test blocks due to limited availability of veneers.

- 1-9 - CYP face / back and hoop core
- 10 -18 - CYP face / back / long band and hoop cross band
- 19 -21 - Full hoop pine
- 22 -24 - Full CYP

Sample preparation

Veneer sheets of CYP and hoop pine were conditioned to 6 % moisture content (MC) and then reduced to sheets measuring 300 x 300 mm using a panel saw. The resultant sheets and a phenol formaldehyde adhesive were used to manufacture the 7-ply plywood panels. This adhesive is moisture and UV resistant, and is an approved adhesive for external, weather exposed and structural applications in accordance with AS/NZS 2754.1 2016.

The adhesive was applied to each face of the veneers targeting a total spread rate of 200 gsm (grams per square metre) per glue line. The assembly stage included an open assembly time of approximately 20 minutes or until the adhesive was tacky. Pre-pressing was undertaken at 1.2 MPa for 15 minutes followed by a hot press for 12 minutes at 135^0C in a laboratory press. The panels were then stored for at least 24 hours before cutting into test blocks. All plywood combinations consisted of 7-ply plywood in either a blended (CYP face / back and hoop core; CYP face / back / long band and hoop pine cross band) or same species (full hoop pine or full CYP) configuration (Figure 12.1)

Test blocks measuring 135 x 70 mm by the thickness of the plywood panel, which varied from 7 to 22 mm depending on the veneer thicknesses, were cut from the panels. Eight test blocks were cut from each plywood panel providing a total of 312 (a combination of 16 replicates and eight replicates) test blocks across the 24 different plywood configurations. To attract termite activity towards the test blocks, 350 feeder blocks (135 x 70 x 20 mm) were cut from low durability softwood (*Pinus* sp.) sawn timber (predominantly sapwood).

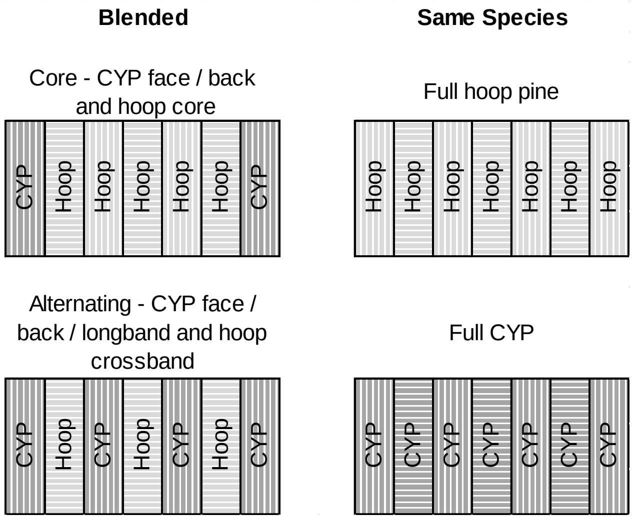


Figure 12.1. 7- ply plywood test block configurations (3 CYP thicknesses; 3 hoop pine thicknesses)

Test block arrangement

All test blocks and feeder blocks were weighed to enable mass loss calculations post-exposure to termites. Test block sets were then prepared alternating a feeder block and one test block from each configuration. Corrugated cardboard was used to separate all samples (Figure 12.2). The test block sets were then randomly distributed across 24 exposure boxes (opaque plastic boxes).

The feeder blocks were included to encourage on-going termite foraging in the exposure box and provide an indicator of termite vigour (based on mass loss of feeder blocks) within each box. The corrugated cardboard was used to provide a series of runways for the termites once they had entered the box and aid the movement of termites throughout the exposure box. Additional feeder blocks and the cardboard were also added to accommodate any free space in the exposure box.

Figure 12.2. Plywood test blocks and pine feeder sapwood blocks positioned in an exposure box

Field exposure

Several weeks prior to the trial, a dedicated trench was prepared at a field trial site at Esk (27.2333^{0} S, 152.4167^{0} E) in South-east Queensland, Australia. This was in an area where *C. acinaciformis* were known to be very active. The trench was excavated and filled with termite susceptible feeder material (pine off-cuts) to promote further activity. Concrete blocks were laid on top of the trench and pine feeder stakes were driven into the trench through the holes in the concrete blocks ensuring that they were in contact with the timber materials buried in the trench. At this stage non-durable pine studs were positioned along the length of the concrete blocks as feeder material to ensure termite activity was present when the exposure boxes were placed in the field. The pine studs were covered with black plastic.

At trial establishment the black plastic was removed to reveal the pine studs heavily infested with termites (Figure 12.3). The exposure boxes were placed upturned on the concrete blocks before the trench was liberally doused with water and the black plastic re-instated to maintain a dark, humid environment conducive to sustained termite foraging (Figure 12.4). The boxes were inspected after one month to ensure termites were active within all the boxes (as observed through the top of the upturned exposure box) and then left un-disturbed for a further 20 weeks culminating in a 24-week exposure period. The trial ran from November 2018 to May 2019 during the hot summer months when the termites are most active.

Figure 12.3. Timber placed atop the aggregation trench was heavily infested with *C. acinaciformis*

Figure 12.4. The exposure boxes were placed atop the trench and covered with black plastic

Post exposure assessment

After the 24-week exposure period, the boxes were retrieved from the field and returned to the laboratory for assessment. Each test block set was removed from the boxes, the test blocks separated from the feeder blocks and any dirt, debris and termites were removed. Live termites were found in the majority of the 24 exposure boxes at this time (Figure 12.5).

n
assessed

Each test and feeder block was visually examined for termite damage. For the test blocks, it was noted whether the face and back veneers and/or the core veneers experienced damage. Then each test block was weighed to determine the mass loss due to termite attack and subsequently, the percentage mass loss was calculated to enable further comparison. From the visual assessment and calculated percentage mass loss, each test block was assigned a score based on the following rating system (Table 12.2) which was adapted from Peters and Creffield (2004). The rating system was modified to accommodate lateral or end damage to individual core veneers (measured as depth in mm using a pointed metal ruler). Surface damage by termites was only a factor where the face and back veneer were hoop pine i.e. configurations 19, 20 and 21. A mean termite damage rating was calculated for each plywood configuration as well as the rating range for all test blocks within the configuration.

Table 12.2. Rating system for assessment of termite damage on test and feeder blocks

Rating	Condition of test or feeder block
1	Sound
2	Superficial damage by termites - nibbling
3	Surface grazing by termites - core veneer damage < 5mm in depth
4	Damage (minor) 5-25 % mass loss - core veneer damage > 5mm in depth
5	Damage (moderate) 25-50 % mass loss - core veneer damage > 5mm in depth
6	Damage (severe) 50-75 % mass loss - core veneer damage > 5mm in depth
7	Destroyed > 75% mass loss

Statistical analysis

Statistical analysis was carried out using GenStat v19 (VSN 2017). CYP controls (plywood configurations 22 to 24) were not analysed as they were not damaged by termites. The average percent feeder mass loss per exposure box was used as a covariate in the analyses to account for variations in termite activity within boxes.

An ANOVA was performed on the hoop pine control data with hoop pine thickness as a treatment effect while an unbalanced ANOVA (to account for different replication numbers) was performed on the blended groups with CYP thickness, hoop pine thickness, blended type and their interaction as treatment effects. Non-significant interactions were subsequently omitted from the model. Means and Standard Errors were determined as well as pairwise comparisons using Fishers Protected Least Significant Difference (LSD), where means with the same letter were not significantly different.

Results and discussion

The majority of the softwood feeder blocks were either substantially damaged or destroyed by termites indicative of strong termite vigour (Figure 12.6). Mean mass losses per exposure box ranged from 29% to 86% and the mean damage rating for all blocks was 6 (severe) with a range from 1 (sound) to 7 (destroyed). Only 16 blocks out of 350 had a rating of 1. These were spread across eight separate exposure boxes.

Figure 12.6. The majority of the softwood feeder blocks were substantially damaged by termites

From the visual assessment and calculated percentage mass loss, each plywood configuration was assigned a mean termite damage rating (Table 12.3).The test blocks (i.e. 24 plywood configurations) had mean termite damage ratings from 1 (sound) to 5 (moderate damage) however in some cases the range included blocks with ratings of 6 (severe) and 7 (destroyed).

Table 12.3. Mean termite damage rating (core/cross band)

CYP veneer thickness (mm)	Hoop veneer thickness (mm)			
	1.0	**1.5**	**3.0**	**None (CYP only)**
1.8	1* / 1**	3* / 1**	4 */ 2**	1
2.8	1* / 1**	2* / 1**	4* / 3**	1
3.0	1* / 1**	3* / 1**	4* / 1**	1
None (Hoop only)	4	4	5	

*core configuration ** cross band / long band configuration

The full hoop pine test blocks (1, 1.5 and 3 mm) were all damaged by *C. acinaciformis* and received individual damage ratings between 2 and 7. Individual mass losses per test blocks ranged from 3% to 56% (1.0 mm veneer thickness blocks), 4% to 61% (1.5 mm veneer thickness blocks) and 10% to 82% (3.0 mm veneer thickness blocks) with mean percentage mass losses of 21%, 26% and 46% respectively. Statistical analysis of the percent mass loss showed no significant difference between 1.0 and 1.5 mm veneer thickness but a significantly higher loss using 3.0 mm veneer thickness (Table 12.4).

Table 12.4. Mean percent mass loss ± se for hoop pine veneer thickness in controls where means with the same letter are not significantly different

Hoop pine veneer thickness (mm)	Hoop control
1	21.00 ± 5.40 a
1.5	25.81 ± 5.40 a
3.0	45.50 ± 5.40 b

This result was not unexpected as hoop pine is a non-durable species with respect to termite attack (DAF 2018) and at a 3.0 mm veneer thickness there is simply more of the non-durable veneer between each glueline for the termites to feed on. Conversely none of the full CYP test blocks were damaged with all blocks receiving a damage rating of 1 (sound) (Figure 12.7). This was also not unexpected as CYP heartwood is known to be resistant to termite and fungal attack (Evans P. D. *et al*. 1997).

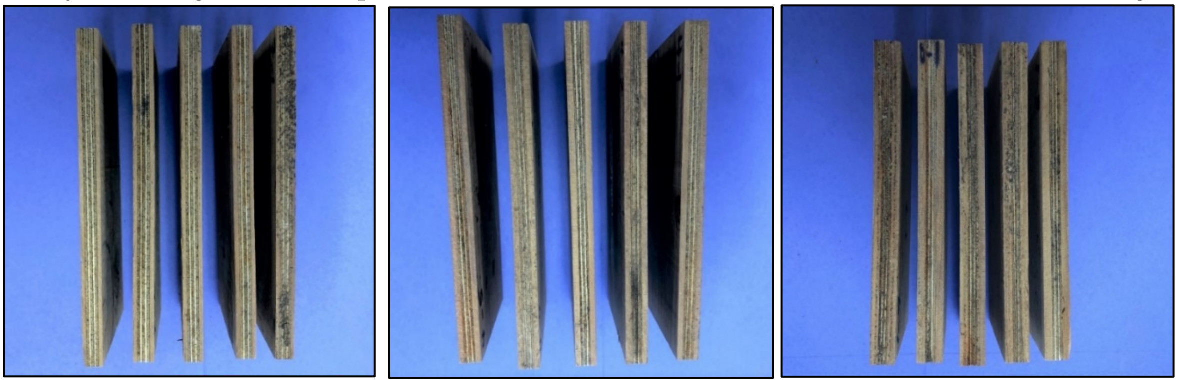
Figure 12.7. Hoop pine control blocks (L) were damaged by *C. acinaciformis* while CYP controls (R) didn't receive any damage

Statistical analysis of percent mass loss showed that CYP thickness had no effect (p=0.854) while there was a significant interaction between Type (either core or cross band) and hoop pine veneer thickness (p<0.001) with the full hoop core blocks (configurations 1-9) showing a percentage mass loss increase as the hoop veneer thickness increased but the alternating CYP long band / hoop cross band blocks (configurations 10 – 18) having little mass loss regardless of hoop veneer thickness (Table 12.5).

Table 12.5. Mean percent mass loss ± se for hoop pine veneer thickness and Type where means with the same letter are not significantly different

Hoop pine veneer thickness (mm)	Type. core	Type. cross band
1	0.478 ± 1.646 a	0.086 ± 1.872 a
1.5	10.202 ± 1.645 b	0.132 ± 2.122 a
3.0	22.843 ± 1.503 c	2.273 ± 1.840 a

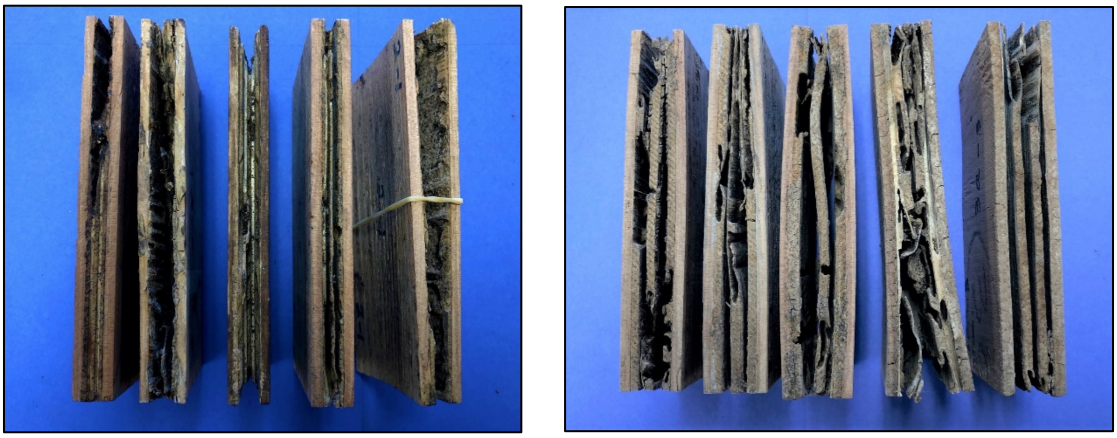
Of the test blocks which had CYP face and back veneers, and a hoop pine core (constituting nine separate plywood configurations) only those with a 1mm hoop veneer thickness were able to resist substantial termite damage irrespective of the thickness of the CYP face and back veneer (Figure 12.8). Of the 40 test blocks manufactured using the 1 mm hoop pine veneer in the core and CYP faces, only nine had evidence of termite damage on the edge of a hoop pine veneer only resulting in a damage score ≤ 3 (only two blocks had a rating of 3, the remainder had either 2 or 1). The mean percentage mass loss across the three test block groups that used 1 mm hoop pine core veneers with either 3 mm, 2.8 mm or 1.8 mm thick CYP face and back veneers was 0.7%, 0.8% and 0.3% respectively. The mass loss was due entirely to damage to the hoop core veneer – the CYP face and back veneer was not damaged.



1.8 mm CYP 2.8mm CYP 3.0 mm CYP

Figure 12.8. The majority of the 1mm hoop core plywood blocks were undamaged.

However when the hoop pine core veneer thickness increased to 1.5 mm and 3.0 mm respectively, then substantial termite damage was sustained by the hoop pine veneers (Figure 12.9 and Table 12.5). This was irrespective of the thickness of the CYP face and back veneers. The mean percentage mass losses for the test blocks which used 1.5 mm hoop pine core veneers and the three CYP face and back veneer thicknesses (1.8, 2.8 and 3.0 mm) were 16%, 7% and 11% respectively. For the test blocks which used 3.0 mm hoop pine core veneers, the mean percentage mass loss was 23% across all three CYP face and back thicknesses. The durable CYP face and back did not aid in the protection of the non-durable core veneers at 1.5 mm and 3.0 mm. In some cases, only the CYP face and back veneers essentially remained due to termite feeding.



1.5 mm hoop   3.0 mm hoop

Figure 12.9. Extensive termite damage was sustained to the 1.5 and 3.0 mm hoop cores

Of the plywood configurations 1 to 9 exposed to feeding by *C. acinaciformis* only configurations with a1.0 mm hoop pine veneer (configurations 1, 4 and 7) received minimal termite damage (Figure 12.10).

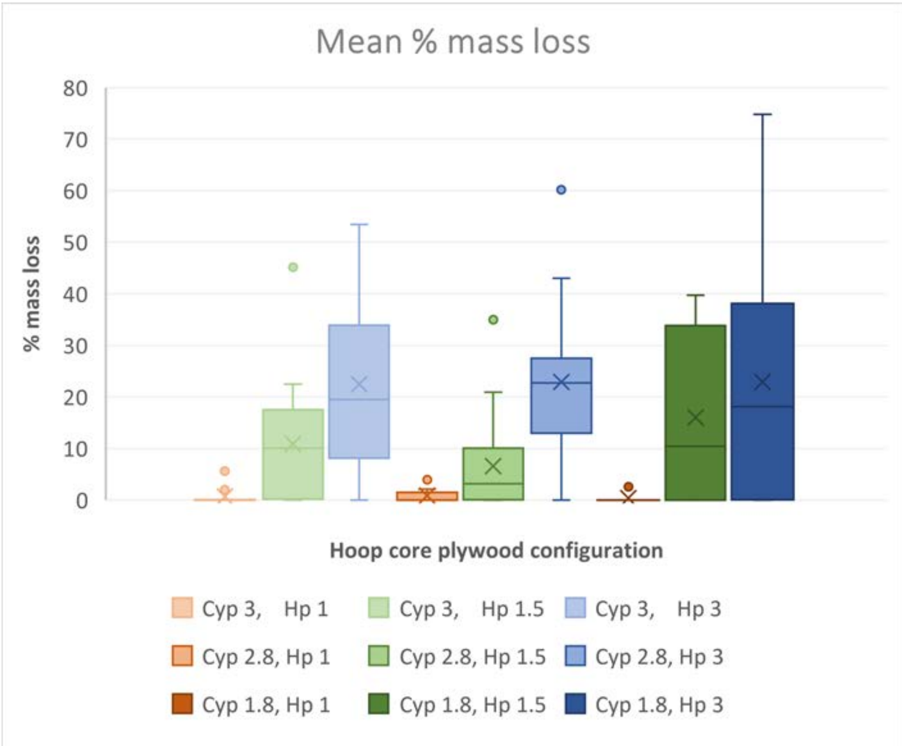


Figure 12.10. Mass loss % of nine plywood configurations comprising a CYP face and back and a hoop pine core (cross is the mean; central horizontal bar is the median)

For the plywood test block configurations (10 to 18) that included CYP and hoop pine arranged in an alternating pattern (CYP long bands and hoop pine cross bands), the durability of the hoop pine veneers (resistance to termite attack) was improved compared to the limiting the CYP to the face and back veneers. Again, while the CYP veneers were essentially untouched by termites there were two blocks that had some minor “nibbling” on the CYP long band.

With 1.0 mm hoop pine cross bands, none of the test blocks received termite damage (across all three CYP long band veneer thicknesses) with damage ratings of 1 being recorded (Figure 12.11). The encouraging performance of the 1 mm hoop pine veneers was in line with the results observed in the 1mm hoop pine core blocks (with CYP face and back veneers) i.e. plywood configurations 1, 4 and 7. One explanation for the resistance to termite attack of the 1.0 mm hoop pine veneers, maybe the influence of possible migration of CYP heartwood extractives into the thinner hoop pine veneers to prevent termite attack (Nzokou *et al.* 2005). Additionally the glueline may also have acted as a barrier to termite feeding when the veneer thickness was minimal e.g. 1.0 mm as the termites could only initiate feeding from the sides and the ends of the blocks due to the presence of durable CYP on the face and back and with configurations 10, 13 and 16, the CYP long band as well. Shulka and Joshi (1992) have previously reported a significant correlation between a reduction in veneer thickness and the resistance to termite attack using a phenol-formol glueline. They surmised that the penetration of glue (during manufacture) into a thin veneer may impart some degree of resistance to termite attack in combination with extractives migration. In "combination with extractives migration" is probably the key factor as the glueline was not an effective barrier when all the veneers were hoop pine (even at 1.0 mm). This was in contrast to the study by Faraji *et al.* 2009 where only the outer 1.3 mm veneers (in a 9-ply configuration of non-durable veneers) were eaten by termites. Again it is emphasised that this was a laboratory trial with small block size and a small number of termite (*R. santonensis*) workers.

Figure 12.11. Test blocks with a CYP long band and a 1.0 mm hoop pine cross band were undamaged

When the hoop pine cross bands increased to 1.5 mm thick veneers, there were some blocks that sustained very minimal damage to the hoop pine cross bands. The mean percentage mass loss across the three CYP veneer thicknesses (1.8, 2.8 and 3.0 mm) was ≤ 0.5% with the worst individual test block with a damage rating of only 2. However, with an increase of the hoop pine veneer thickness to 3.0 mm, there was noticeable increased damage to the hoop pine cross bands in some blocks (and in two blocks, some minor damage to the CYP long bands) (Figure 12.12). It could be surmised that once the hoop veneer thickness increased to 1.5 or 3.0 mm there was simply more area between the individual gluelines for the termites to exploit the non-durable hoop. In addition there was a greater volume of non-durable veneer for the termites to feed upon. It is well known that termites will aggregate more workers to the site of feeding when there is a larger volume of susceptible material available (Peters *et al.* 2014).

The 2.8 mm CYP long band veneers alternating with 3.0 mm hoop pine cross band veneers performed the worst with a mean percentage mass loss of 4.4%. The use of thicker CYP veneers (3.0 mm), produced a mean percentage mass loss of only 2.2% but one block in particular had a mass loss of 16.5%. Interestingly, the test blocks that included 1.8 mm thick CYP long bands received negligible damage regardless of hoop pine cross band thickness.

Figure 12.12. The 3mm hoop pine cross bands were badly damaged in some instances

To summarise, while there was no significant different in percent mass loss between hoop veneer thickness when in an alternating pattern, there is some evidence of more substantial damage in limited number of blocks with 3.0mm thickness. (Figure 12.13).

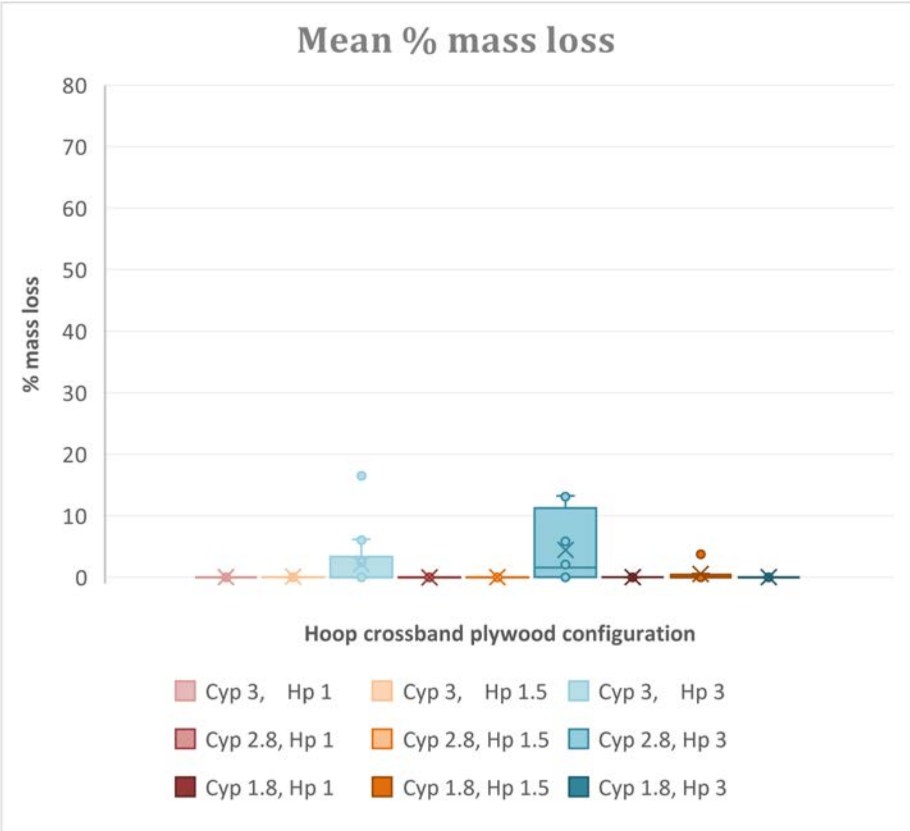


Figure 12.13. Mass loss % of nine plywood configurations comprising a CYP face, back and long band and a hoop pine cross band (cross is the mean; central horizontal bar is the median)

Conclusions

1. The CYP rotary veneers that were present as face, back and/or long band veneers in 21 of the 24 tested plywood configurations were essentially untouched by termites during the field exposure trial. Only two test blocks from 264 blocks that included CYP veneers received some minor 'nibbling' on a CYP long band.
2. A blended species 7-ply plywood block comprised of CYP face and back veneers, and hoop pine core veneers was shown to have some resistance to attack by the subterranean termite *C. acinaciformis*, if the core veneer thickness was limited to 1.0 mm. An increase

in the thickness of the hoop pine veneers to 1.5 mm resulted in significantly more termite damage to the plywood test block. Increasing again to 3.0 mm veneer thickness produced substantial termite damage significantly higher again than both 1.0 mm and 1.5 mm.

3. A blended species 7-ply plywood block comprised of CYP face, back and long band veneers, and hoop pine cross band veneers was shown to have some resistance to termite attack if the hoop pine cross band veneers were no greater than 1.5 mm thick. Increasing the thickness of the hoop pine cross band veneers to 3.0 mm was observed to result in termite damage in some blocks, however, this was not statistically significant. While there was no significant difference between CYP thickness it did appear that at a thickness of 1.8 mm termite damage was almost non-existent.
4. The improved termite resistance that was observed in the thicker hoop pine veneers used in the plywood configurations that alternated CYP long bands and hoop pine cross bands compared to all hoop pine core veneers (long bands and cross bands) indicates the increased protection is a result of the neighbouring white cypress pine.

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Chapter 13: Analysis of the fire performance of laminated veneer lumber (LVL) products

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Introduction

Scope of the report

This report presents a preliminary analysis of the fire performance of a series of Laminated Veneer Lumber (LVL) products manufactured from native forest sourced spotted gum (*Corymbia citriodora*) and white cypress pine (*Callitris glaucophylla*), and plantation hoop pine (*Araucaria cunninghamii*) veneers. The veneer selection and manufacturing process for the samples is detailed in Chapter 8. The fire performance analysis focused on using standard test methods defined by the Australian Standards (AS) framework to determine the advantages of using specific timber species and the influence of the construction layup. An additional preliminary analysis beyond the classification provided by the AS framework was further provided to show the expected different performance and limitations of the current AS framework.

Fire safety of timber structures

The fire safety of timber structures is defined by the interaction that these structures have with the fire evolution and the fire safety design strategy of the building. Classically, the temporal evolution of a fire within an enclosure is defined by three stages described below and shown in Figure 13.1.

1. **Growth stage**, where the fire starts to spread and grow until it reaches the fully-developed stage. This stage is generally a fuel-controlled stage with good ventilation conditions. At this stage, the fire-safe design aims to ensure the safe egress of the occupants from the fire compartment.
2. **Fully-developed stage**, where the fire reaches its maximum size. At this stage, the fire-safe design aims at ensuring that the fire is contained within the compartment, thus controlling its spread, and the structure does not collapse.
3. **Decay stage**, where the fuel load from the compartment is consumed and temperatures continue to drop. At this stage, the fire-safe design aims at ensuring that compartmentation and structural stability is not lost.

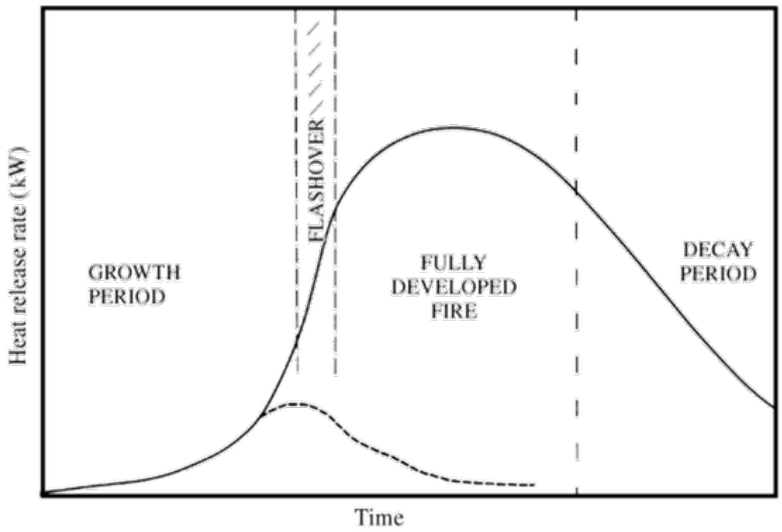


Figure 13.1. Classical temporal evolution of the heat release rate from the fire within a compartment.

The fire performance of timber structures can be analysed looking at these three stages (see Figure 13.2), of which the objectives are:

1. The timber structures do not contribute to a faster fire growth (ignition, flame spread and heat release);
2. The timber structure does not degrade (cross-section loss) sufficiently to cause structural failure; and
3. The timber structures do not continue to burn (self-extinguish) after the fuel load is consumed (burnout).

To achieve a holistic understanding of the fire performance of timber structures, the performance criteria need to be related to the principles above. Each of these criteria are strictly associated with the thermal decomposition processes experienced by timber at high temperatures (pyrolysis) and in the case of glue-laminated engineered timber products, the degradation of the adhesive in the glueline.

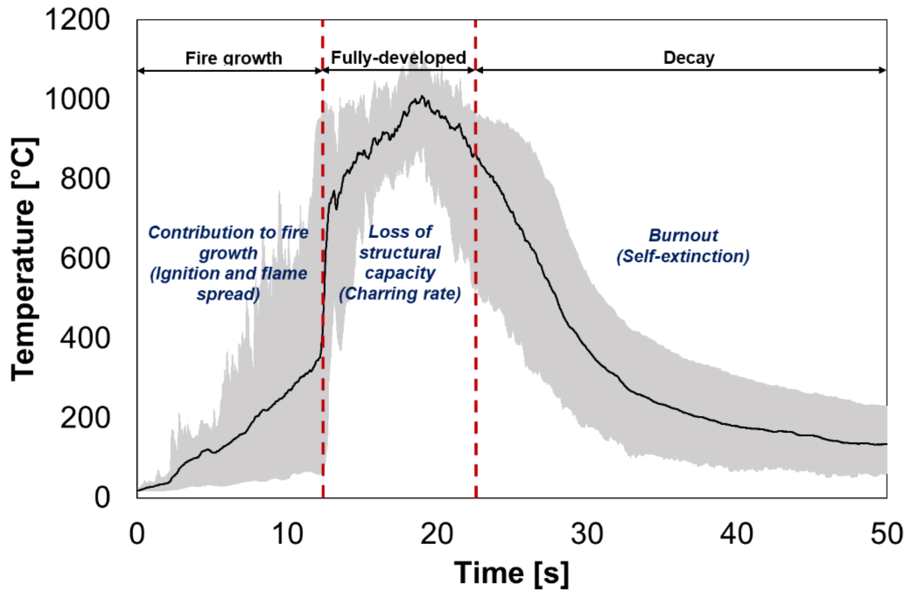


Figure 13.2. Performance criteria for each the stages of the fire. Heat release rate obtained from a full-scale CLT compartment fire test developed by The University of Queensland.

Standard test methods within the current AS framework

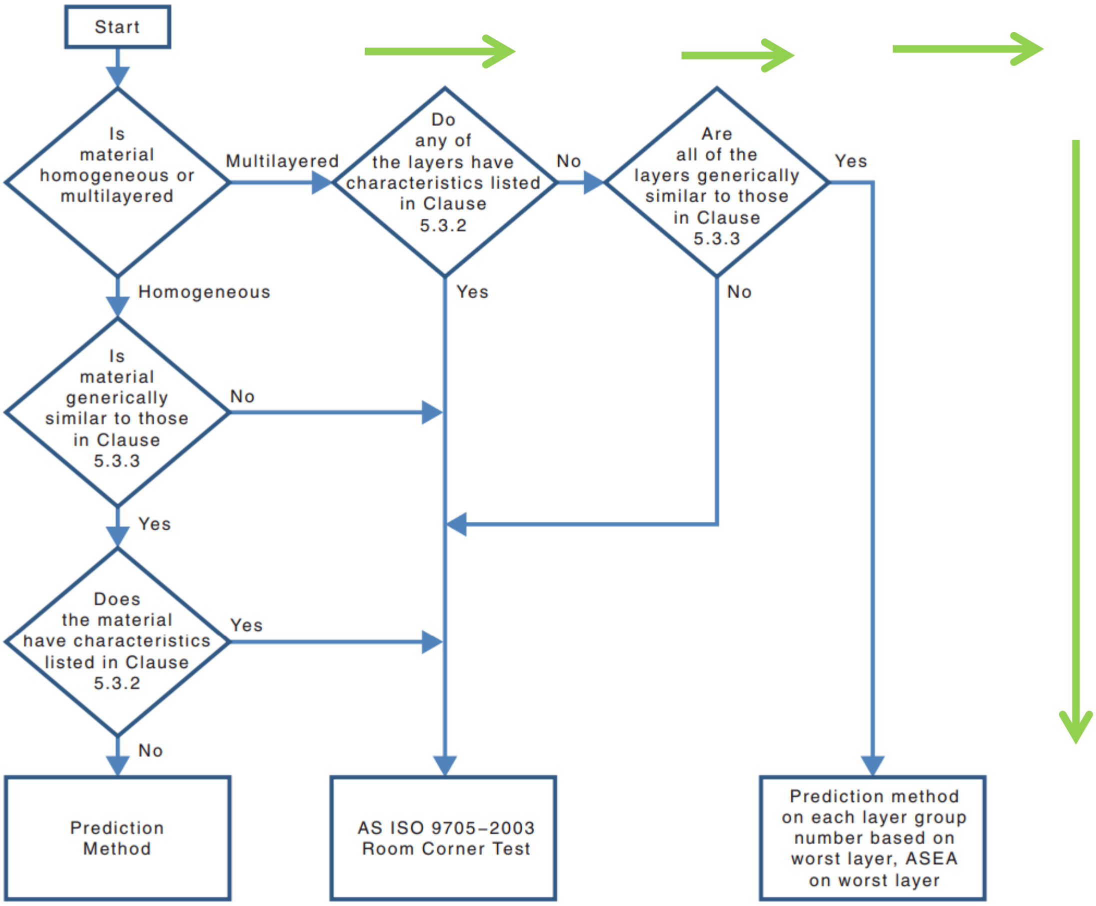
Current standard test methods to assess the fire performance of timber structures consist of a series of reaction-to-fire test methods and a fire resistance test method. The reaction-to-fire test methods aim at identifying the contribution to the fire hazard from the timber materials and structures (growth stage). The fire resistance framework aims at identifying the loss of compartmentation and loss of load-bearing capacity of the timber structure (fully-developed fire stage). It should also be noted that the current framework does not include a test method to evaluate the auto-extinction of timber structures in the burnout stage.

Reaction-to-fire test method

Several methods can be used to assess the contribution to fire (reaction-to-fire) from building materials depending on the material type, e.g. AS 1530.2 for sarking materials or AS 5637.1 for general building products used in walls or ceilings. The particular performance parameters chosen for this analysis corresponds to the ‘material group number’ and ‘smoke growth rate’ indices. The material group numbers indicate a classification of the contribution to fire from the material. Four groups are generally identified in AS 5637.1 including:

- **Group 1**: material does not reach flashover when exposed to 100 kW for 600 s followed by exposure to 300 kW for 600 s.
- **Group 2**: material that reaches flashover following exposure to 300 kW within 600 s after not reaching flashover when exposed to 100 kW for 600 s.
- **Group 3**: material that reaches flashover in more than 120 s when exposed to 100 kW.
- **Group 4**: material that reaches flashover within 120 s when exposed to 100 kW.

The material group can be identified using the Room Corner Test (AS ISO 9705) or, alternatively, using the Cone Calorimeter test at 50 $kW.m^{-2}$ if the material has confirmed correlation following the guidance in Figure 13.3.



(a)

5.3.2 *Unsuitable materials*

The empirical correlations shall not be used for products or assemblies—

(a) with profiled facings not allowed by AS/NZS 3837;

(b) that contain materials that melt or shrink away from a flame;

(c) with joints or openings; and

(d) with a reflective surface.

5.3.3 *Suitable materials*

Materials for which the correlation is permitted include—

(a) painted or unpainted paper-faced gypsum plasterboard;

(b) solid timber and wood products such as particleboard and plywood; and

(c) rigid non-thermoplastic foams such as polyurethane.

(b)

Figure 13.3. (a): Guidance on selection of test method according to AS 5637.1. (b): Clauses 5.3.2 and 5.3.3 extracted from AS 5637.1.

LVL products are multilayered products, and therefore the adequate prediction method should be the Room Corner test or alternatively the material group identification for each layer is required with the worst layer influencing the assigned material group classification for the entire product.

Fire-resistance test method

The fire-resistance test method is based on the use of standard furnace test (AS 1530.4) to assess a Fire Resistance Level (FRL). The FRL is a rating used that corresponds to three performance criteria: load-bearing capacity, integrity, and insulation. The FRL rating is established as the time (minutes) that the structural element can provide those performance criteria when exposed to a standard fire. This performance is strictly dependent on the loss of effective cross-section due to heating and charring.

Alternatively, AS 1740.2 provides a method to assess the charring rate for timber products based on the density only. Other parameters such as heat flux, species, moisture content or delamination are not considered.

Experimental methodology

Materials

Table 13.1 shows a description of each LVL layup type used for this study.

Table 13.1. Description of sample types.

Sample type	Timber species	Adhesive	Other design parameters
A	*Corymbia citriodora*	Melamine urea formaldehyde	12 lamellae of *Corymbia citriodora*
B	*Corymbia citriodora* *Araucaria cunninghamii*	Melamine urea formaldehyde	12 lamellae. External face layers of *Corymbia citriodora.* Core veneers of *Araucaria cunninghamii*
C	*Corymbia citriodora* *Araucaria cunninghamii*	Melamine urea formaldehyde	12 lamellae. External face layers of *Corymbia citriodora.* Central two core veneers of *Araucaria cunninghamii* with remaining veneers alternating between the two species.
D	*Araucaria cunninghamii*	Melamine urea formaldehyde	12 lamellae of *Araucaria cunninghamii*
E	*Callitris glaucophylla*	Melamine urea formaldehyde	12 lamellae of *Callitris glaucophylla*
F	*Callitris glaucophylla* *Araucaria cunninghamii*	Melamine urea formaldehyde	12 lamellae. External face layers of *Callitris glaucophylla.* Central two core veneers of *Araucaria cunninghamii* with remaining veneers alternating between the two species. 12 lamellae.

Test method

To analyse the potential different fire performance of the LVL layup types, the Cone Calorimeter test method was used. The Cone Calorimeter test method enables the identification of the standard material group number and smoke growth rate indices (AS 5637.1), and provides further measurements valuable to the holistic analyse of the contribution to the fire, the loss of cross-section and the extinction phenomena.

It should be noted that in accordance with AS 5637.1 for the product type being tested, the group number should be identified using the Room Corner Test. This former approach is not feasible due to the scale and cost associated and therefore the cone test was adopted.

All tests were conducted using an iCone shown in Figure 13.4, designed by Fire Testing Technology (FTT). This fire testing apparatus is designed according to ISO 5660-1: Reaction-to-fire tests – Heat release, smoke production and mass loss rate – Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement).

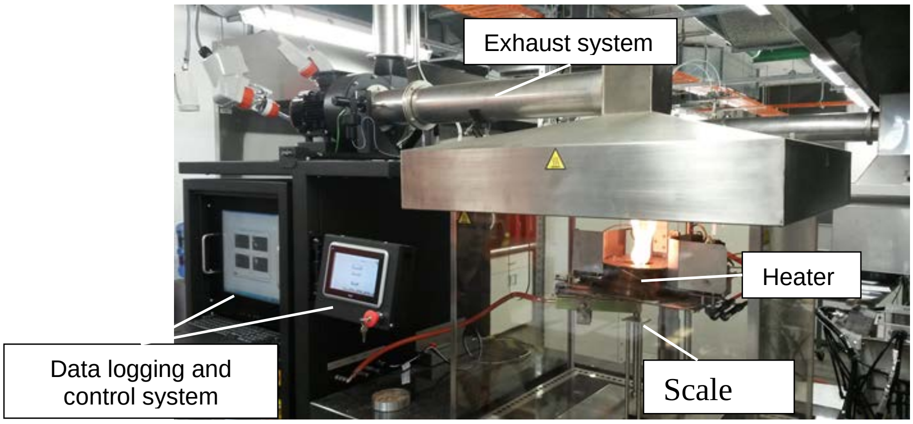


Figure 13.4. iCone cone calorimeter used to determine reaction to fire testing

The iCone is equipped with a cone-shaped radiant electrical heater used to reproduce a uniform irradiance at the surface of samples of a size up to 100 mm by 100 mm. Additionally, the iCone consists of a weighing device (scale) to measure the mass loss of materials when exposed to radiant heat; an exhaust system to collect the thermal decomposition gas emissions from the tested material; and a Servomex gas analyser to measure oxygen, carbon dioxide, and carbon monoxide from the exhaust gases. The system incorporates a spark plug to induce the ignition of the volatiles released during the thermal decomposition of the sample. These are the main elements of the Cone Calorimeter that are used for the scope of the works presented herein. Further technical details regarding this piece of equipment can be found in BS ISO 5660-1.

In addition to the iCone apparatus, a series of K-type mineral-insulated stainless steel sheathed thermocouples of 1 mm bead were used to study the charring behaviour of the samples. These were placed at approximately 3 mm depth intervals. A Data Acquition System from National Instrument NI-9213 model using a cDAQ-9171 chassis was used to collect the temperature data throughout the tests.

Results

Standard classification

The heat release rate results identified that all LVL layup types provided the same material group number of 3.

Preliminary performance assessment

The following sections show a preliminary analysis of the fire performance of the different LVL types based on different performance criteria.

Growth stage criterion: time-to-ignition and peak HRR

The time-to-ignition and peak heat release rate was selected as a performance criteria governing the growth stage. Longer times to ignition indicate that the material will generally require larger amount of energy to ignite and spread; thus, a slower growth of the fire and better fire performance is expected. Larger peak heat release rate (pHRR) indicates that the combustion of the material produces more energy; thus, it is expected that materials with lower pHRR may support a slower growth and a better fire performance.

Figure 13.5 shows the inverse of the square root of the time-to-ignition for three different heat fluxes: 25, 50 and 75 kW.m^{-2}. A larger slope indicates a relatively shorter time to ignite for the same amount of external energy applied. From this analysis, the LVL layup can be ranked as follows:

(best) A > B ≈ C >> E ≈ F >>D (worse)

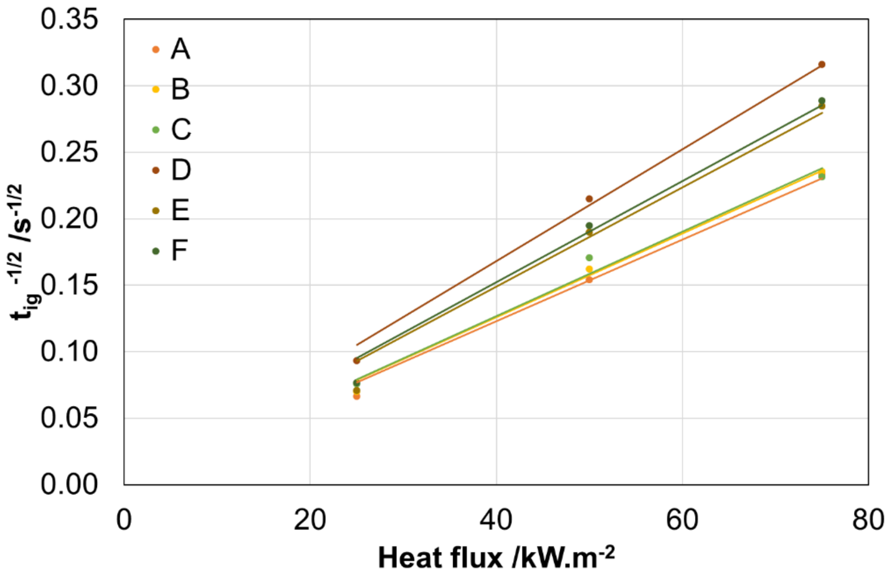


Figure 13.5. Inverse of the square-root of the time-to-ignition versus external heat flux.

Figure 13.6 shows the pHRR for each of the LVL layup types. It was observed that there were minor variability in the pHRR, estimated within the range 230 – 270 kW m^{-2}. Interestingly, LVL layup type D showed the lowest pHRR, which may indicate a lower effective heat of combustion produced from the *Araucaria cunninghamii* veneers.

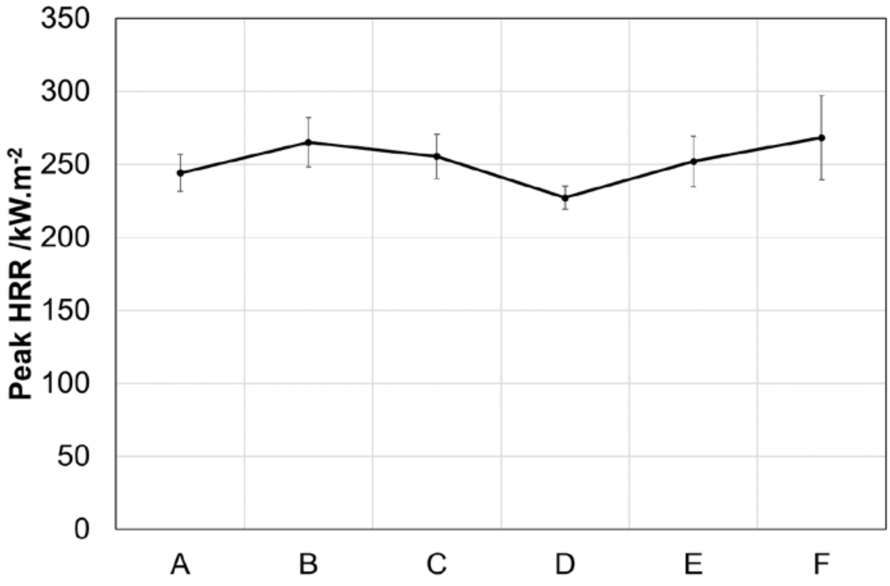


Figure 13.6. Peak Heat Release Rate per unit area for samples A-F.

Future analyses of effective thermal properties and flame spread are required to characterise the performance criteria governing the growth stage completely.

Fully-developed stage criterion: loss of section

Figure 13.7 shows the normalised mass loss of each LVL layup type when exposed to 50 kW m^{-2}. The normalised mass loss is obtained as the mass at any time divided by the initial mass value. This parameter represents how the material is degrading with time, thus equivalent to the charring rate concept. Larger mass loss over time is expected to lead to faster charring rate and therefore faster reduction of load-bearing capacity.

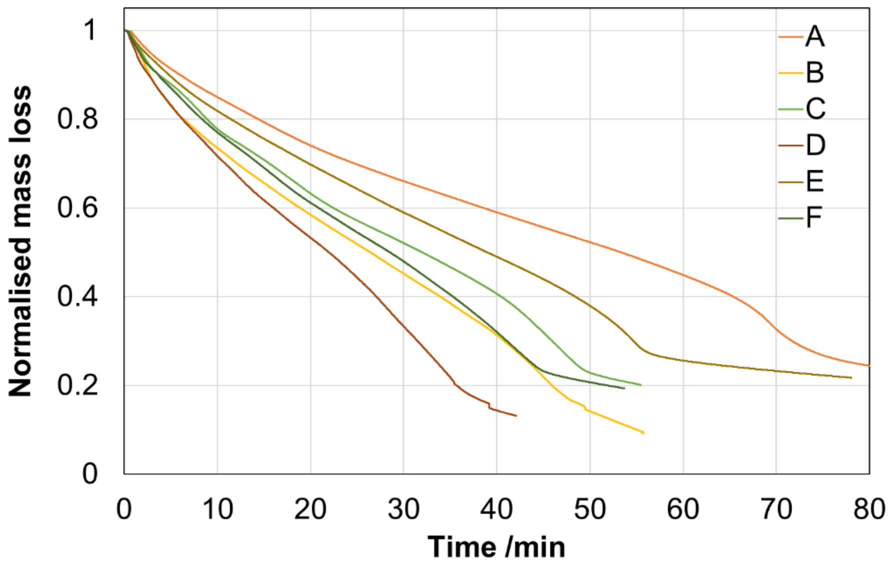


Figure 13.7. Normalised mass loss over time for samples A-F when exposed to 50 kW m^{-2}.

In order to contrast these results, the estimated position of the char depth was further analysed by identifying the in-depth location of the isotherm 300°C. The position of the isotherm 300°C over time was derived using the temperature data extracted with the in-depth thermocouples. Figure 13.8 shows the position of the isotherm 300°C for each LVL type.

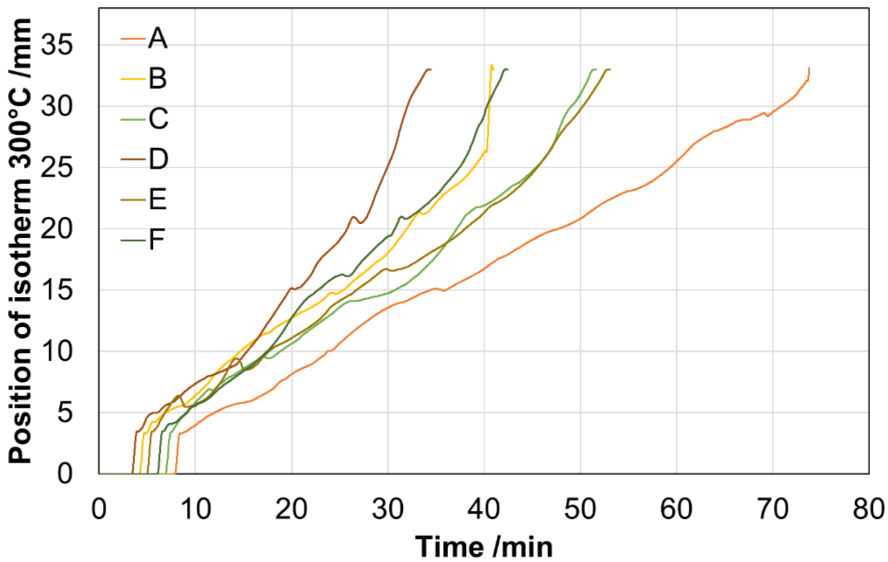


Figure 13.8. Position of the isotherm 300°C over time for sample A-F when exposed to 50 kW m^{-2}.

Figure 13.7 and 13.8 show similar layup ranking as follows:

(worse) D > B ≈ F > C > E > A (best)

Decay stage criterion: flame extinction

The flaming of all LVL layup types showed to self-extinguish at 25 kW.m^{-2}. The sample residue after exposure to 25 kW m^{-2} and normalised mass loss for each of the samples is shown in Figure 13.9 and Figure 13.10, respectively.

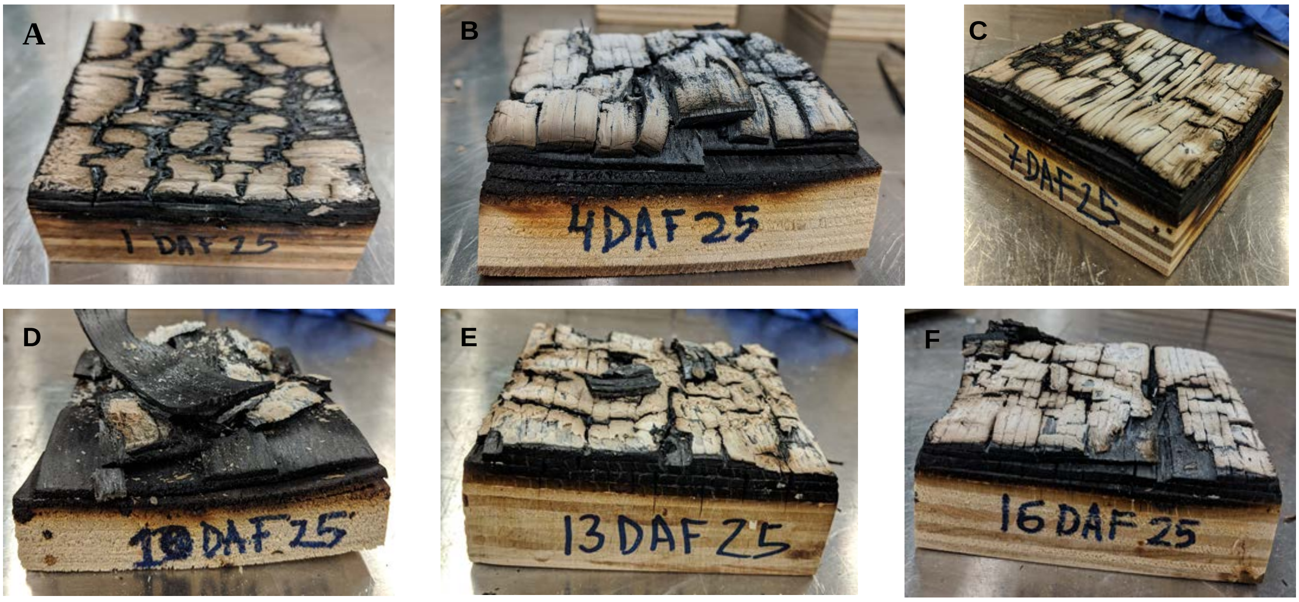


Figure 13.9. Samples A-F after exposure to 25 kW m^{-2}.

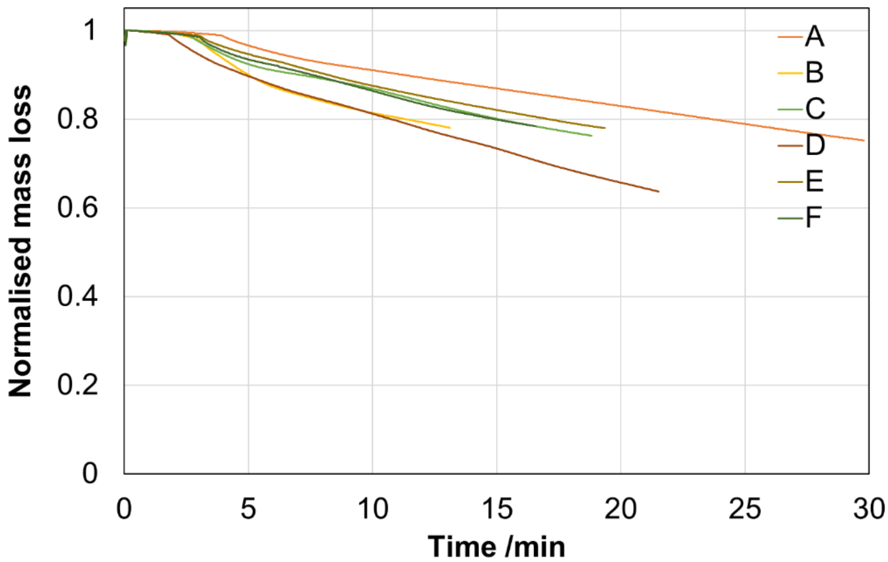


Figure 13.10. Normalised mass loss over time for samples A-F when exposed to 25 kW m^{-2}.

Discussion and conclusions

In accordance with the current AS framework, e.g. material group method or AS1530.4, all six tested LVL layup types achieved Material Group 3.

Further analysis however, identified clearly different performance between the six types of LVL. In order to realise the benefits of the observed performance difference between the tested species and the included layup types, further research is necessary. This further research should also consider a framework to explicitly address each of the criteria relevant to each stage of the fire. Preliminary results from this study show that:

- LVL A has a superior performance regarding ignition.
- LVL D shows the lowest peak heat release rate.
- LVL A has a superior performance regarding the loss of section related to the mass loss and temperature evolution within the sample.
- LVL D shows the worse performance regarding ignition and loss of section.
- All LVL products are shown self-extinguish at 25 kW m^{-2}.

It should be noted that since all samples were tested horizontally to isolate the effect of the glue delamination. Future studies would need to assess the performance of the adhesive on the fire performance parameters analysed.

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AS 1530.4 (2014) Methods for fire tests on building materials, components and structures - Fire-resistance tests for elements of construction. SAI Global Limited

AS 1740.2 (2006) Timber structures - Fire resistance for structural adequacy of timber members. SAI Global Limited

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AS ISO 9705 (2016) Fire tests - Full-scale room test for surface products. SAI Global Limited
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Chapter 14: Opportunities for laminated veneer lumber (LVL) in the cross-arm market

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Wood Products Victoria

Scope of work

A preliminary investigation of the potential market for laminated veneer lumber (LVL) electricity network cross-arm has been undertaken.

Specifically, the various local, state and national standards relevant to electrical network timber cross-arms have been reviewed (traditional and engineered wood products) from a product supply and performance perspective.

Through consultation with relevant electrical authorities, or companies/organizations, collect relevant information including but not limited to:

- Size of the cross-arm market and product types used (timber, steel, fibre composite etc.)
- Quantity of timber cross-arms, type (solid and engineered wood product), grade criteria and dimensions currently being supplied
- Value of cross-arms including breakdown by grade quality, dimensions and type
- The authorities experience (if any) with the use of engineered wood cross-arms
- Any previous experience with EWPs, and especially veneer-based cross-arms
- Identify advantages and disadvantages for EWPs in cross-arm market.

Background

Timber cross-arms are structural pieces of timber mounted on a utility pole to support electrical lines (refer Figure 14.1) or other electrical equipment. They are used for anchoring and supporting conductors along transmission and distribution lines. The reliability of cross-arms is of particular importance when used in both angle and termination applications along the power transmission and distribution lines. Cross-arms are also used in a range of infrastructure applications including telephone, cable, NBN, through to municipal, rural and electrical utilities companies and are a vital part of each infrastructure. As the demand for wider infrastructure coverage continues to grow, so will potentially the demand for lightweight, strong, durable and reliable timber cross-arms.

The electricity distribution networks in Australia were once dominated by timber cross-arm products; but today it is a very different and competitive market. Other materials, such as steel and reinforced fibre composites, have entered the market and are being manufactured and sold to directly compete with, and take market share away from, the traditional timber cross-arm. Some of the reasons for this change are that these new cross-arm materials are designed to be lightweight, strong, durable, reliable and have resilience through all weather conditions. These new cross-arms materials enable ease of undertaking installations, repairs or replacements.

Figure 14.1. Timber cross-arms

Investigation

The timber cross-arm market was briefly investigated and reported in Chapter 9 with the key design issues, relevant design criteria and any secondary issues identified. This investigation has sought to clarify the Australian cross-arm market size and products used as well as the potential for developing an engineered LVL wood product cross-arm product. The specific items investigated are detailed in Table 14.1.

Table 14.1. Market Investigation Issues

Product/System	Key Design Issue	Relevant design criteria	Secondary Issues
Cross-arms	Durability and strength	• Structural capacity and reliability • Glue-line performance • Above-ground durability	• Appearance • Limit splitting on top surface and ends
Product/Market Challenge	**Cross-arms are required to be straight, strong and reliable**		
Investigate	○ *Size of the cross-arm market and product types used (timber, steel, fibre composite etc.)* ○ *Quantity of timber cross-arms, type (solid and engineered wood product), grade criteria and dimensions currently being supplied* ○ *Value of cross-arms including breakdown by grade quality, dimensions and type* ○ *The authorities experience (if any) with the use of engineered wood cross-arms* ○ *Any previous experience with EWPs, and especially veneer-based cross-arms* ➢ *Identify advantages and disadvantages for EWPs in cross-arm market.*		

Cross-arm market

With the estimated 6.3 million utility poles in use throughout Australia and over 5 million of these in timber (Kent, 2006), there may be an opportunity to supply an engineered LVL timber cross-arm to meet the demands of the electricity distribution networks. Of the timber utility poles, an estimated 60,000 are installed/replaced annually (Crews & Horrigan, 2000) along with an estimated 80,000-100,000 timber cross-arms. Other competing materials are also being used as cross-arms including steel and fibre composite materials – refer Figure

14.2. There is potentially an opportunity to manufacture specific LVL cross-arms to service the existing or expand the market for timber.

The utility sector is concerned that the quality of timber has declined in recent years due to the increase in faster grown, regrowth timber being used; making large size structural timber pieces harder to source. Many newly installed timber cross-arms fail within a comparatively short time frame (minimum average service life 20 years (Ergon Energy Corporation Limited)) and according to some utilities the newly installed timber cross-arms are less reliable then older timber cross-arms.

Product types

There are a number of materials/products that are used as cross-arms; these being timber, steel and composite fibre materials (refer Figure 14.2).

Timber

Steel

Fibre Composite

Figure 14.2. Cross-arm Material Types

Solid timber

Timber cross-arms remain relatively popular along the eastern seaboard of Australia due to the upfront costs being lower than competing materials (e.g. steel, composite fibre) as well as being quite readily available. However, timber cross-arms need to be specifically manufactured and 'treated' in order to meet the harsh external environmental conditions and maintain reliability.

Timber cross-arms are manufactured to meet the distribution network's specifications and typically include pre-drilled holes, nail plate reinforced holes, application of an (log) end sealant, installation of anti-split nail plates at each end of the cross-arm, painted top surface and product branding/marking. The addition of painting and nail plates provide substantial long-term cost savings by significantly extending the service life of the timber cross-arm. Note that the installation of end nail plates may not be required on LVL cross-arms.

Timber cross-arms can also be sold as "blanks" where drilling can be done on site for unusual circumstances.

Steel

Steel cross-arms are popular because they can be manufactured into the required shape, they are relatively lightweight, and they do not biodegrade. However, corrosive environments (e.g. coastal, pollution) can significantly impact on lifespan, and care needs to be taken during installation due to steel being conductive and induction can create electrical currents.
Steel products are typically manufactured to meet the distribution network's specifications and include pre-drilled holes and end capping. These products are typically used in the high-tension transmission lines where high strength is required. Being non-combustible there are no concerns about cross-arm fires.

Fibre composite

Fibre composite cross-arms can be manufactured into the required shape, are relatively lightweight, do not biodegrade and are viewed as having the lowest life cycle costs of all cross-arm materials. Previously there were issues with the fibre composite products in terms of UV degradation and strength. These have been addressed through modifications to the manufacture/formulation of the products.

Fibre composite, or fibre reinforced polymer (FRP), products are typically manufactured to meet the distribution network's specifications and include pre-drilled holes and end capping. These products are increasingly being used in the distribution networks and are promoted as being lightweight, having a 40-year lifespan, consistent properties, non-conductive and reduced risk of pole top fires.

Comments regarding the benefit of fibre composite cross-arms are that the cross-arm will "crumple" in the event of failure and don't drop the conductor making it safer for the general public.

Cross-arm size comparison

The following cross-arm size comparison table (Ergon Energy Corporation Limited) (Table 14.2) demonstrates a reduction in size from the traditional F17 hardwood cross-arm to that of the fibre composite products for a range of sizes used. This reduction in size also contributes to a reduction in weight. *Note: The fibre composite product is a hollow section with a typical wall thickness of 5 mm.*

Table 14.2. Timber Cross-arm Characteristics

Hardwood Timber Section (mm x mm)	Equivalent Wagners Section (mm x mm)	Equivalent PUPI/RMS Section (mm x mm)
100 x 100	100 x 100	100 x 100
100 x 125	100 x 100	100 x 100
100 x 150	125 x 125	125 x 125
175 x 125	125 x 125	125 x 125

Note: PUPI© is a fibreglass cross-arm.

Timber cross-arm characteristics

Solid timber

Timber cross-arms typically have the following characteristics:

Table 14.3. Timber Cross-arm Characteristics

Lengths	Typically 1.8, 2.1, 2.4, 2.7 and 3.6 m (range 1.2 m to 6.3 m)
Cross-sections	100x100mm, 100x125mm, 100x150mm and 175x125mm (in either orientation)
Bending strength	F17, F22
Strength group	S2 (minimum S3)
Durability	Natural – Class 1 and 2 (above ground) Where treated – H3 ACQ
Top surface	No imperfections, high quality painted

Laminated veneer lumber (LVL)

There may be an opportunity for advanced hardwood/hybrid LVL timber cross-arms that provide consistency in supply, uniformity in strength/stiffness, flexibility in available dimensions, adequate durability (timber and glueline) and reliable in-service performance; like the manufactured consistency provided by fibre composites and steel. The benefit of manufactured veneer-based timber cross-arms is that they can be manufactured in the typical sizes listed in Table 14.3 or as specified. Softwood LVL cross-arms had previously been manufactured in Australia as a direct substitute for solid hardwood cross-arms; and to be of equivalent strength.

Grades and properties

Timber cross-arms are typically required to comply with the grade requirements of the electricity network distributor's specification, followed by the requirements in the Australian Standards AS

3818.1 *Timber - Heavy structural products - Visually graded - General requirements* and the visual Grade 1 requirements of AS 3818.4 *Timber - Heavy structural products - Visually graded - Cross-arms for overhead lines*. The network distributor's specification tends to increase the quality of the graded cross-arms. The production of a manufactured LVL cross-arm would need to be able to meet the specification requirements.

From a strength perspective, solid timber cross-arms are required to meet an F17 stress grade; although there are cross-arm specifications (Ausgrid, 2013) requiring an F22 stress grade. As has been demonstrated via testing in the Advanced Engineered Wood Products Project (the main Project), high strength LVL is achievable.

Structural grade rule No 1 (or 2) is specified to limit the size of the natural characteristics (e.g. knots, gum vein) present in order to minimize the chance or water entry and weathering degradation. The top surface of the cross-arm is required to be without visual defect. Solid timber cross-arms are also supplied in the unseasoned state with a dimensional cross-section tolerance of ±3 mm.

Table 14.4 lists the structural timber properties, for both F17 and F22 Tallowwood, as given by AS 1720.1 *Timber structures – Design methods;* a comparison to existing marketplace LVL is provided for comparison. In order to minimize the potential for user confusion, achieving at least the equivalency to these stress grade properties would make substitution more achievable. Key target design properties would include bending strength, bending stiffness and shear at joints.

Table 14.4. Timber Properties

			Solid Timber (Unseasoned)		LVL	
Timber Strength Properties:[1]			F17	F22	Hyspan 17 LVL14 (F17)	Wesbeam e-beam 17 E14 (F17)
Average Elastic Modulus (MoE)	**E**	**MPa**	**14,000**	**16,000**	**14,000**	**14,000**
Average Modulus of Rigidity	G	MPa	930	1,070	700	700
Bending Strength	f'_b	MPa	42	55	42-50	62
Tension Parallel to grain	f'_t	MPa	25	34	25	34
Tension Perpendicular to grain	f'_{tp}	MPa	0.8	0.8	0.5	4.2
Compression Parallel to grain	f'_c	MPa	34	42	41	47
Compression Perpendicular to grain	f'_p	MPa	13	13	12	16
Shear	f'_s	MPa	3.6	4.2	4.6	5.3
Shear at Joints	f'_{sj}	MPa	5.4	5.4	4.2	4.2
Moisture Content		%	>15%	>15%	7-15%	8-15%
Joint Group			J1	J1	JD3/JD4	JD3
Strength Group			S2	S2	SD6	SD6
Timber Species			Tallowwood	Tallowwood	Radiata	Pinaster
Average Green Density	□	kg/m^3	1200	1200	560-650	650
Durability Class: above ground			1	1	4	4

(1) Characteristic values as per AS 1720.1
(2) Items in red are assumed

Cross-arm opportunity

Market and value

Based on the estimated 60,000 timber utility poles that are currently installed/replaced annually (Crews & Horrigan, 2000), with each pole requiring at least one cross-arm, 80,000 cross-arms are assumed (125 x 100 x 2100mm) to be required on an annual basis equating to a potential volume in excess of 2,400 m^3 per annum currently required to supply this demand; with an additional opportunity to replace the steel and fibre composite alternatives. Cost estimates for timber cross-arms are in the range of \$2,500-\$3,000/m^3 which would equate to a market opportunity in the order of \$5M per annum.

Fire and durability

The electricity network suppliers are increasingly looking to minimise their distribution network risks and costs. The risk of timber cross-arm fires is ever present, and a desire to extend the design life of cross-arms, has led to an increase in demand and use of non-combustible cross-arms. There are a number of ways that the concerns relating to cross-arm fires and durability issues can be addressed. This includes the use of a combination of fire-retardai and preservative treatments, or the use of non-combustible capping on timber cross-arms which could be installed to provide protection from fire and enhance durability – refer Figure 14.3.

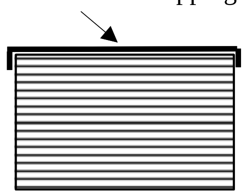


Figure 14.3 Capped cross-

Cost

Timber cross-arms are currently the most cost-effective cross-arms compared to the fibre composite products. As a guide, fibre composite products are stated (Ergon Energy Corporation Limited) to be in the order of twice the price of the equivalent timber cross-arm. The timber cross-arms are recommend for new constructions where the cross-arms can be fitted at ground level prior to lifting of the pole into place and where lifting does not cause any difficulty or safety concerns on existing poles.

Cross-arm challenges

Fires

"*Many cross-arm fires are caused by a small induced voltage across the cross-arm creating a source of heat and smouldering that eventually causes the wooden cross-arm to catch fire. A conductive medium is needed to start this process, mostly commonly arising from dust deposition and high humidity (generally due to mist). The higher levels of cross-arm fires on the Powercor network could simply be due to a greater exposure to the environmental drivers required to create a conductive medium...*" (Energy Safe Victoria, 2016)

Cross-arm fires are major reason for network distribution companies moving away from timber cross-arms. For instance, Western Australia does not use timber cross-arms at all due to their concerns regarding pole top fires and therefore require the use of non-combustible cross-arms. This has led to steel cross-arms being used for the high-tension transmission power lines and composite fibre cross-arms used in the general distribution network lines.

Weight

The weight of timber cross-arms is also viewed as a negative by electricity network suppliers when compared to competing materials. Fibre composite cross-arms have begun to dominate the market and are promoted as being 1/3rd the weight of timber and reducing the risk of injuries to field workers. The Ergon Energy specification (Ergon Energy Corporation Limited) states that the 100 x 100 mm fibre composite section weighs 5.5 kg/m and the 125 x 125 mm section 8 kg/m which would equate to be around 1/2 the weight of an unseasoned durable hardwood cross-arm (1000-1200 kg/m^3).

LVL cross-arms could be 'designed' to reduce their weight by using lower density veneers distributed throughout the cross-section; however, the overall strength/stiffness of the LVL cross-arms would need to be equivalent to an F17 hardwood stress grade.

Durability

Electrical network distributor's timber cross-arm specifications (Ausgrid, 2013) typically require hardwood timber of (above ground) natural durability class 1 to be used. Although treated timber is not described, a H3 hazard class preservative treatment should be appropriate – care would need to be taken to ensure a corrosive environment does not occur and deteriorate fasteners.

LVL cross-arms

Norply LVL

Norply Pty Ltd had developed an ACQ treated, Hoop pine LVL cross-arm as a replacement for hardwood. Although this product was well researched and intentioned, the cross-arms did not perform as expected and the product was eventually withdrawn from the market.

Key issues were:

- delamination occurring 2-3 years in service
- galvanic reaction of the ACQ preservative with fasteners
- failure typically occurred at holes (e.g. king bolt (main connection)); some cross-arms presumed treated after gluing but before drilling
- market turned against the product following failures

Features of the LVL cross-arm product were:

- painted grey with white top surface (improved durability)
- similar price to hardwood
- comparatively light
- consistent properties

A technical paper (Pathirana, 2003) describes the LVL cross-arm product as containing only the sapwood portion of the rotary peeled veneers, being fully preservative treated. The veneers were continuous in length (i.e. no joints), joined using phenol and resorcinol formaldehyde glues (for external exposed durability) with thinner face veneers to minimize surface checking.

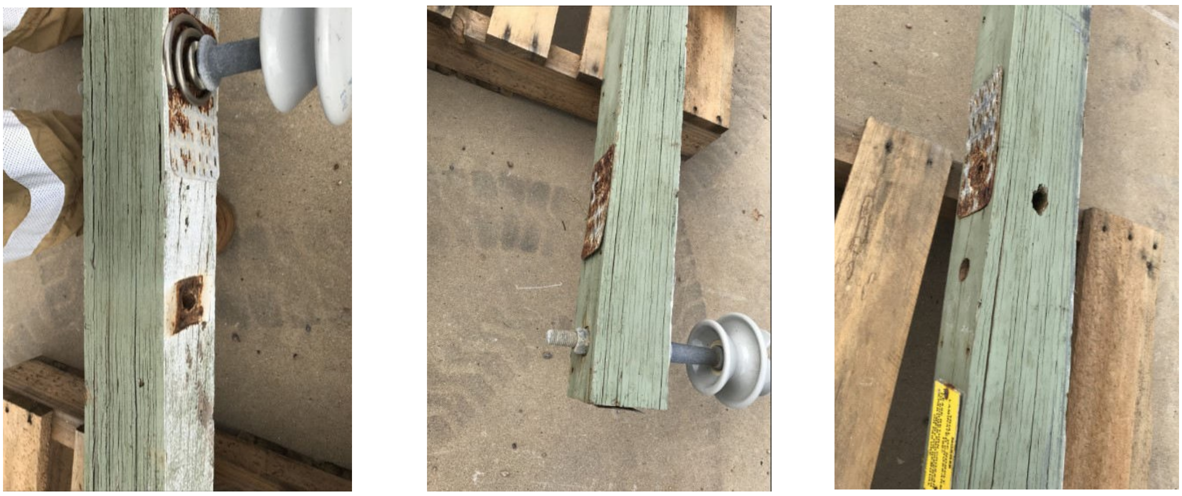


Figure 14.4. LVL cross-arm delamination

The images (see Figure 14.4) illustrate the use of nail-plates to reinforce locations around hardware installation points. The cross-arm has been painted to enhance and protected the cross-arm from weathering; however, delamination has still occurred.

Network distribution experience

Discussions with a major distribution company indicate that there are some concerns about using timber cross-arms as part of the distribution network. Specifically, these concerns revolve around timber's durability (minimum 30-year life cycle), mode of failure and visual means of determining the residual strength of the timber cross-arms.

Indications are that Ergon are moving away from timber cross-arms to the fibre composite product. This move has commenced in the high rainfall (greater than 2,000 mm), wet tropic areas in Queensland. Key reasons for the change to fibre composite cross-arms are that the fibre composite product is considered:

- very lightweight resulting in easier handling for on-site staff and reduced workplace health and safety concerns,
- has a ductile mode of failure and remains intact and attached to the pole (i.e. non-brittle failure), and
- is anticipated to have a long service life (50 years plus).

An interesting comment made regarding LVL cross-arms was that the size of the LVL cross-arm was "upped a size" to account for uncertainty in performance.

Feedback regarding the LVL cross-arms previously used is that the cross-arms were manufactured by gluing together 10-layer LVL sections (approx. 36 mm thickness), hereon referred to as a lamella, to form the desired LVL cross-arm thickness; which typically comprised of 3 lamellas (i.e. 3 x 36 mm). The lamellas were glued together, and the glue microwave cured. Comments regarding delamination is that this typically occurred along the lamella gluelines.

The LVL cross-arms were ACQ treated which caused corrosion to the installed hardware. Even though the cross-arms were treated, brown rot occurred within the cross-arms. This only became apparent when the cross-arms were removed and inspected. It was suggested that the brown rot occurred due to checking in the veneers which allow water to enter the cross-arm section and decayed the untreated portions of the cross-arm.

Conclusions

Durable solid hardwood timber cross-arms have a long history of use in the electricity distribution market and proven performance. However, with the emergence of new fibre composite products into this market, questions are being asked about the availability, reliability, durability and relative performance of solid timber cross-arms. An opportunity exists to develop a new LVL engineered cross-arm wood product (ECWP) that addresses these issues.

However, there are some challenges that will need to be addressed prior to developing a new laminated veneered lumber (LVL) cross-arm; these include:

- Reducing the possibility of cross-arm fires
- Reducing the timber cross-arm weight
- Improving the weather exposed durability of the LVL cross-arm
- Preventing delamination of the LVL cross-arm
- A need to be able to visually assess the residual strength of the LVL cross-arm

With today's gluing, treatment and manufacturing knowledge, these challenges are not insurmountable although significant effort will be required to 'convince' the electricity distribution network companies to trial new LVL cross-arms based on their previous experience.

References:

Ausgrid, E. E. (2013, June). Timber Cross-arms-Technical Specification.

Crews, K. & Horrigan, A. (2000). Strength Assessment of Timber Utility Poles in Australia. *New Zealand Timber Design Journal* 9(2).

Energy Safe Victoria. (2016, October 14). Consultation Paper Electrical Infrastructure Comparative Analysis.

Ergon Energy Corporation Limited. (n.d.). Technical Specification for Hardwood Cross-arms. Specification ETS07-02-01 Ver 7.

Gilbert, B. (2014). "Veneer Based Composite Hollow Utility Poles Manufactured from Hardwood Plantation Thinned Trees," *Construction and Building Materials* 66(2014), 458-466.

Kent, H. (2006). Options for the Continued Supply of Power Poles. Australian Wood Pole Resources Workshop. Queensland Department of Primary Industries and Fisheries.

Pathirana, S. (2003). Laminated Softwood Cross-arms-An Alternative to Old Growth Hardwood Cross-arms. 7th International Energy Transmission & Distribution Conference & Exhibition. Port Melbourne: Engineers Australia.

Appendices

Appendix 14.1: Non-mid-rise timber products

Utility Poles

Product/System	Key Design Issue	Relevant design criteria	Secondary Issues
Utility Poles	Durability and strength	• Structural capacity • Glue-line performance • Ground line durability	• Appearance • Maintenance systems
Product/Market Challenge	**Utility poles are required to be straight, long, durable and strong**		
Investigate	➢ *what are the characteristic property requirements for use in this application?* ➢ *would an advanced hardwood LVL product, or hybrid LVL, product provide a cost-effective solution in this application?* ➢ *what is the estimated size of these product/market opportunities?*		

There is estimated to be 6.3 million utility poles in use throughout Australia with over 5 million of these in timber (Kent, 2006). Of the timber utility poles, an estimated 60,000 are installed/replaced annually (Crews & Horrigan, 2000). Other competing materials are also used in the manufacture of utility poles including concrete, steel and hybrid (concrete/steel) materials. There may be an opportunity to manufacture specific veneer-based utility poles to service the existing or expand the market for timber provided the required strength and durability can be achieved.

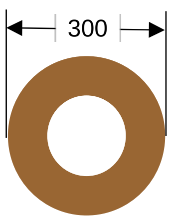
Utility pole characteristic properties

Typical, timber utility poles have the following characteristics:

Total length (above-ground & in-ground)	10-12 m
Mean diameter	0.3 m *(least diameter of a pole shall be not less than eighty (80) percent of the greatest diameter)*
Bending strength	80-100 MPa
Durability	Natural – Class 1 and 2 Treated – H5 CCA

LVL utility poles

There may be an opportunity for an advanced hardwood/hybrid LVL utility pole that can provide a consistency of supply and strength/stiffness, long length, durable (timber and glueline) and reliability; like the perceived consistency provided by concrete and steel. The timber utility pole could be manufactured in a hollow, cylindrical shape to best utilise the required structural capacity of the timber and to enable the running of cabling internally if required.



The technique of forming the poles could be further investigated as a continuous, layer wrapped pole or formed in two semi-circular halves are “fixed” together. There has been considerable research work undertaken (Gilbert, 2014) that could be further explored as part of this project.

Market opportunity

Based on the estimated 60,000 timber utility poles that are currently installed/replaced annually (Crews & Horrigan, 2000), a (hollowed) pole volume of more than 45,000 m^3/pa would be required to supply this demand; with an additional opportunity to replace the concrete and steel alternatives.

Typical repair costs (including product and installation) for the utility sector is provided below in Figure A.14.1:

Figure A.14.1. Indicative Utility Poles Replacement Costs

The pole replacement cost would predominately comprise labour, location and equipment costs. Estimates of timber utility pole costs range from $450-$600 depending on length. Concrete costs are approximately twice the timber cost.

Assuming a hollowed pole volume of approximately 0.85m^3 and a current utility pole cost of $450 (as advised) would equate to approximately $530/$m^3$. This may not currently provide a great return but a product that provided additional benefits (e.g. fire performance) would attract a higher value.

Appendix 14.2: Cross-arms

Product/System	Key Design Issue	Relevant design criteria	Secondary Issues
Cross Arms	Durability and strength	• Structural capacity and reliability • Glue-line performance • Above-ground durability	• Appearance • Limit splitting on top surface and ends
Product/Market Challenge	**Cross-arms are required to be straight, strong and reliable**		
Investigate	➢ *what are the characteristic property requirements for use in this application?* ➢ *would an advanced hardwood LVL product, or hybrid LVL, product provide a cost-effective solution in this application?* ➢ *what is the estimated size of these product/market opportunities?*		

With the estimated 6.3 million utility poles in use throughout Australia and over 5 million of these in timber (Kent, 2006), there is an opportunity to supply an engineered LVL timber cross-arm. Of the timber utility poles, an estimated 60,000 are installed/replaced annually (Crews & Horrigan, 2000). Other competing materials are also used in the manufacture of cross-arms including steel and composite (fibreglass) materials. There is an opportunity to manufacture specific LVL cross-arms to service the existing or expand the market for timber. The utility sector in concerned that the quality of timber has declined in recent years as only faster grown, regrowth timber is available; making large size structural pieces harder to source. Many newly installed wood cross-arms fail within a relatively short time (minimum average service life 20 years (Ergon Energy Corporation Limited)) and according to some utilities the newly installed timber cross-arms are less reliable then older timber cross-arms.

Cross-arm characteristic properties

Typical timber cross-arms have the following characteristics:

Lengths	2.4, 2.7, 3.0 and 3.3 m
Cross-sections	100x100mm, 100x125mm, 100x150mm and 175x125mm
Bending strength	F17
Durability	Natural – Class 1 and 2 Treated – H3 CCA/ACQ
Top surface	No imperfections, painted

Other key cross-arm product improvements include pre-drilling to assist with on-site installation, anti-split end nail plating, painting (top surface) and product branding/marking. The addition of painting and nail plates provide substantial long-term cost savings by significantly extending the service life of the cross arm.

LVL cross-arms

There may be an opportunity for an advanced hardwood/hybrid LVL timber cross-arms that provide consistency in supply, uniformity in measured strength/stiffness, flexibility in available dimensions, adequate durability (timber and glueline) and reliable in-service performance; like the manufactured consistency provided by concrete and steel. The veneer-based cross-arm could be manufactured in typical sizes as listed in the table above; or as requested.

Market opportunity

Based on the estimated 60,000 timber utility poles that are currently installed/replaced annually (Crews & Horrigan, 2000), each pole requiring at least one cross-arm, a volume in excess of 2,500 m^3/pa is currently required to supply this demand; with an additional opportunity to replace the steel and composite fibre alternatives. Cost estimates for timber cross-arms are in the order of $2,500-$3,000/m^3.

Appendix 14.3: Railway track timber

Product/System	Key Design Issue	Relevant design criteria	Secondary Issues
Railway Track Timbers	Durability and strength	• Mechanical strength (compression, shear, pull-out, bending) • Durability	• Aesthetics •
Product/Market Challenge	**Railway track timbers are required to be straight, strong, durable and reliable**		
Investigate	➢ *what are the timber property requirements for use in this application?* ➢ *would an advanced hardwood LVL product, or hybrid LVL, product provide a cost-effective solution in this application?* ➢ *what is the estimated size of these product/market opportunities?*		

The demand for traditional sawn railway track timbers such as sleepers, transoms and turnouts have been in decline for many years due to the perceived reduction if quality resulting in a potential reduction in reliability and longevity of timber sleepers in comparison to concrete sleepers. There may be an opportunity for improved advanced LVL track timbers that are specifically manufactured to meet the demand of the rail network. It is interesting to note that, although in decline in Australia, in the US, approximately 93% of all railway sleepers are made of timber with the majority of these (90%) treated (RTA, 2010).

Sleeper characteristic properties

Typical timber sleepers have the following characteristics:

Lengths Typical Turnouts	 2.15, 2.4, 2.44, 2.5 and 2.59 m As specified.
Cross-sections Thickness Width	 115, 127 and 130mm 230, 235 and 254mm
Strength	F17
Durability	Natural – Class 1 and 2 H5 Treated *Note: Treated sleepers are typically not used in Australia. However, in the US, Ammoniacal Copper Zinc Arsenate (ACZA) and Copper Naphthenate (CuN) are widely used* (RTA, 2010).

LVL sleepers

There may be an opportunity for an advance hardwood/hybrid LVL timber sleepers that provide uniformity in supply, measured strength/stiffness, long length, durable (timber and glueline) and reliable sleepers; like the manufactured consistency provided by concrete. The timber sleepers could be manufactured in typical sizes as listed in the table above; or as requested.

With the advent of modern high-speed lines, concrete sleepers “boast” a generally superior load capacity and a smoother ride as a result of their greater weight and vertical / lateral stability. There may be an opportunity to “design” an equivalent LVL sleeper.

Market opportunity
Based on an estimated 500,000 timber sleepers that are currently installed/replaced annually, a volume in excess of 40,000 m^3/pa is required to supply this demand; with an additional opportunity to replace the concrete, steel and composite alternatives. *Note: Austrak has the combined capacity to manufacture 1.68 million concrete sleepers.*

Timber sleepers cost approximately $70 per sleeper and with a volume of around 0.07 m^3/sleeper, equating to approximately $7,000/$m^3$ (RTA, 2010).

Appendix 14.4: Summary of Australian wood products supply chain, including new advanced LVL

RESOURCE	PROCESS	PROCESS PRODUCTS	MARKET APPLICATIONS
High value Native Forest Sawlog	Sawn Hardwood Mill	Square Dressed Appearance	Flooring Lining Cladding Mouldings and joinery Windows Doors Furniture & cabinetry
		Square structural	Framing (S) Beams (S) Lintels (S) Trusses (S) Glulam (S) Cross-arms (S&D) Industrial decks (S&D) Retaining walls (S&D) Bridges (S&D) Wharves & piers (S&D)
		Rounds	Poles/posts (S&D) Piers (S&D)

RESOURCE	PROCESS	PROCESS PRODUCTS	MARKET APPLICATIONS
	New Advanced Blended Hybrid LVL *Niche Speciality*	*Square Appearance*	*Doors ← (MR) fire doors* *Flooring*
Low Value Native Forest		*Square Structural*	*Studs ← (MR) high strength* *Plates ← (MR) improved perp to grain* *Trusses ← (MR) floor truss chords* *← (MR) long span roofs* *Post & beam ← (MR) high strength* *F27 framing (NSW residential)* *Industrial decks??* *Wharves & piers ??* *Cross arms??*
Hardwood Plantation		*Panels*	*Floor-slab cassettes ← (MR) long span* *Mass floor and wall panels ← (MR) CLT altern* *Stairs ← (MR) fire perf* *Portal frames*
	Current EWP Panels	Hardboard Particleboard Plywood	Bracing Flooring Lining / cladding Shipping container floors
Low Value Softwood	LVL	LVL 14 LVL 13	Trusses Beams /Lintels Framing Portal frames Large structural i.e. Box-beams
	Sawn Softwood Mill	Structural MGP10 MGP12 *(MGP15 – limited)*	Trusses Framing Lintels Glulam
High Value Softwood Sawlog		Appearance	Decking Lining Cladding Mouldings

Appendix 14.5: Technical specification for hardwood cross-arms-acceptable species

Common Name	Botanical Name	Durability Class (Note 1)	Strength Group to AS 2878 (Note 2)	Minimum Accept. Cross-arm Grade
ash, Crow's	Flindersia australis	1	S2	No.2
ash, hickory	Flindersia ifflaiana	1	S1	No.2
blackbutt	Eucalyptus pilularis	2	S2	No.2
bloodwood, brown	Eucalyptus trachyphloia	2	S3	No.1
bloodwood, gumtopped	Eucalyptus arenaria	1	(S3)	No.1
	Eucalyptus dichromophloia	1	(S3)	No.1
	Eucalyptus niphophloia	1	(S3)	No.1
bloodwood, pale	Eucalyptus collina	1	(S3)	No.1
	Eucalyptus terminalis	1	(S3)	No.1
bloodwood, range	Eucalyptus abergiana	1	(S3)	No.1
bloodwood, red	Eucalyptus gummifera	1	S3	No.1
	Eucalyptus intermedia	1	S3	No.1
	Eucalyptus polycarpa	1	S3	No.1
box, bimble	Eucalyptus populnea	1	(S2)	No.2
box, black	Eucalyptus largiflorens	1	(S2)	No.2
box, Coowarra	Eucalyptus cambageana	1	(S2)	No.2
box, grey	Eucalyptus microcarpa	1	S2	No.2
	Eucalyptus moluccana	1	S2	No.2
	Eucalyptus woollsiana	1	S2	No.2
box, red, Molloy	Eucalyptus leptophleba	1	(S2)	No.2
box, white	Eucalyptus albens	1	(S2)	No.2
box, white-topped	Eucalyptus quadrangulata	2	S2	No.2
box, yellow	Eucalyptus melliodora	1	S3	No.1
cadaga	Eucalyptus torelliana	2	S2	No.2
carbeen	Eucalyptus tessellaris	1	(S1)	No.2
carbeen, broadleaved	Eucalyptus clavigera	1	(S3)	No.1
	Eucalyptus confertiflora	1	(S3)	No.1
gum, grey	Eucalyptus canaliculata	1	S1	No.2
	Eucalyptus propinqua	1	S1	No.2
	Eucalyptus punctata	1	S1	No.2
gum, red, forest	Eucalyptus blakelyi	1	S3	No.1
	Eucalyptus tereticornis	1	S3	No.1
gum, spotted	Eucalyptus citriodora	2	S2	No.2
	Eucalyptus henryi	2	S2	No.2
	Eucalyptus maculata	2	S2	No.2
ironbark, grey	Eucalyptus drepanophylla	1	S1	No.2
	Eucalyptus paniculata	1	S1	No.2
	Eucalyptus siderophloia	1	S1	No.2

Common Name	Botanical Name	Durability Class[1]	Strength Group to AS 2878[2]	Minimum Accept Cross-arm Grade
ironbark, gum-topped	Eucalyptus decorticans	1	(S2)	No.2
ironbark, red	Eucalyptus sideroxylon	1	S2	No.2
ironbark, red, broadleaved	Eucalyptus fibrosa subsp. fibrosa	1	S1	No.2
ironbark, red, narrow leaved	Eucalyptus crebra	1	S2	No.2
ironbark, silver-leaved	Eucalyptus melanophloia	1	(S2)	No.2
ironwood, Cooktown	Erythrophleum chlorostachys	1	S1	No.2
mahogany, red	Eucalyptus pellita	2	(S2)	No.2
	Eucalyptus resinifera	2	(S2)	No.2
mahogany, southern	Eucalyptus botryoides	2	S2	No.2
mahogany, white	Eucalyptus acmenoides	1	S2	No.2
	Eucalyptus umbra subsp. umbra	1	S2	No.2
	Eucalyptus umbra subsp. carnea	1	S2	No.2
	Eucalyptus tenuipes	1	S2	No.2
messmate, Gympie	Eucalyptus cloeziana	1	S2	No.2
penda, brown	Xanthostemon chrysanthus	1	(S2)	No.2
penda, red	Xanthostemon whitei	2	(S2)	No.2
peppermint, Queensland	Eucalyptus exserta	1	(S2)	No.2
rustyjacket	Eucalyptus peltata subsp. peltata	2	(S2)	No.2
	Eucalyptus peltata subsp. leichhardtii	2	(S2)	No.2
stringybark, Darwin	Eucalyptus tetrodonta	1	S1	No.2
stringybark, white	Eucalyptus eugenioides	2	S3	No.1
	Eucalyptus globoidea	2	S3	No.1
	Eucalyptus phaeotricha	2	S3	No.1
tallowwood	Eucalyptus microcorys	1	S2	No.2
woollybutt, northern	Eucalyptus miniata	2	(S2)	No.2
yapunyah	Eucalyptus ochrophloia	1	(S2)	No.2
yapunyah, mountain	Eucalyptus thozetiana	1	(S2)	No.2

Notes [1]*Durability classifications in accordance with Table 4 of the Notification under the Timber Utilization and Marketing Act 1987 (Queensland) published in the Queensland Government Gazette on 27 June 1987.*
[2]*The Strength Group classifications shown in brackets ( ) are only provisional ratings until such time as additional mechanical test data becomes available.*

Chapter 15 Reflection on market opportunities and examples of commercial progress

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Introduction

The demand and use of engineered wood products continues to increase globally (Market Research Future, 2020). The drivers in Australia for this are varied, however, can be essentially grouped into two broad categories – production driven and market driven.

From a production perspective, the average log diameter and overall log quality available to processors from native forests is generally declining. While the forest and forest product industries strive to gain the most value from the available resources, some traditional timber products are becoming increasingly challenging to supply from lower quality and smaller diameter logs. This can be due to either technical constraints such as simple geometrical conflicts where the target product dimension exceeds the possibilities to saw from the available log sizes, and/or economic constraints where the resource inputs costs exceed the product price. For example, large dimension sawn timber posts and beams, which have been traditionally the target, profitable sawn product range for Australia's hardwood industry, are increasingly unable to be produced. Instead, smaller board sizes are increasingly produced that more align with the available log resources. These products don't necessarily have the same market demand or attract the same premium prices. Indeed, the inability for the timber industry to reliably supply many of these traditional products (e.g. timber bridge components such as girders, corbels and decking; wharf and jetty timbers; railway track timbers) has resulted in consumers seeking alternative products and in many cases, the timber industry are losing these once lucrative markets.

The manufacture of substitute engineered wood products (EWPs) is considered an opportunity to take advantage of the changing resource while still maintaining access to traditional markets. One advantage of EWPs is they are able to use smaller section size feedstock to manufacture larger dimension products (Leggate *et al.* 2017). For example, small section sawn boards can be glue-laminated to create large dimension post and beams, however, there are additional constraints, challenges and costs associated with suitably drying the feedstock, achieving satisfactory glue bonds, product certification etc., especially when considering the use of native hardwoods. With amplified costs and market perceived risks (e.g. uncertainty about long-term glueline performance), alternative products (e.g. steel, concrete and other more cost effective EWPs from plantation softwood) can often be viewed as more favourable and despite best efforts, the hardwood sector may still lose access to their traditional markets.

In general, the Australian hardwood timber industry has dealt with the gradual decline in resource characteristics (increasingly smaller and lower quality logs) by attempting to adapt to markets that accept smaller dimension sawn boards. This has included products such as sawn flooring and decking, and light structural sawn sections. Any large diameter logs received are reserved to capitalise on the higher profits that larger traditional structural sections attract. However, the inefficiencies of sawing boards from small diameter logs has been demonstrated in Chapter 4, meaning that this strategy alone may not be profitable long-term, hence the investigations into veneer-based EWPs are justified.

From a market driven perspective, the building professional community increasingly have a preference for building materials that are straighter, more stable and uniform in size, exceed the performance capabilities of traditional timber products, are lighter in weight and have certified structural performance with reduced variability. EWPs provide these positive attributes and increasingly, the global timber industry are responding to the market demand that is emerging with new product solutions (e.g. mass timber panels for mid-rise construction).

A challenge for Australia's hardwood timber industry is identifying markets they can economically access with suitably designed and constructed EWPs. Low conversion rates when recovering sawn timber from small diameter logs (see Chapter 4), slow feedstock drying rates, board stability concerns, difficulties achieving long-term reliable glue bonds etc. means that many sawn hardwood timber based EWPs are economically challenging. Rotary veneer processing has been demonstrated as an efficient log processing method (see Chapter 4) with the resulting veneer being quick and easy to dry, and easier to bond (compared to sawn hardwood). Identifying target products that build on the traditional competitive advantages of Australia's native species and their wood properties may be a sensible pathway of development for veneer-based EWPs.

Competitive advantages of native timber species

Australia's native commercial timber species is dominated by the *Eucalyptus*, *Corymbia* and *Callitris* genera. While the commercial species within the *Callitris* genus is limited to very few species, there are a much larger number of commercial species from the *Eucalyptus* and *Corymbia* genera Within these species, significant variation in wood properties exist, however, in general, Australia's native forest timbers have an international reputation for being superior in mechanical performance and in many cases, have good to excellent natural durability.

For example, the wood density of most native commercial timber species in Australia exceed the wood density of plantation softwood species. Similarly with mechanical properties, the Modulus of elasticity (MOE) values obtained from veneer recovered from even small diameter native forest spotted gum far exceed that possible from Australia's plantation softwood resources (see Chapter 4). All of Australia's plantation softwood species are regarded as non-durable, however, many of Australia's native commercial timber species are considered to be durable including a high representation with the durability class 1 and 2 categories.

With the development of the plantation softwood estate in Australia, low to mid-range structural capacity timber products are able to be produced at competitive costs, partly due to processing efficiencies of scale. The resulting wood is preferred in some markets over native timbers due to its ease of working properties including nailing, screwing and gluing. Decreased product weight and ease of drying also add to the attraction. This has contributed to the loss of market share for the native forest timber industry, especially in small section structural markets. This has had a substantial impact of the cypress industry for example, who have lost almost all markets for house framing to plantation pine. The plantation softwood industry rely largely unable to compete in the traditional large dimension hardwood product markets due to limited log size preventing large sawn sections from being produced and also inferior mechanical properties. With appropriate preservative treatments, comparable wood durability can be achieved.

Most commercial timber species available on the international market remain unable to compete with Australia's native species in terms of high mechanical performance, natural durability and aesthetics (although the latter is more difficult to define). It is for these reasons that many of the markets developed and traditionally dominated by the native hardwood sector have not been lost to other timber products, rather they have been lost to material competitors such as steel, concrete and fibre composites. These options often come at substantial cost increases and in many cases, are only pursued due the unavailability of traditional timber products. For the Australian native timber industry to prosper into the future, new markets need to be developed that enable the timber industry to supply products with competitive advantage. These markets may be genuinely 'new' (i.e. not previously supplied by the timber industry) or substitute products (i.e. new products that can be used in place of traditional timber products).

Opportunities in the emerging mid-rise construction

Technical opportunities have been identified within Australia's emerging timber mid-rise construction for EWPs that offer superior mechanical performance and potentially improved aesthetic qualities. Products with mechanical properties that are higher than those currently offered from plantation softwood resources have advantages in being more capable of handling the higher structural loads resulting from the larger structures, but also provide opportunities for bridging longer spans without the need to significantly increase section sizes. These opportunities are described in detail within Chapters 5 and 9.

Veneer based EWPs, and in particular laminated veneer lumber (LVL), are starting to be included in mid-rise building design (see Figure 15.1) and have the potential to be a product of choice for this construction type. Scaled LVL products manufactured from native forest sourced spotted gum and white cypress pine, along with blends of these species with plantation grown hoop pine were evaluated with clear mechanical performance advantages being demonstrated particularly with the use of spotted gum veneers either as a single species lay-up or blended with hoop pine veneers (see Chapter 8). For blended LVL using spotted gum and hoop pine, the strategic placement of specific veneer qualities within the lay-up was clearly demonstrated.

Given these products are not yet commercially available and the building design profession largely do not know that higher performing LVL products are technically possible, there is currently no market demand for this product type. Without a market demand, producing these products is low priority for the manufacturer. To facilitate market adoption of higher performing LVL products, either made from species such as spotted gum, or a blend of species, it will be key for a manufacturer to collaborate closely with building designers to increase awareness of the potential new products and their competitive advantages (e.g. longer spans, LVL beams of reduced depth etc.), and explore opportunities for building designs to incorporate these products where appropriate. This partnership is likely to create demand, justifying manufacturers to increase efforts to develop and commercialise these product types.

Figure 15.1. Laminated veneer lumber products featured in the recent construction of 25 King Street in Brisbane, Australia

Substitution into traditional timber markets

When the competitive advantages of Australia's native forest species are reviewed, with superior mechanical performance and natural durability being dominant characteristics when compared to most commercial wood species in the international market, it is not surprising that historical markets for these species have been heavy structural timbers, and often for use in weather exposed applications (e.g. railway sleepers and transoms, bridge girders and decks, wharfs and jetties etc.). With a long successful history of Australian hardwood being used in these products, a review of these uses could be an effective mechanism to identify market opportunities for veneer-based engineered wood products from the same species. Establishing markets for well designed and manufactured veneer-based EWPs made from native forest veneers, either entirely or incorporated a blend with different species, would be expected to be more likely to succeed when targeting markets already used to accepting traditional timber products, potentially of the same species. These markets are aware and value the performance of native forest timbers, have the necessary skills to use and maintain similar products. Possible traditional timber products that could substituted by suitably designed veneer-based EWPs include (but not limited to):

- Bridge girders, corbels, headstocks and other timber bridge components (see Figure 15.2),
- Mining timbers,
- Railway sleepers, transoms, turnouts and other railway timber components,
- Post and beams for large industrial sheds,
- Electrical network pole cross-arms, and
- Wharf and jetty beams, decking, railing etc.

Figure 15.2. Example of a traditional timber railways bridge using timbers sections that are becoming increasingly scarce

Project industry partner, the Big River Group, with support from the project team, pursued the development and commercialisation of veneer-based bridge girders. This was in recognition of industry and market feedback that replacement traditional girders were increasingly becoming difficult to source and the demand for bridge components to maintain the many thousands of existing timber bridges in Australia was quickly increasing. Indeed, it is understood that many timber bridges are slowly being replaced by local and state governments at significant expense using concrete and other alternative solutions due to the reduced ability of industry to supply replacement traditional timber products. An additional motivator for the Big River Group was to produce a product that complimented an existing veneer-based bridge deck product that the company had been manufacturing for many years (originally developed and introduced to the Australian market in the mid-1980s).

The market intelligence of the Big River Group provided an initial design constraint of 450 mm girder beam depth to ensure compatibility with common traditional girder dimensions. Therefore, an end-of-life traditional girder could be removed from a bridge and replaced with a new veneer-based girder without significant disturbance with road or bridge deck heights. A wide flat top face was seen as advantageous, especially during the construction phase allowing construction staff to more safely walk along the beams compared to the traditional round or hexagonal girders. The structural performance of a new girder also needed to be at least comparable to the traditional F22 and F27 hardwood girders. More predicable performance and the ability to provide certification of structural properties was also viewed as attractive for the market. Lightweight girders was also a key design feature for a new timber girder. Market feedback asserted that one of the negative features of moving to alternative girder product solutions such as concrete, which is substantially heavier than the traditional timber products, is the loss of bridge carrying capacity due to the increased dead load on the existing supporting structure. A lightweight girder solution would enable originally designed carrying capacities to be maintained and also prevents additional extensive ground and foundation works that are required when increasing bridge weights. The market also indicated its attraction to girder products that performed similar to the traditional timber girder and that required similar methods to install and maintain. They also saw significant advantages in girders being supplied with minimal size variations, meaning girders wouldn't need onsite trimming, notching etc. to make them fit as is commonly required with traditional products.

Based on the design targets and various other commercial limitations, a LVL based design was developed and prototypes manufactured. Based on the required structural performance, native forest hardwood veneers were included in the construction layup along with plantation softwood veneers which aided in limiting the overall weight of the new girder. Staying within the 450 mm beam depth constraint, a suitable beam width was determined to ensure the beam structural performance at least equalled the traditional timber girder. Veneer orientation was kept horizontal to provide durability performance and connector performance benefits. Veneers are bonded with either a standard phenol-formaldehyde or resorcinol-formaldehyde adhesive system which are proven systems to provide reliable, long-term durable structural bonds. Manufactured beams are preservative treated to Hazard Level 5 to ensure suitable resistance to biological attack (e.g. decay and termites). The girder is completed with a series of surface coating to minimise weathering and to boost the protection of the girder against water ingress.

Prototype girders were mechanically tested to determine key mechanical properties, to validate design targets and facilitate engineering certification (see Figure 15.3). An analysis of the preservative treatment process confirmed compliance to current standards. The Big River Group are reporting that the new veneer-based girder is in the order of 22% lighter, 35% stronger and 5% stiffer than a traditional F22 hardwood girder.

At the time of this chapter preparation, the Big River Group had manufactured and sold 150 veneer-based bridge girders at a value exceeding $600,000 (see Figure 15.4). To date seven bridges have been constructed using the new girder systems including two bridges on Browns Road at Shannon Vale in the New England Region of NSW (see Figure 15.5). Market feedback is reported to be positive and an increasing number of local governments are considering the product as a viable option for maintaining their timber bridge network and also as part of new bridge construction. The Big River Group have also extended their bridge component range to include veneer-based corbels, headstocks and kerbs as they strive towards the ability to supply total bridge solutions (see Figure 15.6).

Figure 15.3. Strength testing of prototype veneer-based bridge girders

Figure 15.4. Veneer-based bridge girders ready for dispatch

Figure 15.5. Veneer-based bridge deck and girders used for new bridge construction

Figure 15.6. Painted veneer-based bridge kerbs

Posts and bollards

While not a veneer-based engineered wood product and therefore not a core focus of the project, an opportunity to produce speciality posts and bollards was investigated. Markets have long existed for post and bollards, especially those made from timber. While these products can be produced in a variety of ways (e.g. sawn, natural rounds etc.), a market is believed to exist for uniform shape and sized, round products. In addition, a potential market exists that have a preference for naturally durable products rather than preservative treated timber products (e.g. organic farming).

While mechanical approaches exist to produce ‘round’ logs of relatively uniform shape (cylindrical) and diameter, these approaches can have a high capital cost and don’t always leave the surface smooth. As an alternative to this, a standard spindleless debarking machine was trialled. This machine is used to prepare logs in preparation for rotary peeling in a spindleless veneering lathe. This equipment has a relatively low capital cost (e.g. ~A$50,000), requires minimal supporting infrastructure, low operator skill etc. In addition, this equipment item forms part of a standard spindleless veneer processing line, therefore the production of rounded posts and bollards could be a ‘side product’ for a veneer operation that may have spare peeling capacity.

Standard spindleless debarking machines are capable of removing the bark and natural irregularities (sweep, ovality, bumps etc.) on logs up to approximately 2600 mm in length. The range of log diameters that the spindleless debarker can accommodate is dependent on make and model, however commonly range between 100 and 400 mm. While the spindleless debarker is generally operated until the log is considered ‘round enough to peel’ with a range of log diameters resulting, for the purposes of the study, some guides were positioned on the machine so that the log could continue to be ‘rounded’ until not only cylindrical, but also to a specific target diameter.

A trial was conducted on both hardwood (plantation and native forest) and white cypress pine logs at a semi-industrial (1300 mm length) and industrial scale (2600 mm length) targeting products less than 250 mm in diameter. The trial demonstrated that the spindleless debarker was very effective at producing uniform shape and sized, round posts/bollards up to a maximum length of 2600 mm (Figures 15.7 and 15.8).

The relatively narrow sapwood band that is characteristic of many of Australia’s sub-tropical hardwood species and white cypress pine, especially from trees that are slow-grown (e.g.

small-diameter suppressed native forest logs) was considered attractive for this purpose as the option to remove the non-durable sapwood during 'rounding' resulted in minimal volume loss, resulting in a naturally durable product (assuming the species has naturally durable heartwood) that doesn't require preservative treatment.

Heart shakes resulting during the post-processing seasoning was identified as a potential limitation. This was more evident with the faster-grown plantation hardwood and to a lesser extent, the native forest hardwoods (Figure 15.9). The severity of the heart shakes were dependent on specie, tree age and seasoning method/rate. The white cypress pine showed minimal heart shakes, probably as a result of the much lower shrinkage rates of this specie (Figure 15.10). Seasoning practices are expected to reduce the heart shake formation and there are other established methods that can assist in controlling/managing heart shakes such as cutting grooves along the length, end-coring etc. Technical Design Guide 47 Timber Bollards (Wood Solutions, 2018) provides extensive detail on bollards preparations, design and maintenance. Additional market research, product performance definition and economic analysis are all necessary to further progress these products.

Figure 15.7. A newly installed spindleless debarker for the production of posts and bollards

Figure 15.8. Hardwood posts/bollards resulting from trials


Figure 15.9. An extreme example of severe heart shakes caused during post-processing drying


Figure 15.10. Proto-type bollards processed from white cypress pine

Conclusions

Reviewing the competitive advantages of Australia's native timber species has been demonstrated as an effective tool to steer the product development strategy for new, high performance EWPs. In addition, reflecting on the traditional markets which have been historically held by the native forest industry identifies a range of products which are unable to be supplied from most commodity timber species. These products demand the performances that are unique to Australia's native timber species, however, it is becoming increasingly difficult for the native forest industry to supply due to the general decline of log quality. In many cases, the market has a preference for a timber-based solution, however, are forced due to the limited supply, to pursue other products made from alternative materials to service the demand. Given these markets already value timber-based products, have established skills and knowledge on using and maintaining timber-based products, it makes sense to explore options to develop substitute EWP solutions using the same fundamental wood resource. This strategy has been effective pathway to commercialise new, high performance EWPs as demonstrated by the commercialisation of the veneer-based bridge girders by project partner, the Big River Group.

References

Leggate, W., McGavin, R. and Bailleres, H. (Eds) (2017). A guide to manufacturing rotary veneer and products from small logs. Australian Centre for International Agricultural Research: Canberra, ACT. 159pp.

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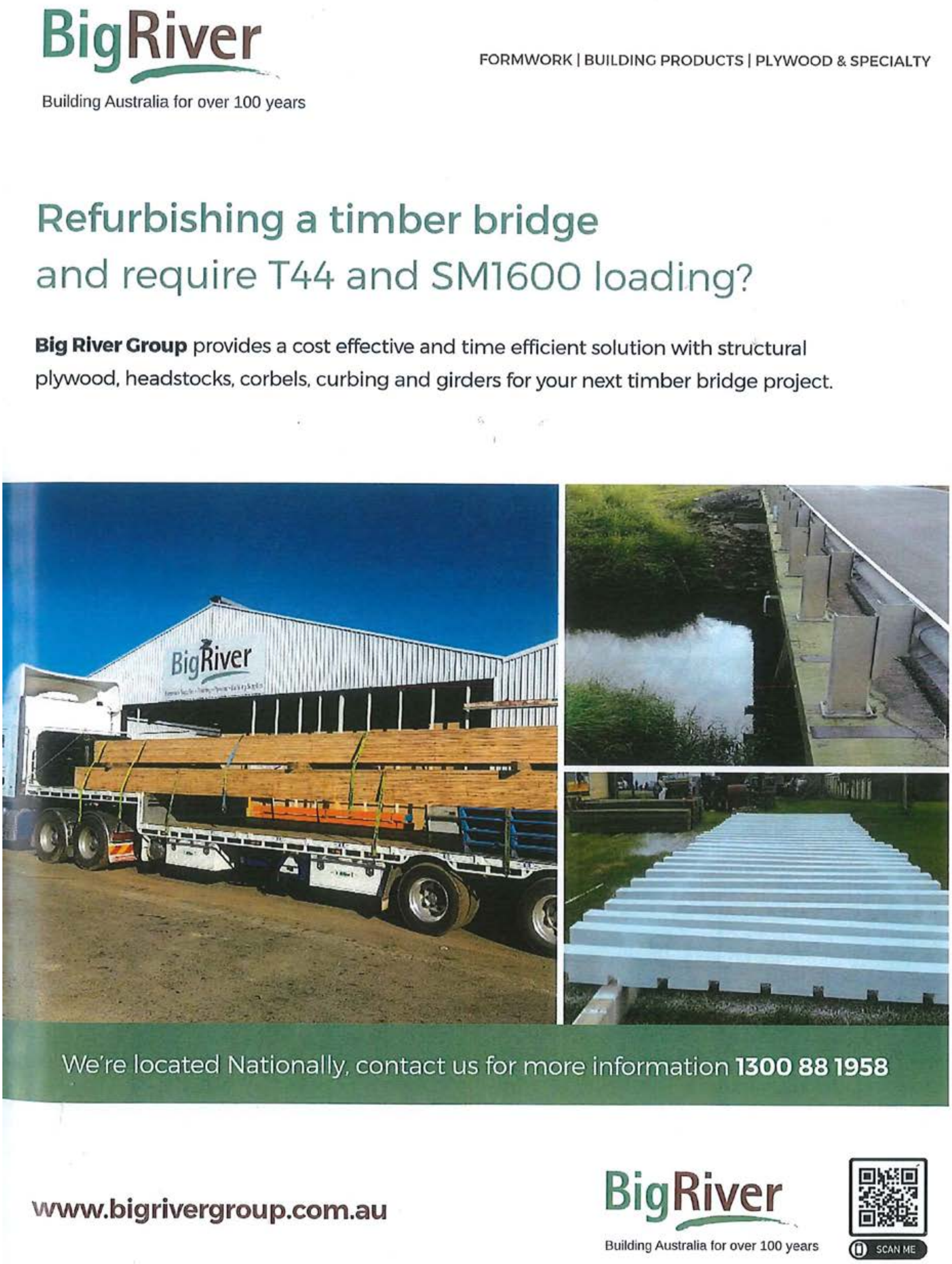
The Roadbuilder and Construction Equipment Journal (2019). Engineered Timber Bridge System a Lifeline for State's Deteriorating Timber Bridges. Article in: The Roadbuilder and Construction Equipment Journal, October 2019 Edition.

Wood Solutions (2018). Technical Design Guide 47 – Timber Bollards, Forest and Wood Products Australia.

Appendices:

Appendix 15.1: Big River Group's veneer-based bridge components advertised in the Roadbuilder and Construction Equipment Journal



Source: The Roadbuilder and Construction Equipment Journal (2019).

Appendix 15.2: Article promoting Big River Group's veneer-based bridge components

Engineered Timber Bridge System a Lifeline for State's Deteriorating Timber Bridges

Timber specialist and plywood manufacturer, **Big River Group**, has launched a full timber bridge refurbishment system, manufactured in Grafton, New South Wales, from its chain of custody certified timber mill, as a cost effective and quick installation solution for the reconditioning and refurbishing of timber bridges.

Bridges form a vital part of Australia's transport network, with around 30,000 timber road bridges in service throughout the country. However, heavier and faster moving vehicles have put a considerable strain on these old timber bridges, accelerating the rate at which many of these ageing timber structures have been deteriorating.

As a way to extend the life of timber bridges a full Engineered Bridge system was developed by Big River Group, and includes engineered decking, engineered girder beams, headstocks, corbels and kerbing, as a cost effective solution to steel and concrete alternatives. The system is an engineered substitute for traditional hardwood timbers and its install speed, a critical measure of its success.

The longer length engineered bridge decking product available up to 14 metres for a single span, offers quick installation. When complemented with engineered girder beams, head stocks and corbels the strength to weight ratio combination of the system increases the live load capacity of structures up to 22 per cent, and is up to 35 percent stronger than traditional timbers, therefore extending the life of the timber structure it's installed on and using less natural resource.

A retrofit engineered solution, with a H5 treated 40 year design life that meets T44 and S1600 loadings, means the Big River bridge system can extend the life of timber bridges by decades. The system is certified to replace all round or sawn timbers of the same section sizes in F22 and F27, and offers a low-cost option for rehabilitating existing, older timber structures without needing to replace the entire bridge. All components are manufactured from a renewable plantation timber resource, providing a negative carbon footprint, meaning it stores 17 times more carbon than is released to manufacture.

Faster to install due to its light weight, the Big River bridge system can be moved in larger sections with the same machinery used for alternative materials, so less trucks are required for delivery and less crane movement to install components is needed.

Additionally, as a timber-based product, environmental impact is minimal with a lower carbon footprint than concrete and steel bridges. Most of the machinery alterations such as drilling, can be done on site with traditional skills and tools. This, together with the lightweight material, means installation can occur in a timely manner, with minimal disruption to local traffic and the community.

The Cedar Creek Bridge in Cessnock, New South Wales, was given a new lease of life in less than a week. As one of 74 bridge assets in the Cessnock local government area, the ageing timber bridge was highlighted as a priority for urgent restoration given the significant deterioration of the corbels, girders and deck planks. Heavier vehicle usage had caused vibration in the bridge as they passed over; this can cause bolts and fasteners to rattle loose over time requiring higher maintenance and causing increase wear to the joints in the timber. The council had implemented a six-tonne load limit on the bridge as a short-term solution while it searched for a low-cost alternative to a steel or concrete replacement, both of which come at significant costs to the community.

Using Big River Group's Engineered Timber Bridge System, the bridge restoration took just three days – four days ahead of schedule – with the council contracting two work crews around-the-clock to restore it quickly.

In full consultation with the residents, the council managed issues of transport and water, with a shuttle bus made available to transport residents to and from their properties, and a pedestrian walk bridge was maintained throughout the project to enable continued access for those getting around on foot. Cessnock City Council estimates that to take the old bridge down and replace it with a new steel and concrete bridge would take a minimum of two months, likely even longer.

For further information on the Big River bridge system please contact Big River Group on 1300 88 1958.

Source: The Roadbuilder and Construction Equipment Journal (2019).

Chapter 16: Impact of log geometry on gross margins from rotary veneer production

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Introduction

About 10.1 M ha or 20% of Queensland's total forest area is on private (including indigenous) land (MPIGA and NFI 2013), and this supplies about 60% of the log resource to the local hardwood timber industry (DAF 2016). Historically, private native forests have been periodically selectively harvested without follow-up silvicultural treatment. In some cases, retained stems of low merchantability have suppressed regrowth, and in other cases excessive regrowth has resulted in high inter-tree competition (Ryan and Taylor 2006). This has left the majority of Queensland's private native forests in a state of low productivity with a high stocking of trees that do not meet traditional product specifications for sawlogs, electrical distribution poles and bridge girders (Queensland CRA/RFA Steering Committee 1998, MBAC Consulting Pty Ltd. 2003, Bureau of Rural Sciences 2004).

According to Private Forestry Service Queensland, if private native forests could be managed according to best practice, they are capable of sustainably producing several times the current annual demand for hardwood logs in the state (see Chapter 2). A major reason these forests are not being silviculturally treated to increase productivity is the cost of thinning small and large diameter trees that do not meet the traditional market specifications for logs to be at least 30 cm in diameter and 2.6 m in length[16]. Research by the Queensland Department of Agriculture and Fisheries (DAF) has demonstrated the potential to use emerging spindleless rotary veneering technologies to process hardwood plantation and native forest logs of sizes and qualities previously considered unmerchantable (i.e. less than 2.6 m length and 30 cm diameter) (McGavin *et al.* 2014a, b; McGavin *et al.* 2015a, b, Chapter 4). That research has shown that spindleless rotary veneering can recover much higher proportions of marketable product from small log volume than can be achieved through sawing. Indeed for small native forest *Corymbia citriodora* subsp. *varigata* logs, spindleless rotary veneering produced double the marketable product recovery of sawing, and the resulting veneer contained visual qualities and mechanical properties well-suited to the manufacture of veneer-based engineered wood products (see Chapter 4). Spindleless lathe rotary veneering could represent a financially viable manufacturing opportunity that utilises non-traditional hardwood logs, while also facilitating the necessary silvicultural treatment in native forests to increase their productivity and ensure future supplies of traditional sawlogs, poles and girders.

The purpose of this report is to investigate the effect of log geometry on the financial performance of spindleless lathe rotary veneering. This study forms part of the Queensland Government, Forest and Wood Products Association (FWPA) and industry funded project, entitled—"Increasing the value of forest resources through the development of advanced engineered wood products". The main objective of this project is to investigate the feasibility of using rotary-veneer produced from sub-optimal quality native forest logs in combination with other wood-based feedstocks to manufacture high performance 'next generation' engineered wood products, suitable for structural and appearance applications.

[16] Some sawmills have recently begun accepting small diameter hardwood logs at low log prices (see Chapter 4).

Research objective and analysis assumptions

The objective of this study is to investigate the effect of log geometry on the financial performance of rotary veneer production with hardwood logs. To support log procurement decisions, the maximum that can be paid for mill-delivered logs with alternative log geometries (small-end diameter under bark (SEDUB), length, taper, sweep, and ovality) while achieving particular target gross margins per hour of operation will be determined. The analysis assumes:

1) an automated veneer production process with one operating spindleless lathe capable of peeling logs up to 2.6 m in length;

2) hardwood logs are pre-conditioned (heated) prior to being docked to length, prepared for peeling in a rounding-debarking lathe (to provide a rounded billet with bark, taper, sweep and ovality removed), and then loaded into the spindleless lathe and peeled;

3) green veneer is clipped to the desired sheet width, dried, and then visually graded in accordance with Australian and New Zealand Standard *AS/NZS 2269.0:2012* (Standards Australia 2012) to produce marketable veneer;

4) log preparation costs (e.g. handling, storage, pre-conditioning, and docking) per cubic metre prior to peeling, and the labour and machinery operating costs per hour of peeling, are independent of log geometry; and

5) grade recovery per unit of green veneer is consistent regardless of log geometry.

Research method

The impact of log geometry on the financial performance of a rotary veneer processing operation where spindleless lathe technology is used will be estimated by examining the maximum mill-delivered log cost for logs of alternative geometries in order to achieve particular target gross margins from the sale of veneer. Marketable veneer is dried veneer which meets D-grade criteria or better in accordance with ASNZS2269.0:2012. The gross margin is defined as the market value of marketable dry-graded veneer, less the log cost. The analysis has been performed in four steps, namely:

1. Determine net recovery of marketable veneer by log geometry;
2. Develop regression models to predict total veneering time by rounded log diameter;
3. Predict the value of marketable veneer produced per hour by rounded log diameter; and
4. Calculate the maximum mill-delivered log cost for logs of alternative geometries to achieve a target gross margin.

These steps are now described in turn.

Determine net recovery of marketable veneer by log geometry

Logs arriving at the veneer processing plant are typically not cylindrical, rather they are affected by geometrical irregularities including sweep, taper and ovality. Before veneer can be recovered, the logs must be rounded; the process whereby the billet is machined using a rounding-debarking lathe to a cylinder with consistent diameter and parallel sides (McGavin et al 2014a). This process generates waste. Veneer can be recovered from the rounded log diameter until the peeler core is reached. The peeler core is a residual cylindrical core from the log centre with a diameter usually in the order of 4 cm to 5 cm. In this analysis, a peeler core of 4.5 cm diameter has been adopted, which has a volume of 1.59×10^{-3} m^3/m of log length.

Peelable log volume (PLV) in cubic metres from logs with taper, sweep and ovality, and with small-end diameter under bark (SEDUB) ranging from 0.14 m to 0.6 m in 2 cm increments, was estimated using the following equations.

$$PLV_{taper} = L * \pi * \left(\frac{SEDUB}{2}\right)^2 - CV \quad \text{[eq. 16.1]}$$

$$PLV_{sweep} = L * \pi * \left(\frac{SEDUB - S*L}{2}\right)^2 - CV \quad \text{[eq. 16.2]}$$

$$PLV_{ovality} = L * \pi * \left(\frac{SEDUB - \left(\frac{OV}{2} * SEDUB\right)}{2}\right)^2 - CV \quad \text{[eq. 16.3]}$$

where L is log length (m);

π is pi;
CV is the peeler core volume (m^3) where no veneer can be recovered;
S is sweep in m/m of log length;
SEDUB is the small end-diameter under bark (m), as measured by a diameter tape around the circumference of the log; and
OV is ovality in percent, entered in the equation as a fraction, as defined in Table 16.1.

These equations were used to estimate peelable log volumes for logs with the log geometry characteristics reported in Table 16.1. The PLV_{taper} equation was used to estimate peelable log volume for the two log lengths (1.3 and 2.6 m). Peelable log volumes for logs with sweep and ovality were only estimated for 2.6 m logs.

Mill-delivered log volume (MDLV) from which PLV is obtained after rounding was calculated as follows for logs with taper, sweep and ovality, and SEDUB ranging from 0.14 m to 0.6 m in 0.02 m increments

$$MDLV_{taper} = L * \frac{\pi}{4}\left(\frac{2*SEDUB + T*L}{2}\right)^2 \quad \text{[eq. 16.4]}$$

$$MDLV_{sweep\&ovality} = L * \pi * \left(\frac{SEDUB}{2}\right)^2 \quad \text{[eq. 16.5]}$$

where T is log taper in m/m log length; and
all other variables are as previously defined.

Equation 16.4 was used to calculate mill-delivered log volumes for logs with taper for both log lengths examined. The term in parentheses in Equation 14.4 calculates the mean of SEDUB and large-end diameter under bark (LEDUB), where LEDUB is SEDUB + T * L. Equation 16.5 was used to calculate mill-delivered log volumes for logs with sweep or ovality. Equation 16.5 assumes no taper, thus the effect of sweep and ovality has been examined assuming SEDUB = LEDUB.

Table 16.1. Log geometry assessed

Log geometry characteristic	Units of measure	Levels assessed
Length (L)	m	2.6, 1.3
Taper (T)	m taper /m log length	0, 0.005, 0.01, 0.02, 0.04, 0.08
Sweep (S)	m sweep / m log length	0, 0.005, 0.01, 0.02, 0.04, 0.08
Ovality (OV)	%, defined as $(LSEDUB - SSEDUB)/SSEDUB$, where LSEDUB is the largest small-end diameter under bark (m), as measured across the face of the small-end of the log, and SSEDUB is the smallest small-end diameter under bark (m), as measured across the face of the small-end of the log.	0, 5, 10, 15, 20

Due to defects in the veneer sheets (from imperfections inside the log), trimming veneer to marketable dimensions and shrinkage of veneer during drying, there is further loss in processing green peeled veneer into recovered volume that meets grade quality and is therefore marketable veneer. Hence, marketable veneer volume is less than PLV. The percentage net recovery of marketable veneer from mill-delivered log volume (NR) for logs ranging in SEDUB from 0.14 m to 0.6 m in 2 cm increments, is calculated as

$$NR = \left(\frac{PLV}{MDLV}\right)/MVRPLV \qquad \text{[eq. 16.6]}$$

where PLV is the peelable log volume estimated from eq. 16.1, 16.2 or 16.3;
MDLV is the mill-delivered log volume estimated from eq. 16.4 or 16.5; and
MVRPLV is marketable veneer recovery from peelable log volume (%).

The authors are not aware of any research trials using spindleless lathes that have estimated MVRPLV. Table 16.2 summarises net recovery (NR) of marketable veneer from MDLV from spindleless lathe research trials, as well as the proportion of marketable veneer recovered by veneer grade. However, these reported estimates of NR combine the effects of waste due to log geometry, and defects, trimming and other losses from green peeled veneer. An estimate of MVRPLV is necessary to isolate the effect of log geometry on gross margins.

Table 16.2. Veneer recovery by grade from research trials where spindleless lathe technology was used

Species	Res. type[1]	Age (y)	Mean DBHOB (cm)[2]	Mean log SEDUB (cm)[3]	NR (%)[4]	Recovery by veneer grade (%)			
						A	B	C	D
Corymbia citriodora subsp. *variegata* [a]	N			19.6	45	0	0	0	100
C. citriodora subsp. *variegata* [a]	N			23.7	48	0	9	5	86
C. citriodora subsp. *variegata* [a]	N			27.8	43	0	1	11	88
C. citriodora subsp. *variegata* [b]	P	10 to 12	20.6	15.6	48	0.3	1	16.4	82.3
Eucalyptus cloeziana [b]	P	12 to 15	31.9	23.5	58	0.2	4.8	27.1	68
E. dunnii [b]	P	11	22.9	17.5	55	0	0	7.7	91.9
E. pellita [b]	P	13	28.1	20.9	55	0	1.5	10.4	86.1
E. nitens [b]	P	20 to 22	34	28.9	55	0.4	9.1	13.7	76.9
E. globulus [b]	P	13 to 16	30.6	25.7	50	0	0.9	2.3	96.8

Notes: 1. Resource type, where N is native forest and P is plantation forest.
2. Mean diameter at breast height over bark.
3. Mean SEDUB of docked logs for veneering. Note that many trees produced more than one docked log for veneering.
4. Net recovery of marketable veneer (% of MDLV).

Sources: a. Refer to Chapter 4.
b. McGavin et al. (2014a).

Empirical evidence from the spindleless lathe veneer manufacturing facility at which observations were made for this study indicated MVRPLV is about 60% for their operation. For a 2.6 m length, 30 cm SEDUB log with 0.01 m/m taper, setting MVRPLV to 60% results in NR of 54% (calculated with eq. 16.1, 16.4 and 16.6). This is consistent with NR estimates in Table 16.2, and 60% MVRPLV has been adopted as the base case for analysis in this study.

Develop regression models to predict total veneering time by rounded log diameter

Data collection at a commercial veneer processing operation that has adopted spindleless lathe technology revealed that veneer production from logs with a rounded log diameter (RLD) of between 16 cm and 46 cm is limited by the rate at which the lathe can peel veneer. For the business model examined, green veneer production is assumed to be limited only by the rate at which the lathe will peel logs into veneer, which is a function of the time to load logs into the lathe and the time to peel veneer from the logs.

Several variables not related to log geometry, including machine operator skill, can affect the time to load logs into the lathe. However, log diameter is positively related to log loading time, because at the completion of peeling a log, the log drive rollers will be closed at the peeler core position (e.g. 4.5 cm). The log drive rollers then need to retract to accept placement of the next log. The larger the diameter of the next log, the further the log drive rollers need to retract. The time required to retract the log drive rollers is greater than the time required for the log loader to position the next log ready for loading into the lathe, since the latter task is typically performed while peeling the log already in the lathe. Log loading time data was collected at a commercial spindleless lathe veneer facility for 211, 2.6 m rounded logs that ranged in rounded log diameter (RLD) from 16 cm to 46 cm. Log loading time was measured as the time from when peeling of one log stopped to when peeling of the next log commenced.

Peeling time in seconds (PT) for the 211 rounded logs observed was estimated as follows

$$PT = \pi * \frac{\left[\left(\frac{RLD}{2}\right)^2 - \left(\frac{CD}{2}\right)^2\right]}{VT*PS} \qquad \text{[eq. 16.7]}$$

where RLD is rounded log diameter (m);
CD is peeler core diameter (m);
VT is veneer thickness (m); and
PS is lathe operating speed (lm/second).

A lathe operating speed of 40 lm per minute (0.67 lm/second), which is a common operating speed for spindleless lathes working with many species, has been adopted for this analysis. PT was calculated for two common veneer thicknesses, 2.15 mm and 3.2 mm (0.00215 m and 0.0032 m), and CD of 0.045 m.

Total veneering time in seconds (TVT) for each log peeled to 2.15 mm and 3.2 mm veneer was estimated as the sum of observed loading time and the calculated PT (from eq. 16.7). A simple linear regression model was then fitted to the TVT data to predict TVT as a function of RLD. The TVT regression model assumes a lathe utilisation rate of 100%. That is, logs are continuously being loaded and peeled in the lathe, and there are no stoppages due to issues such as log jams, waste removal, green veneer removal, or lathe sharpening. This is unlikely in practice; however, utilization rates can vary substantially depending on many factors, including labour skill, and level of processing automation. Results from this analysis are presented on the basis of 100% utilization, because it facilitates fractional adjustment of financial performance estimates to an alternative utilization rate.

Predict the value of marketable veneer produced per hour by rounded log diameter

Marketable veneer volume produced per hour of peeling time (MVV) from logs of particular RLDs was calculated as follows

$$MVV = \frac{3600}{TVT} * PLV * MVRPLV \qquad \text{[eq. 16.8]}$$

where 3600 is the number of seconds in an hour;
TVT is the total veneering time in seconds for a log of a particular RLD as predicted with the regression model fitted in step 2;
PLV is peelable log volume from the rounded log estimated using Equation 16.1, 16.2 or 16.3, as appropriate; and
MVRPLV is as previously defined.

For a log with a particular SEDUB, and taper, sweep or ovality, the RLD from which veneer can be peeled and for which TVT was estimated is the numerator in parenthesis in equations 14.1, 14.2 or 14.3, as appropriate. For example, a 30 cm SEDUB log with 10% ovality has a RLD of 28.57 cm (0.3 m – 0.1/2 *0.3 m).

For the purposes of analysis, this study assumes veneer grade recoveries at approximately the middle of the ranges reported in Table 16.2: A-grade 0%; B-grade 5%; C-grade 15%; and D-grade 80%. Commercial dry-graded veneer values are challenging to determine, as the veneer producers are typically manufacturing engineered wood products with the veneer, and the costs of production and final market prices for these products vary substantially. Anecdotal information indicates that 3.2 mm and 2.15 mm D-grade veneer in Australia has a wholesale value of about \$400/m^3. Engineered Wood Products Association of Australasia (2014) asserted that C-grade veneer is about 1.2 times D-grade, B-grade is 1.7 times D-grade, and A-grade is 3 times D-grade. This study has adopted these relative values for C, B and A-grade veneers, which equate to \$480/m^3, \$680/m^3 and \$1200/m^3, respectively. Marketable veneer value or revenue (R) per hour of operation has been estimated with Equation 16.9

$$R = \sum_{g=A}^{D} MVV * GR_g * P_g \quad \text{[eq. 16.9]}$$

where GR_g is veneer recovery by grade, g (%);
P_g is market price for veneer grade, g (\$); and
MVV is as previously defined

Calculate the maximum mill-delivered log cost for logs of alternative geometries to achieve a target gross margin

The gross margin from sale of veneer produced from logs of particular log geometries is defined as the value of marketable veneer produced, less the log cost. Log cost per cubic metre of marketable veneer (LC) for logs with log geometry characteristics examined in this study has been calculated as follows

$$LC = \frac{MDLC}{NR} \quad \text{[eq. 16.10]}$$

where MDLC is mill-delivered log cost (\$/m^3 of log); and
NR varies with log geometry and MVRPLV as previously defined.

Two common ways of reporting gross margins are per hour of operation (GM/h) and per cubic metre of marketable veneer (GM/m^3), which have been calculated as follows.

$$GM/h = R - LC * MVV \quad \text{[eq. 16.11]}$$

$$GM/m^3 = \frac{R}{MVV} - LC \quad \text{[eq. 16.12]}$$

All variables are as previously defined.

However, to support log procurement decisions, a more useful way to report the impact of log geometry on the financial performance of veneer manufacture is in terms of the maximum that could be paid for mill-delivered logs with particular geometries while achieving a target gross margin. The target gross margin could be stated per cubic metre of marketable veneer, but since log geometry does affect marketable veneer output per unit time, and a large proportion of operating costs (e.g. labour) vary with time, adopting a target gross margin per hour is most appropriate. All non-log veneer manufacturing costs, including the desired profit margin, need to be covered by the target gross margin per hour (GM/h_{target}). With a target gross margin determined, the maximum that can be paid for mill-delivered logs of a particular log geometry, $MDLC_{max}$ (in \$/m^3 of log), is estimated as follows

$$MDLC_{max} = R - \frac{GM/h_{target}}{MDLV\left(\frac{3600}{TVT}\right)} \quad \text{[eq. 16.13]}$$

where the denominator in the second term calculates the volume of mill-delivered logs of a particular geometry processed per hour. MDLV is estimated from Equation 16.4 or 16.5 as appropriate and 3600 is the number of seconds in an hour. TVT (in seconds) is for the rounded log derived from the mill-delivered log of a particular geometry (as described with eq. 16.8).

$MDLC_{max}$ provides a simple metric with which to assess the impact of log diameter, length, taper, sweep and ovality on the financial performance of veneer manufacture. The sensitivity of $MDLC_{max}$ to MVRPLV (alternative levels 50% and 70%), veneer lathe utilisation rate (60% and 80%) and veneer market price (D-grade prices of $\$400/m^3 \pm \$50/m^3$ and $\pm \$100/m^3$) has been examined.

Results

Net recovery of marketable veneer by log geometry

NR from mill-delivered 2.6 m logs with SEDUB ranging from 14 cm to 60 cm is presented for logs with taper in Figure 16.1, with sweep in Figure 16.2, and with ovality in Figure 16.3. NR of cylindrical logs is asymptotic with MVRPLV. These figures highlight the positive relationship between log SEDUB and NR, and the negative relationship between log taper, sweep and ovality, and NR. Sweep has the greatest impact on NR and ovality the least impact. Log geometry does substantially affect gross margins in veneer production. For example, 49% of log volume will be converted into marketable veneer from a 30 cm SEDUB log with 0.02 m/m taper, relative to 59% from a cylindrical log with the same SEDUB. This is equates to 20% less marketable veneer being produced from the log with taper.

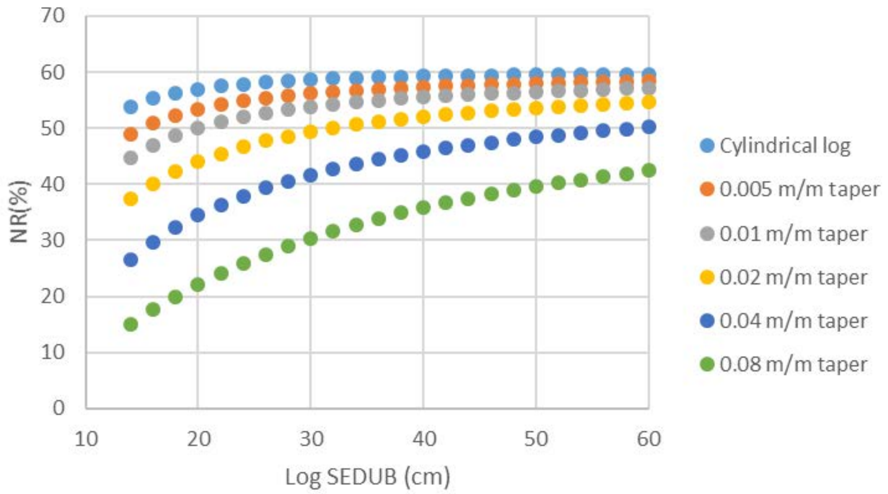


Figure 16.1. Net recovery of marketable veneer from 2.6 m logs by SEDUB and log taper

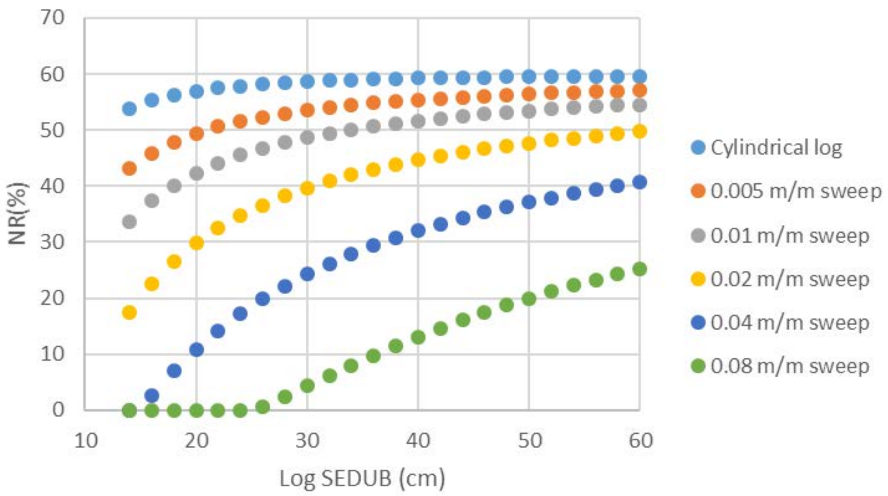


Figure 16.2. Net recovery of marketable veneer from 2.6 m logs by SEDUB and sweep

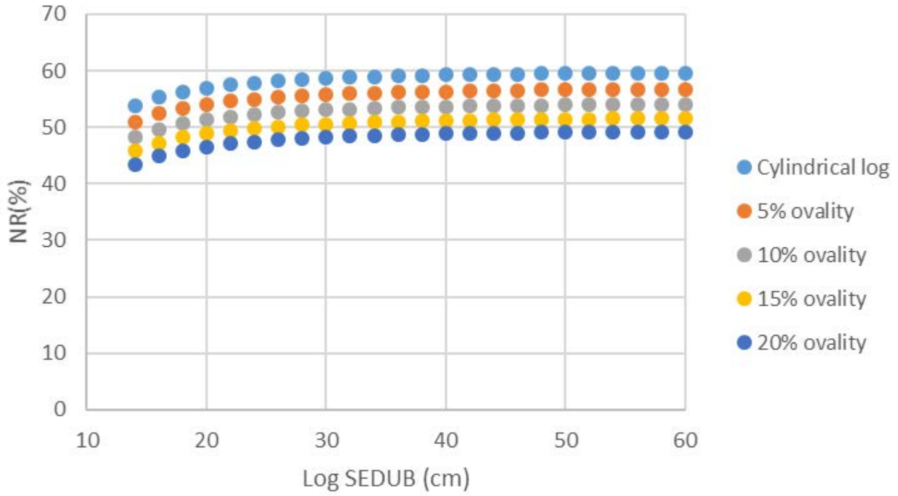


Figure 16.3. Net recovery of marketable veneer from 2.6 m logs by SEDUB and ovality

Total veneering time by rounded log diameter

Observed log loading time ranged from 8 to 21 seconds. PT for the observed logs was calculated with Equation 16.7, and Figure 16.4 presents TVT for these rounded logs for 3.2 mm veneer. The linear regression models fitted to TVT for 2.15 mm veneer (not illustrated) and 3.2 mm veneer are, respectively:

-40.165 + 3.4203 RLD (R^2 = 0.9714); and

-25.641 + 2.4229 RLD (R^2 = 0.9579).

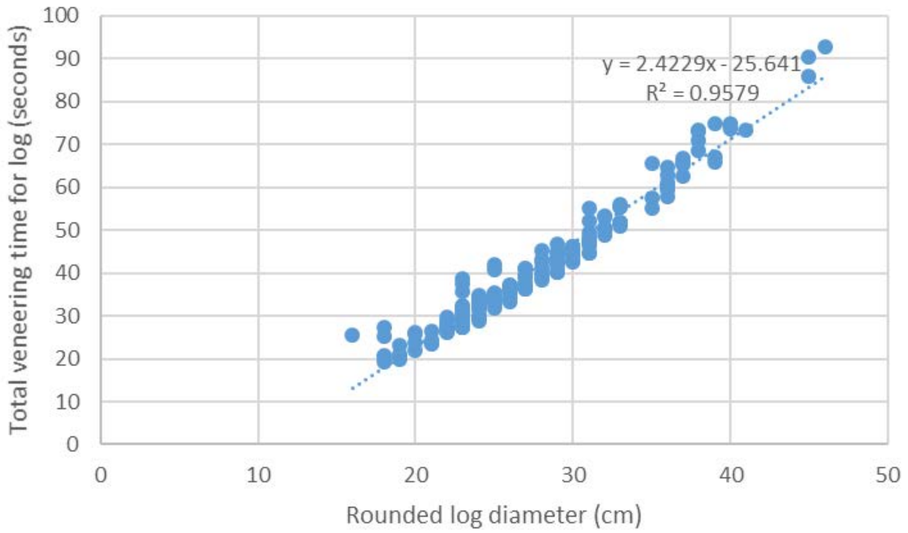


Figure 16.4. Total veneering time by rounded log diameter for 3.2 mm thick veneer peeled at 40 lm per minute

Volume and value of marketable veneer produced per hour by rounded log diameter

MVV and R are presented in Figure 16.5 for 2.15 mm and 3.2 mm veneer produced from 2.6 m logs[17] with RLD ranging from 18 cm to 60 cm. Volumes and values for 2.15 mm veneer

[17] If 1.3 m logs are processed rather than 2.6 m logs, marketable veneer volume produced is halved, as loading and peeling time does not change.

are lower than for 3.2 mm veneer because peeling time per cubic metre of veneer is longer for 2.15 mm veneer. Given the recovery of veneer by grade in Table 16.1, and the veneer prices by grade adopted for this study, the average value of marketable veneer (R/MVV) is $426/m^3. The slightly U-shaped relationship of volume and value with RLD arises because of the short loading time for small rounded logs. As rounded log diameter increases, loading time increases, and for smaller RLD logs this additional loading time is not offset by the additional veneer volume produced from the log. For example, 18 cm and 32 cm RLD logs produce the same volume of 2.15 mm veneer per hour, and 18 cm and 24 cm RLD logs produce the same volume of 3.2 mm veneer per hour.

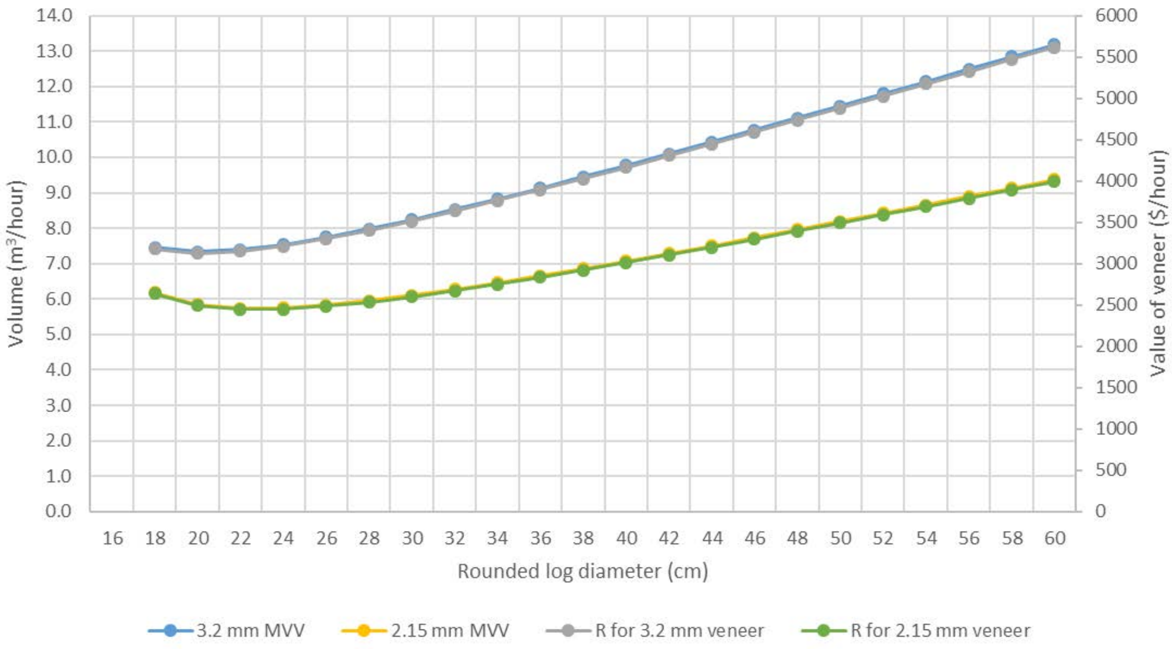


Figure 16.5. Volume and value per hour of 2.15 mm and 3.2 mm veneer produced from 2.6 m logs

Maximum mill-delivered log cost for logs of alternative geometries to achieve a target gross margin

This section presents the impact of log geometry on the financial performance of spindleless lathe veneering as follows. First, gross margins and the maximum mill-delivered log cost ($MDLC_{max}$) for perfectly cylindrical logs are reported for 3.2 mm veneer produced from 2.6 m logs. This represents the most desirable log geometry for veneering (i.e. longer logs with zero taper, zero sweep and zero ovality). LEDUB equals SEDUB, and there is effectively zero log rounding waste. $MDLC_{max}$ for 2.15 mm veneer is then presented for comparison.

Second, the sensitivity of $MDLC_{max}$ for 2.6 m cylindrical logs to key analysis parameters – lathe utilisation rate, MVRPLV and veneer market price (P) – is assessed. Third, the effects of sweep, ovality and log length on $MDLC_{max}$ are examined.

Gross margins and the maximum mill-delivered log cost for 2.6 m cylindrical logs

In this analysis, 2.6 m cylindrical logs peeled to 3.2 mm thick veneer with MVRPLV of 60% serve as the benchmark against which logs with alternative geometries are compared. Figure 16.6 presents GM/h for 2.6 m cylindrical logs with SEDUB ranging from 20 cm to 60 cm, given MDLC is between $80/m^3 and $280/m^3. The increasing gross margins with increasing SEDUB arises because the proportion of log volume that is peelable is higher for larger SED logs (Figure 16.1), and because a larger volume of larger SEDUB logs can be processed per unit of time (Figure 16.5). At $\$80/m^3$ mill-delivered log cost, gross margins range from \$2100/h for 20 cm SED logs to \$3850/h for 60 cm SEDUB logs. Gross margins per hour for logs of all SEDUB examined are minimal at a mill-delivered log cost of $\$240/m^3$. In the Australian log market, mill-delivered log costs typically rise with log diameter, so veneer manufacturers face a trade-off between higher mill-delivered log cost and higher gross margins per unit time for large diameter logs, and lower mill-delivered log cost and lower gross margins per unit time for small diameter logs.

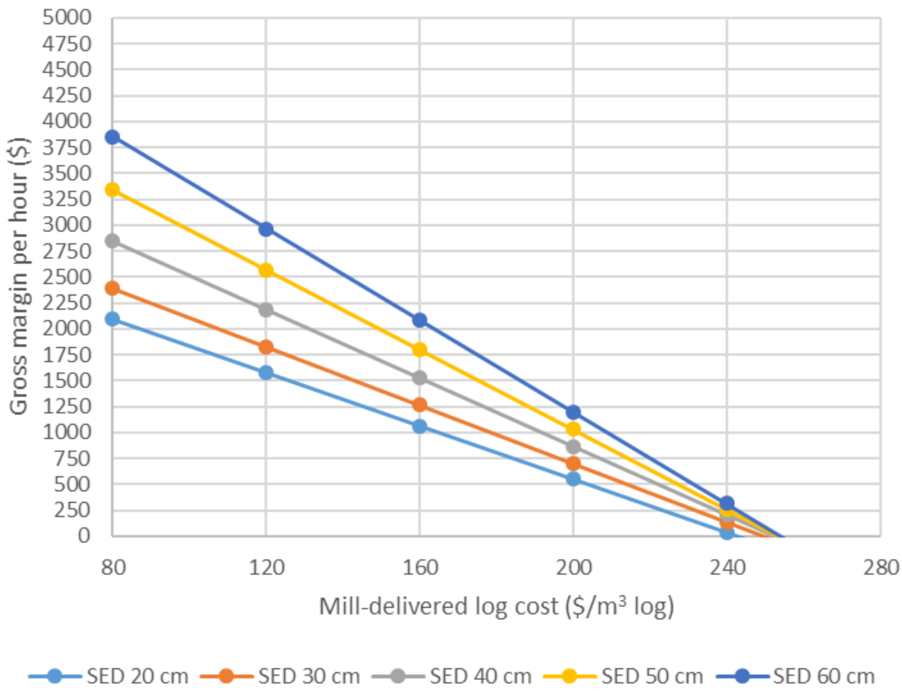


Figure 16.6. Gross margins per hour for 3.2 mm veneer by mill-delivered log cost and SEDUB for 2.6 m cylindrical logs

Figure 16.7 illustrates GM/m^3 for 2.6 m cylindrical logs. At a mill-delivered log cost of $\$80/m^3$, the gross margins range from $\$286/m^3$ of marketable veneer for 20 cm SEDUB logs, to $\$292/m^3$ of marketable veneer for 60 cm SEDUB logs. Figure 16.7 disguises the large differences in gross margins per hour presented in Figure 16.7, indicating that the difference in gross margins per hour between small and large diameter cylindrical logs is predominantly due to the larger volume of larger SEDUB logs that can be processed per hour, not the higher proportion of log volume that can be peeled from larger SEDUB logs.

Figure 16.8 presents $MDLC_{max}$ to generate particular gross margins per hour of peeling with 2.6 m cylindrical logs. For example, in order to earn gross margins of \$1000/h (i.e. GM/h_{target} = \$1000), the maximum that can be paid for 20 cm SEDUB logs is $\$165/m^3$, and the maximum for 60 cm SEDUB logs is $\$209/m^3$. The format of Figure 16.8 is useful for supporting log procurement decisions, and throughout the remainder of the report, this format has been adopted to facilitate comparison of the effects of log geometry on gross margins and the maximum that can be paid for mill-delivered logs.

Figure 16.8 is for a lathe utilization rate of 100%. If lathe utilization is actually 50%, then the gross margins on the x-axis are halved. For example, in order to earn gross margins of \$500/h, the maximum that can be paid for 20 cm SEDUB logs is $\$165/m^3$, and the maximum for 60 cm SEDUB logs is $\$209/m^3$. This illustrated fractional conversion for Figure 16.8 can be performed for any utilisation rate; nevertheless, the sensitivity of $MDLC_{max}$ to two plausible lathe utilisation rates, 60% and 80%, is described in the next section.

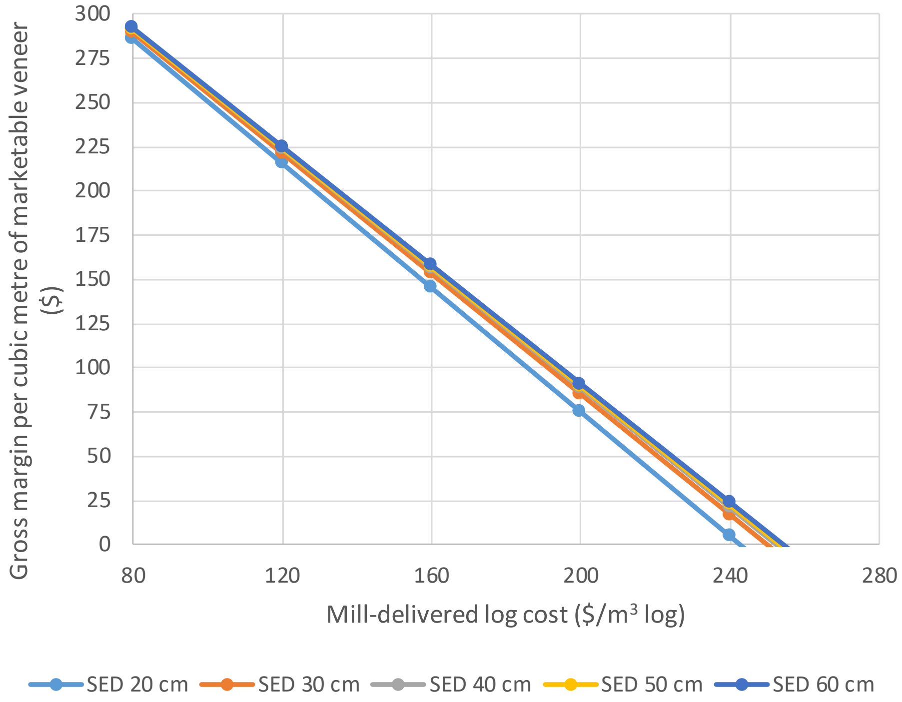


Figure 16.7. Gross margins per cubic metre of 3.2 mm marketable veneer by mill-delivered log cost for 2.6 m cylindrical logs

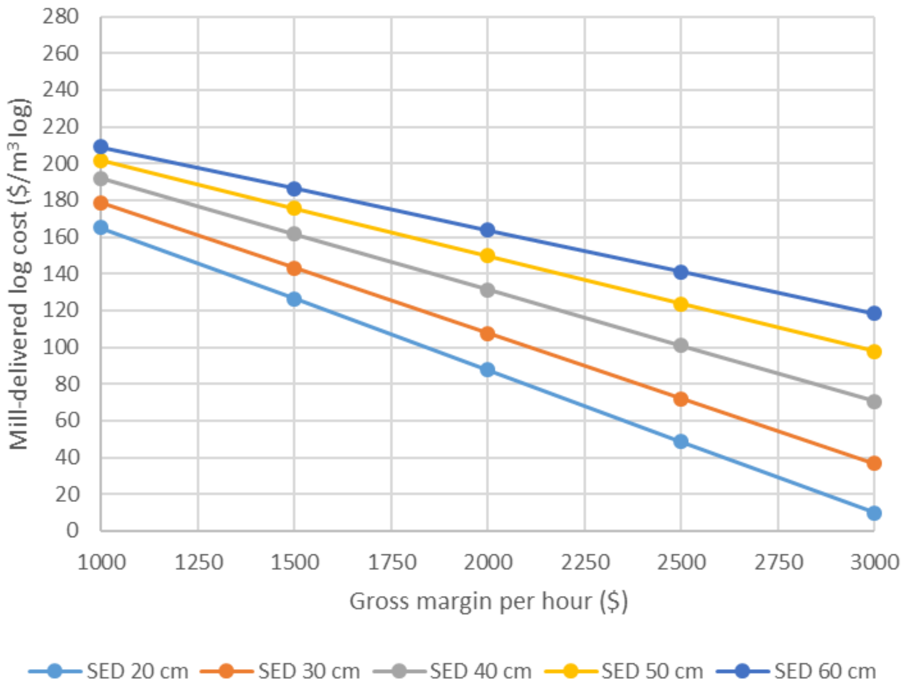


Figure 16.8. Maximum mill-delivered log cost to achieve particular target gross margins per hour peeling 3.2 mm veneer from 2.6 m cylindrical logs

If market price per cubic metre of veneer does not vary with veneer thickness, then gross margins per cubic metre of veneer produced are not affected by veneer thickness[18]. However, thinner veneer will require longer peeling time per cubic metre of veneer, and therefore less veneer will be produced in any given time period (Figure 16.5). The reduction in production

[18] Theoretically, the same volume of veneer can be peeled from a log regardless of veneer thickness.

is greater for larger SEDUB logs, because log loading time, which is not affected by veneer thickness, is a smaller fraction of total peeling time for larger logs. As illustrated in Figure 16.9, the slower peeling time per cubic metre of 2.15 mm veneer results in $MDLC_{max}$ to achieve particular gross margins per hour of between about \$20/m^3 to \$60/m^3 lower than for equivalent SEDUB logs peeled to 3.2 mm veneer thickness (Figure 16.8). At any positive MDLC, it is not possible to earn gross margins exceeding about \$2500/h with 20 cm and 30 cm SEDUB logs.

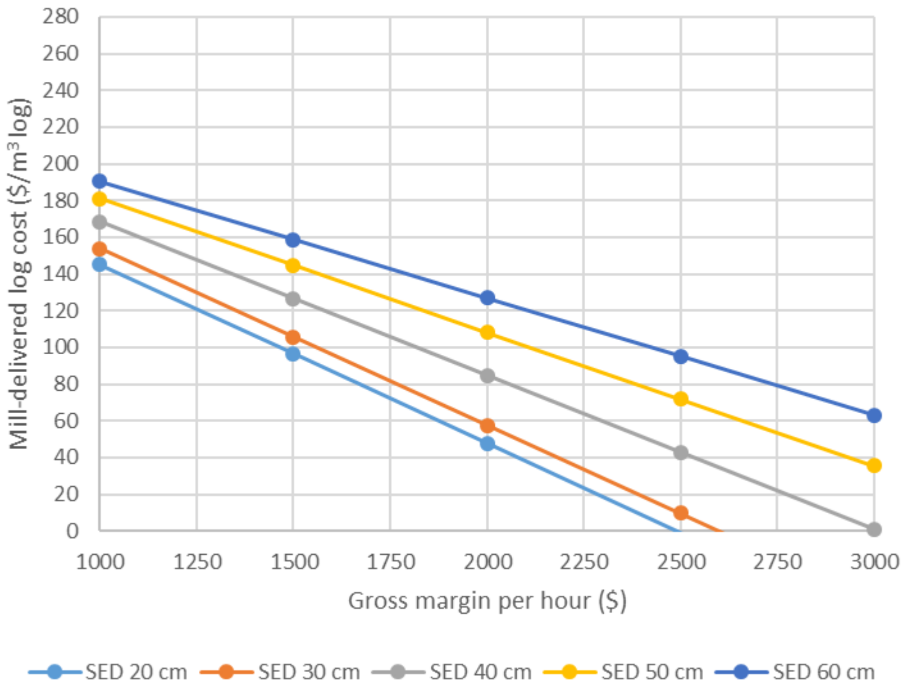
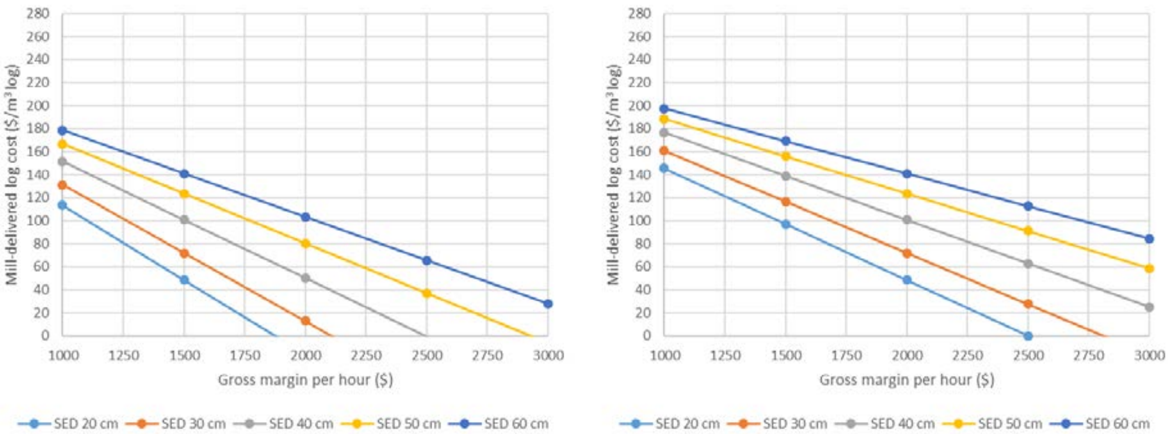


Figure 16.9. Maximum mill-delivered log cost to achieve particular gross margins per hour of operation for 2.15 mm veneer from 2.6 m cylindrical logs with MVRPLV of 60%

Unless otherwise specified, throughout the results that follow, lathe utilisation rate is 100%, MVRPLV is 60%, veneer thickness is 3.2 mm and log length at 2.6 m

Sensitivity of maximum mill-delivered log cost to utilisation rate, the proportion of peelable log volume recovered as marketable veneer (MVRPLV) and veneer market price

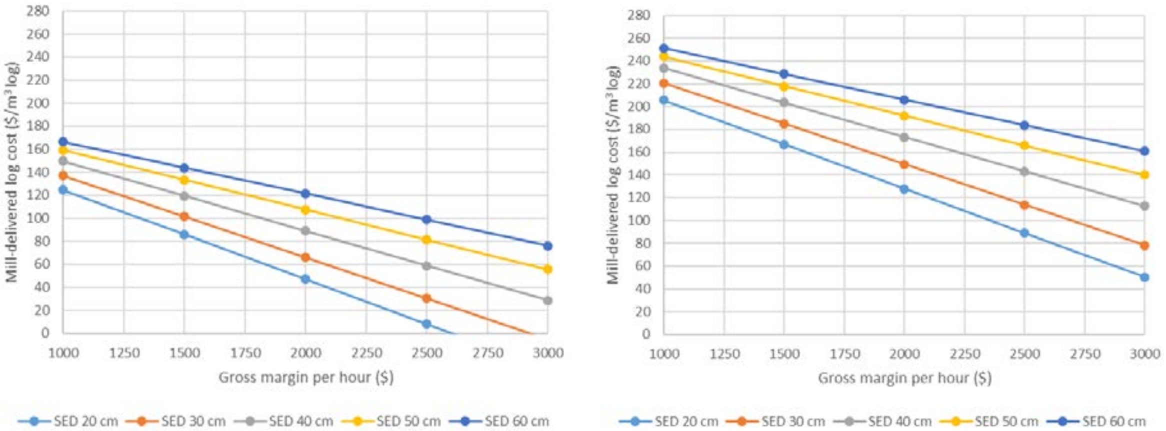
Figure 16.10 illustrates the sensitivity of $MDLC_{max}$ to lathe utilisation rates of 60% and 80%. A lathe utilisation rate of 60% means MVV and revenues per hour (R) are 60% of the levels illustrated in Figure 16.5, and Figure 16.10 indicates this substantially lowers $MDLC_{max}$. For example, in order to earn gross margins of \$1000/h, the maximum that can be paid for 20 cm SEDUB logs is \$113/m^3, and the maximum for 60 cm SEDUB logs is \$179/m^3, which are 32% and 14% lower, respectively, than when utilisation rate is 100%. $MDLC_{max}$ for smaller diameter logs is more sensitive to utilisation rate than for larger diameter logs, because the target gross margin per hour is a larger proportion of R for smaller logs.



(a) (b)

Figure 16.10. Sensitivity of maximum mill-delivered log cost to lathe utilisation rate
Notes: (a) lathe utilisation rate is 60%; and (b) lathe utilisation rate is 80%

Figure 16.11 reveals the sensitivity of $MDLC_{max}$ to plausible alternative levels of MVRPLV. When MVRPLV is 50%, maximum mill-delivered log costs fall by about \$40/m^3 for all assessed SEDUB and target gross margins, relative to when MVRPLV is 60%. $MDLC_{max}$ increases by about \$40/m^3 when MVRPLV is 70%, relative to when MVRPLV is 60%.



(a) (b)

Figure 16.11. Sensitivity of maximum mill-delivered log cost to marketable veneer recovery from peelable log volume (MVRPLV)
Notes: (a) MVRPLV is 50%; and (b) MVRPLV is 70%

An analysis has also been performed to assess the sensitivity of $MDLC_{max}$ to ±\$50/m^3 and ±\$100/m^3 changes in D-grade veneer market price, with the same proportionate mark-up for C-grade and B-grade veneer as described for the base case. Figure 16.12 presents that sensitivity, indicating that $MDLC_{max}$ changes by the level of veneer market price change multiplied by NR. For cylindrical logs, NR varies little with SEDUB; hence the illustrated change in $MDLC_{max}$ is consistently about ±\$30/m^3 for ± \$50/m^3 in veneer price for all SEDUB examined, and ±\$60/m^3 for ±\$100/m^3 change in veneer price (i.e. change in $MDLC_{max}$ = NR multiplied by the change in veneer price). As NR reduces when logs have taper, ovality or sweep, the sensitivity of $MDLC_{max}$ to veneer price will decrease for logs that are less cylindrical.

Impact of log taper on maximum mill-delivered log cost

Figure 16.13 illustrates the impact of taper on $MDLC_{max}$. Panel (a) repeats Figure 16.8 to better facilitate comparison with zero taper, cylindrical logs. To achieve gross margins of \$2000/h, the $MDLC_{max}$ for mill-delivered logs with 0.01 m/m taper (panel c) is about \$10/m^3 less than for logs of the same SEDUB with zero taper. At a gross margin of \$2000/h, the $MDLC_{max}$ for logs with 0.08 m/m taper is about \$50/m^3 lower than for logs with zero taper. To put this into context, a 2.6 m, 20 cm SEDUB log with 0.08 m/m taper, has a LEDUB of 40.8 cm. Thus, much waste is generated when these logs are rounded to the SEDUB. The effect of 0.08 m/m taper on $MDLC_{max}$ is similar to MVRPLV falling from 60% to 50%.

Further examination of Figure 16.13 reveals that SEDUB has a greater effect on $MDLC_{max}$ than taper. This is evidenced by the difference in $MDLC_{max}$ between 20 cm and 60 cm SEDUB logs in panel (a) being greater than the difference in $MDLC_{max}$ between logs with zero taper (panel a) and 0.08 m/m taper (panel f), but having the same SEDUB.

Impact of sweep on maximum mill-delivered log cost

Figure 16.14 illustrates the impact of sweep on $MDLC_{max}$. Panel (a) presents the cylindrical log case for comparison. Mill-delivered log costs for any particular gross margin are considerably lower for logs with sweep than for logs with the same level of taper. This is because of the much greater impact of sweep on NR relative to taper, as highlighted by comparing Figures 16.1 and 16.2. For example, $MDLC_{max}$ for 20 cm and 60 cm SEDUB logs with 0.01 m/m sweep at a gross margin of \$2000/h is \$19/m^3 and \$17/m^3 lower than for cylindrical logs, respectively. At 0.04 m/m sweep, positive gross margins cannot be earned with 20 cm SEDUB logs, and $MDLC_{max}$ for a 60 cm SEDUB log while earning a gross margin of \$2000/h is \$62/m^3 lower than for a cylindrical log. At 0.08 m/m sweep, positive gross margins cannot be earned with 30 cm SEDUB logs.

In Figure 16.14, panel (d), the mill-delivered log cost schedule for 20 cm SEDUB logs is noticeably flatter than for larger SEDUB logs. This arises because 20 cm SEDUB mill-delivered logs with 0.02 m/m sweep are rounded to only 14.8 cm for peeling, resulting in considerably shorter predicted total veneering time per cubic metre of veneer (from the TVT regression model) than for larger mill-delivered logs. Since the smallest observed rounded log was 16 cm, this result should be applied with caution.

Figure 16.14 suggests that sweep has a greater effect on $MDLC_{max}$ than SEDUB. The difference in $MDLC_{max}$ between 20 cm and 60 cm SEDUB logs in panel (a) is less than the difference in $MDLC_{max}$ between logs with zero taper (panel a) and 0.08 m/m sweep (panel f), but having the same SEDUB.

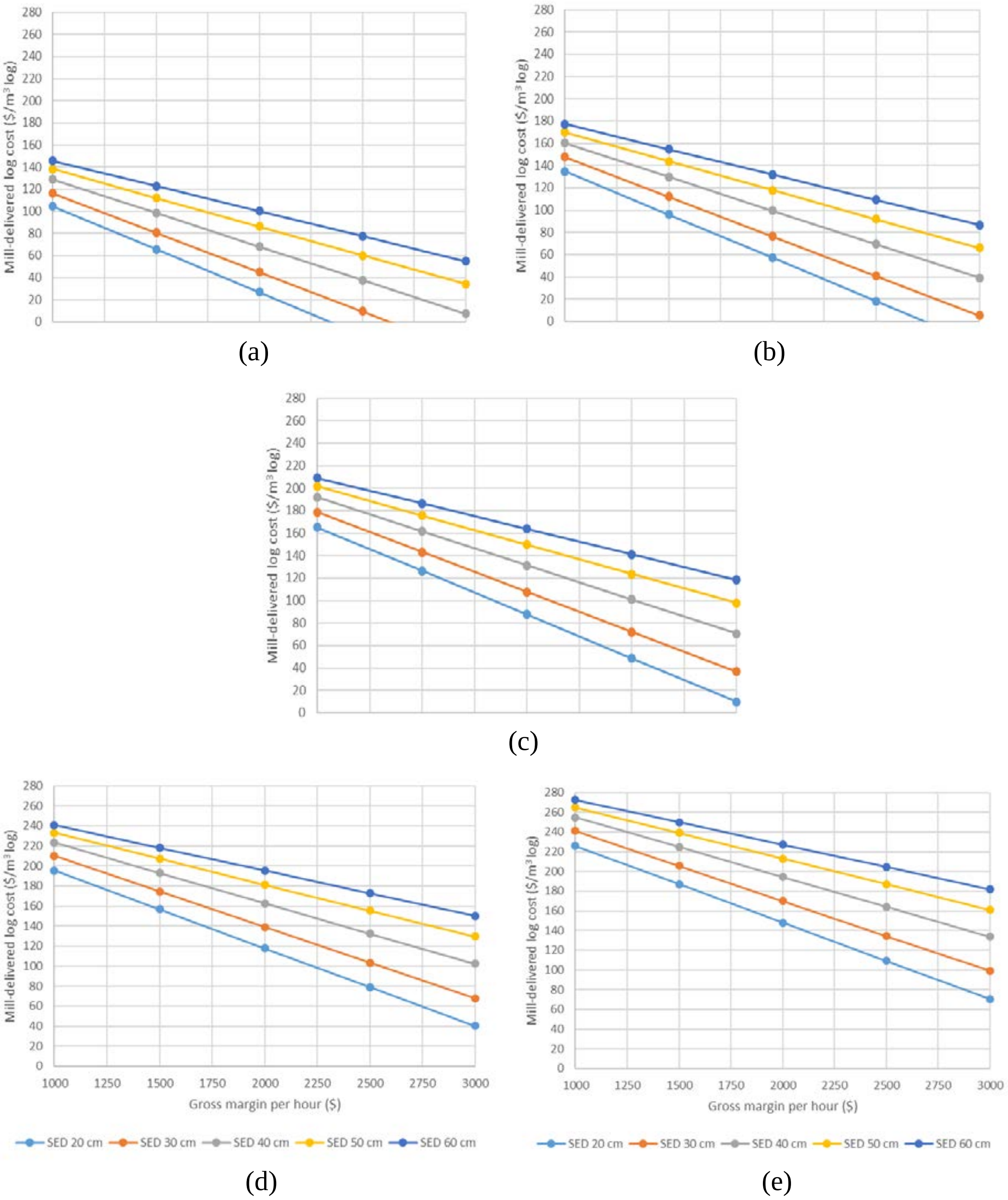


Figure 16.12. Sensitivity of maximum mill-delivered log cost to market price of veneer

Notes: (a) D-grade veneer $300/m^3; (b) D-grade veneer $350/m^3; (c) D-grade veneer $400/m^3 (base case); (d) D-grade veneer $450/m^3; and (e) D-grade veneer $500/m^3.

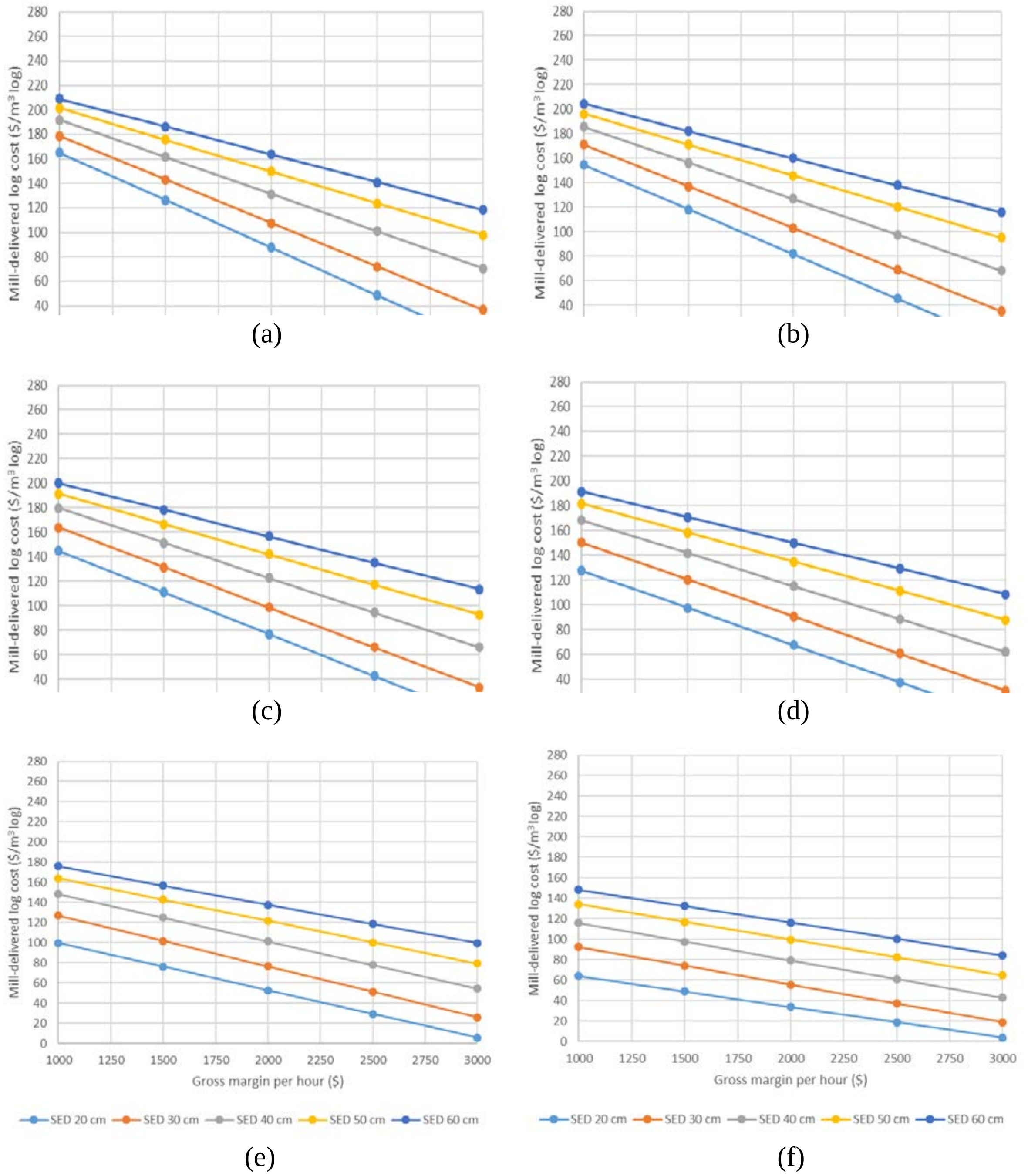


Figure 16.13. Impact of taper on maximum mill-delivered log cost to achieve particular gross margins per hour

Notes: (a) cylindrical log, (b) 0.5 cm/m taper, (c) 1 cm/m taper, (d) 2 cm/m taper, (e) 4 cm/m taper, and (f) 8 cm/m taper.

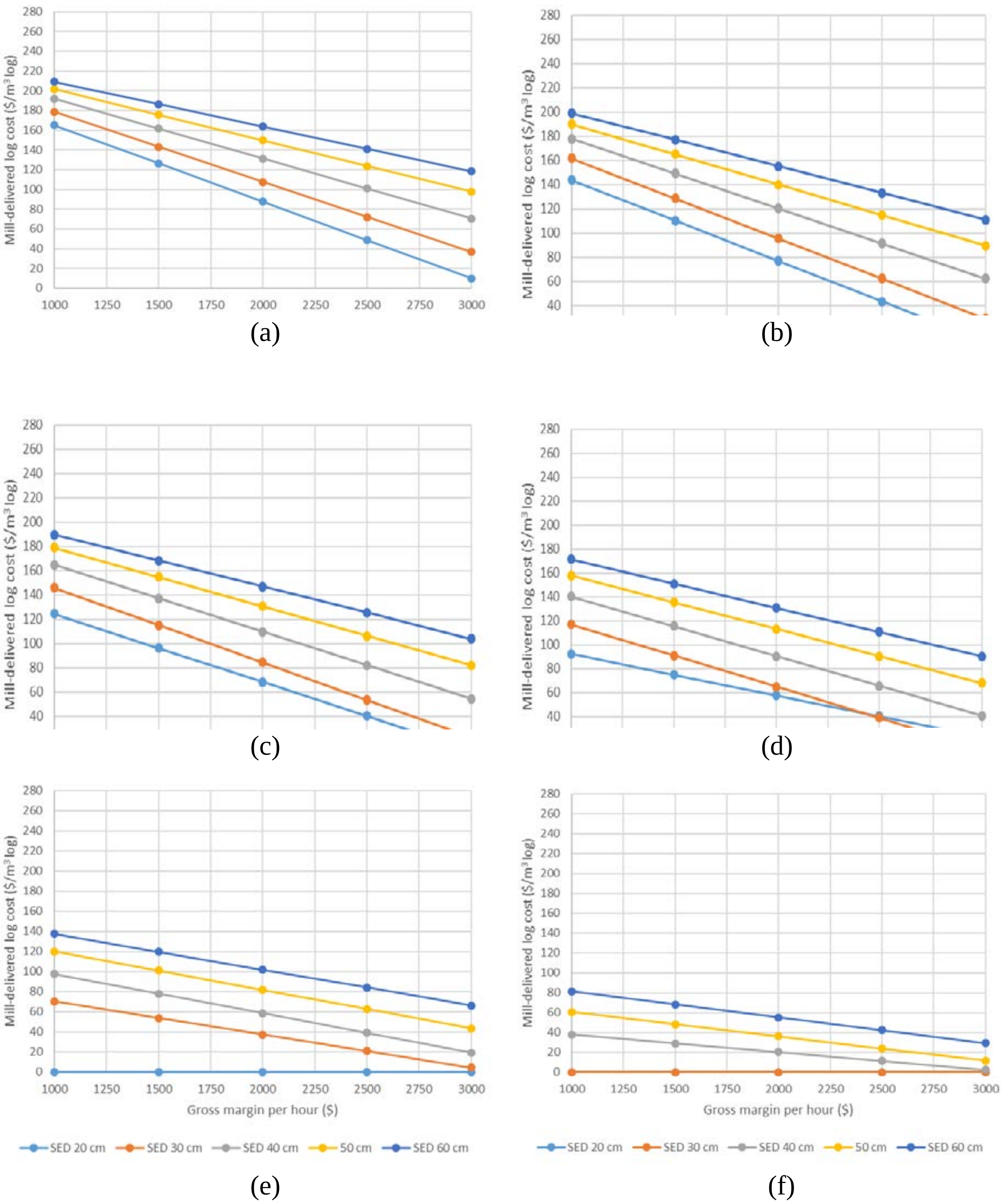


Figure 16.14. Impact of sweep on maximum mill-delivered log cost to achieve particular gross margins per hour

Notes: (a) cylindrical log, (b) 0.5 cm/m sweep, (c) 1 cm/m sweep, (d) 2 cm/m sweep, (e) 4 cm/m sweep, and (f) 8 cm/m sweep.

Impact of ovality on maximum mill-delivered log cost

Figure 16.15 presents the impact of ovality on $MDLC_{max}$. For the levels of ovality examined, the level of impact is small relative to the projected impact of taper and sweep, and this is explained by the relatively high NR from logs with ovality (compare Figures 16.1, 16.2 and 16.3). At 20% ovality (panel e), $MDLC_{max}$ for 20 cm SEDUB logs while maintaining $2000/h gross margin is $14/m^3 lower than for cylindrical logs (panel a). This is similar to the level of impact on $MDLC_{max}$ for 20 cm SEDUB logs with 0.01 m/m sweep or 0.02 m/m taper. The difference in $MDLC_{max}$ between 20% ovality and cylindrical 60 cm SEDUB logs is $35/m^3. This is similar to the level of impact on $MDLC_{max}$ for 60 cm SEDUB logs with 0.02 m/m sweep or 0.04 m/m taper.

Figure 16.15 also reveals that SEDUB has a greater effect on $MDLC_{max}$ than ovality. This is evidenced by the difference in $MDLC_{max}$ between 20 cm and 60 cm SEDUB logs in panel (a) is greater than the difference in $MDLC_{max}$ between logs with zero ovality (panel a) and 20% ovality (panel e), but having the same SEDUB.

Impact of log length on maximum mill-delivered log cost

Shorter log lengths reduce the volume of veneer produced per unit of time, which reduces gross margins per unit of time relative to peeling with longer log lengths. Figure 16.16 illustrates the maximum that can be paid for 1.3 m logs with alternative rates of taper to achieve particular gross margins per hour. The impact of taper on $MDLC_{max}$ of short logs is minimal. Panel (a) in Figure 16.16 represents a 1.3 m log with zero taper. Relative to 2.6 m logs with zero taper, the maximum that can be paid for 1.3 m logs while earning a gross margin of $1000/h is $78/m^3 lower for 20 cm SEDUB logs and $45/m^3 lower for 60 cm SEDUB logs. Panel (a) also reveals that with 1.3 m logs, gross margins of $2000/h are only technically possible with logs at least 40 cm SEDUB. Cylindrical logs of 1.3 m by 40 cm, 50 cm or 60 cm SEDUB, would have to be delivered to the mill for only $10/m^3, $45/m^3 and $75/m^3, respectively, in order to gross $2000/h. This is a similar level of impact on $MDLC_{max}$ as 0.08 m/m sweep with 2.6 m logs.

When rates of taper of logs are less than 0.02 m/m, 2.6 m logs always generate higher gross margins than 1.3 m logs when they have the same MDLC. However, close examination of the gross margins for 1.3 m and 2.6 m logs reveals that, at rates of taper of at least 0.02 m/m, the gross margins per hour of operation from 1.3 m logs sometimes exceed the gross margins from 2.6 m logs when these logs have the same MDLC. That is, the wood waste associated with rounding 2.6 m logs with high rates of taper results in such a large reduction in NR relative to a 1.3 m log, that 1.3 m logs generate higher gross margins per hour. Table 16.3 reports gross margins by log SEDUB and MDLC for rates of taper of 0.02 m/m, 0.04 m/m and 0.08 m/m. Blue-shaded cells indicate negative gross margins per hour from both 2.6 m and 1.3 m logs. Green shaded cells indicate that 2.6 m logs generate positive gross margins that are higher than for 1.3 m logs. Brown shaded cells indicate that 1.3 m logs generate positive gross margins that are higher than for 2.6 m logs. In the cases where 1.3 m logs generate higher returns than 2.6 m logs, the gross margins never exceed $710/h.

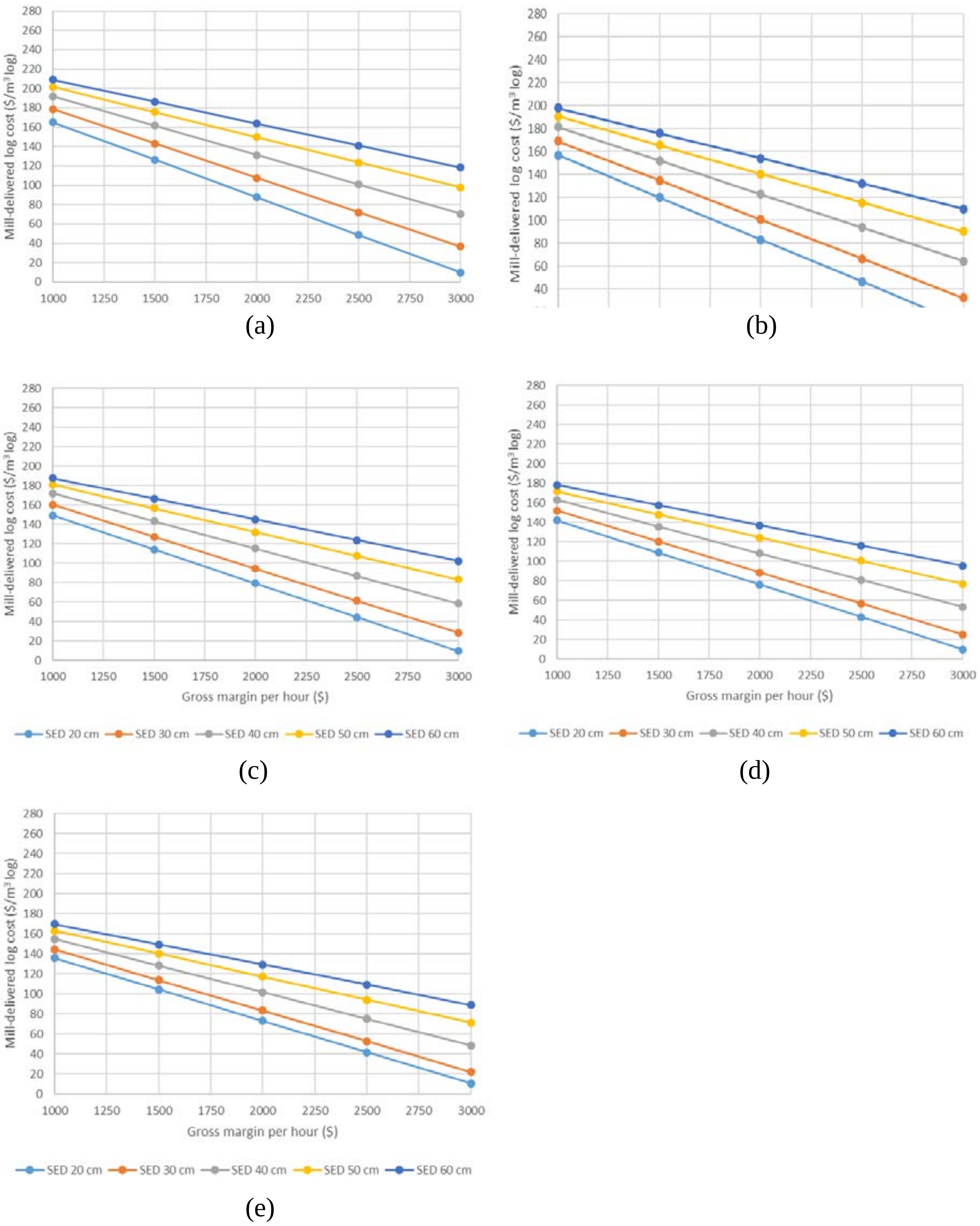


Figure 16.15. Impact of ovality on maximum mill-delivered log cost to achieve particular gross margins per hour

Notes: (a) cylindrical log, (b) 5% ovality, (c) 10% ovality, (d) 15% ovality, (e) 20% ovality.

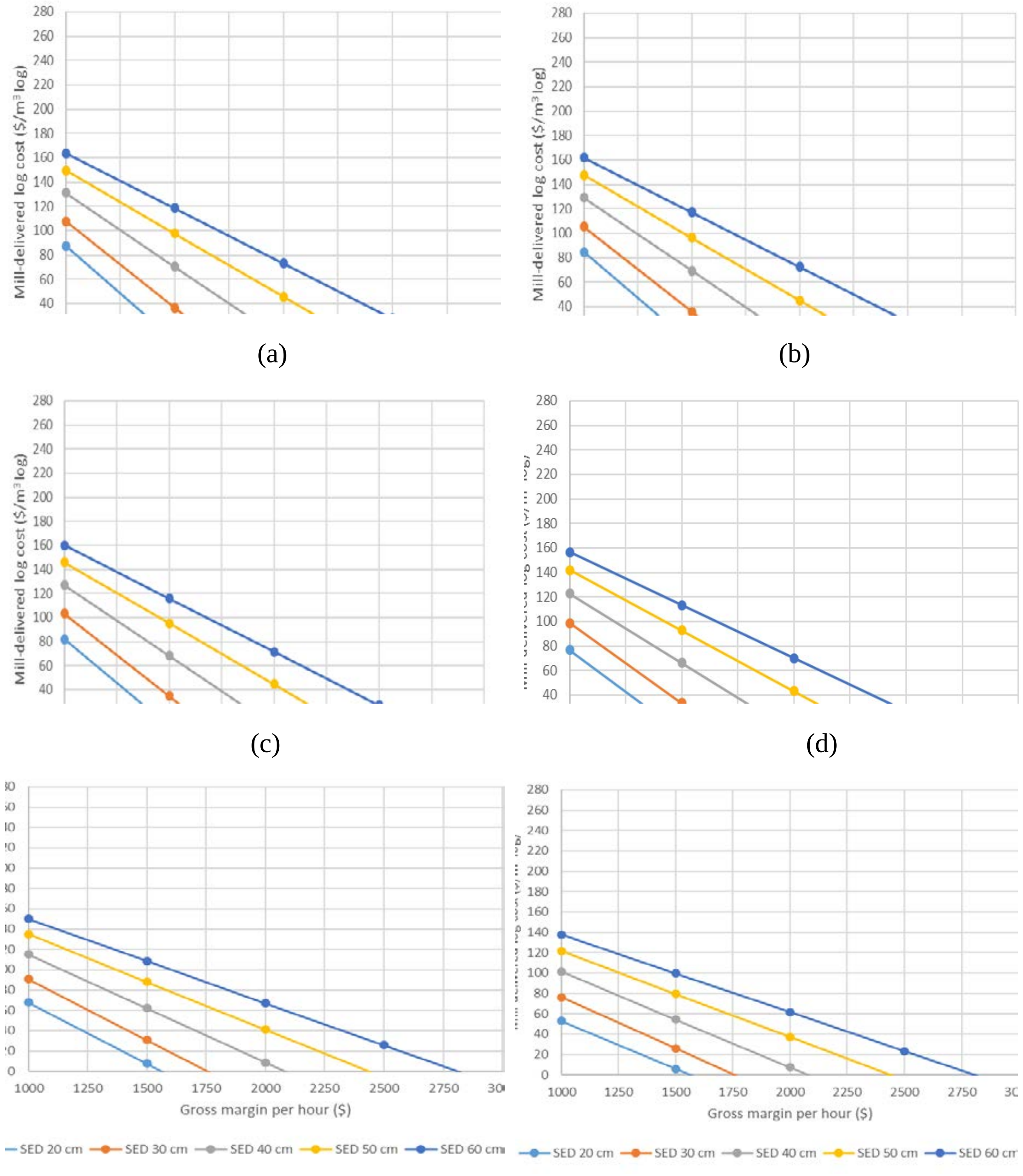


Figure 16.16. Impact of log length (1.3 m logs) and taper on maximum mill-delivered log cost to achieve particular gross margins per hour.

Notes: (a) zero taper, (b) 0.5 cm/m taper, (c) 1 cm/m taper, (d) 2 cm/m taper, (e) 4 cm/m taper, and (f) 8 cm/m taper

Table 16.3. Optimal log length to maximise gross margins per hour of operation

SED (cm)	Taper (cm/m)	Gross margin per hour ($) of operation by mill-delivered log price ($/m^3)					
		80	120	160	200	240	280
20	2	1,793	1,126	459	96	<0	<0
20	4	1,421	568	230	<0	<0	<0
20	8	710	284	<0	<0	<0	<0
30	2	2,177	1,508	840	223	<0	<0
30	4	1,931	1,140	420	86	<0	<0
30	8	1,338	570	174	<0	<0	<0
40	2	2,662	1,910	1,159	407	<0	<0
40	4	2,457	1,603	749	204	<0	<0
40	8	1,979	887	374	<0	<0	<0
50	2	3,171	2,317	1,463	609	7	<0
50	4	2,986	2,039	1,093	305	<0	<0
50	8	2,566	1,409	546	73	<0	<0
60	2	3,690	2,726	1,762	797	39	<0
60	4	3,516	2,466	1,415	399	<0	<0
60	8	3,130	1,887	708	182	<0	<0

Notes: Blue-shaded cells indicate negative gross margins from both 2.6 m and 1.3 m logs. Green shaded cells indicate that 2.6 m logs generate positive gross margins that are higher than for 1.3 m logs. Brown shaded cells indicate that 1.3 m logs generate positive gross margins that are higher than for 2.6 m logs.

Discussion and conclusions

The maximum that can be paid for mill-delivered logs while earning a particular target gross margin ($MDLC_{max}$) is the metric used in this study to estimate the impact of log geometry. $MDLC_{max}$ is positively related to SEDUB, because net recovery of marketable veneer from log volume (NR) increases with SEDUB. $MDLC_{max}$ is negatively related to taper, sweep and ovality, because NR decreases with these log characteristics. $MDLC_{max}$ is positively related to log length, because more veneer can be peeled per unit of time. A comparison of the relative importance of alternative log geometry characteristics on $MDLC_{max}$ is necessarily somewhat subjective. However, given the ranges of these attributes considered in this study, log geometry characteristics can be arranged in decreasing order of impact on $MDLC_{max}$ as follows:

1. length;
2. sweep;
3. SEDUB;
4. taper; and
5. ovality.

The analysis confirmed that spindleless lathe veneer manufacture can generate gross margins of at least $2000/h (100% utilisation rate) with relatively cylindrical 20 cm and 30 cm SEDUB logs at mill-delivered log costs of $80/m^3 to $110/m^3. This does suggest spindleless lathe veneer manufacture could present opportunities for utilisation of small diameter hardwood logs. However, short (1.3 m) logs only generate gross margins of $2000/h when SEDUB is at least 40 cm SEDUB, and mill-delivered log costs are between $10/m^3 (for 40 cm logs) and $75/m^3 (for 60 cm logs). Thus, spindleless lathe veneering with short log lengths is unlikely to be financially viable.

The utility of this report is in the practical application of findings to guide log procurement decisions[19], which is demonstrated with an example. Suppose the business model of a particular veneer manufacturer demands that gross margins of at least $1000/h are earned to cover all non-log costs (e.g. labour and energy) and the desired profit margin. The utilisation rate of the lathe is 50%. In Figures 16.14 to 16.17, a gross margin $2000/h for a utilisation rate of 100%, is interpreted as $1000/h with a 50% utilisation rate. Table 16.4 represents the log market faced by the firm. For simplicity, log costs vary by SEDUB and log length only, where 1.3 m logs are half the log cost per cubic metre of 2.6 m logs of the same SEDUB.

Table 16.4. Hypothetical log market faced by a veneer manufacturer and optimal log purchases

SEDUB	Log cost ($/m^3) [a]	Financially viable log purchases by log geometry															
		1.3 [b]	Cyl [c]	Taper (mm/m)					Sweep (mm/m)					Ovality (%)			
				5	10	20	40	80	5	10	20	40	80	5	10	15	20
20	80																
30	100																
40	120																
50	150																
60	180																

Notes: a. The reported mill-delivered log costs are for 2.6 m logs. Log costs for 1.3 m logs are assumed to be half the indicated 2.6 m log cost.
b. 1.3 m logs. Even cylindrical 1.3 m logs are not financially viable purchases at half the listed 2.6 m log cost per cubic metre.
c. Cylindrical 2.6 m logs, i.e. no taper, sweep or ovality.

In Figures 16.13 to 16.16, the appropriate gross margin per hour is located on the x-axis, and the $MDLC_{max}$ can be read from the y-axis where the selected gross margin intersects the downward sloping maximum log cost schedule. If $MDLC_{max}$ is greater than the log cost in Table 16.4, then logs with that geometry are a financially viable purchase for veneer manufacture. The shaded cells in Table 16.4 indicate financially viable purchases in this scenario, which are relatively straight 2.6 m logs up to 40 cm SEDUB. Short (1.3 m) logs and 60 cm SEDUB logs are never financially viable purchases in this scenario.

Log geometry does substantially affect the financial performance of veneer manufacture. Sensitivity analyses on lathe utilisation rate, MVRPLV and veneer market price also revealed that $MDLC_{max}$ is highly sensitive to these parameters. Context-specific research should be performed to determine appropriate levels for these parameters when evaluating particular spindleless lathe operations. Although veneer thickness is not a log geometry characteristic, it is notable that $MDLC_{max}$ is strongly positively related to veneer thickness, because thicker veneer takes less time to peel per cubic metre. This suggests firms should minimise production of thinner veneer, unless thinner veneer commands substantial market price premiums.

[19] Or to guide species selection and silviculture to grow logs valued by veneer manufacturers.

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Chapter 17: Mill-delivered log cost and gross margins

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Introduction

Research by the Queensland Department of Agriculture and Fisheries (DAF) has demonstrated the potential to use emerging spindleless rotary veneering technologies to process hardwood plantation and native forest logs of sizes and qualities previously considered unmerchantable (i.e. less than 2.6 m length and less than 30 cm diameter) (McGavin *et al.* 2014a, b; McGavin *et al.* 2015a, b, Chapter 4). That research has shown that spindleless rotary veneering can recover much higher proportions of marketable product from small log volume than can be achieved through sawing. Indeed for small native forest *Corymbia citriodora* subsp. *varigata* logs, spindleless rotary veneering produced double the marketable product recovery of sawing, and the resulting veneer contained visual qualities and mechanical properties well-suited to the manufacture of veneer-based engineered wood products (see Chapter 4).

Due to a lack of management, the majority of Queensland's private native forests are in a state of low productivity, with a high stocking of trees that do not meet traditional product specifications for sawlogs, electrical distribution poles and bridge girders (Queensland CRA/RFA Steering Committee 1998a, MBAC Consulting Pty Ltd. 2003a, Bureau of Rural Sciences 2004). A major reason these forests are not being silviculturally treated to increase productivity is the cost of thinning small and large diameter trees that do not meet the traditional market specifications. Spindleless lathe rotary veneering could represent a financially viable manufacturing opportunity that utilises non-traditional hardwood logs, while also facilitating the necessary silvicultural treatment in native forests to increase their productivity and ensure future supplies of traditional sawlogs, poles and girders.

The purpose of this report is to present a case study that estimates mill-delivered log costs and gross margins for spindleless lathe veneer production in southern Queensland. This study forms part of the Queensland Government, Forest and Wood Products Association (FWPA) and industry funded project, entitled—"Increasing the value of forest resources through the development of advanced engineered wood products". The main objective of this project is to investigate the feasibility of using rotary-veneer produced from sub-optimal quality native forest logs in combination with other wood-based feedstocks to manufacture high performance 'next generation' engineered wood products, suitable for structural and appearance applications.

Research objective

The objective of the study was to estimate the cost of delivering logs to a spindleless rotary veneering facility and to estimate gross margins (per cubic metre of log input) from the sale of veneer. Gross margins account for the impact log small-end diameter under bark (SEDUB) has on marketable veneer recovery. Larger SEDUB logs have shorter veneer processing times (i.e. lower processing costs) per cubic metre of veneer produced (see Chapter 16).

There is substantial interest in the potential for spindleless rotary veneering to provide a market for small diameter trees (referred to as small peeler logs in this report), and thus help facilitate silvicultural treatments to increase long-term forest productivity. This report has a strong focus on evaluating the technical feasibility and financial viability of producing veneer from small peeler logs.

Research method

A mill-delivered log costs and gross margins spreadsheet model was developed. The model has been populated with default parameter estimates that are broadly representative of the commercially important subtropical native forest hardwood resource of eastern Australia. These were collected from a literature review and key informant interviews with experts within the industry and DAF. The analysis has been performed in seven steps.

1. Define the case study area, veneer processing scale scenarios, and log type scenarios
2. Estimate the distribution of the commercial and harvestable native forest resource
3. Estimate competition for the native forest resource and annual harvestable area available to the mill
4. Predict annual harvestable volume available to the mill
5. Determine stumpage, harvest and haul costs
6. Determine the volume and value of marketable veneer produced by log type
7. Calculate the mean mill-delivered log cost, marketable veneer revenue and gross margin by resource distribution, log type and veneer processing scale scenarios

The spreadsheet model has been used to evaluate 96 veneer processing scenarios, consisting of:

- four veneer processing scales;
- six log type scenarios; and
- four resource distribution scenarios.

The research steps and scenarios are now described.

Case Study Area, Veneer Processing Scale Scenarios and Log Type Scenarios

The default data in the model was designed to be broadly representative for the case study area outlined in Figure 17.1. This area was defined by Lewis *et al.* (2010) as approximating the spatial extent of the commercially important subtropical native hardwood resource in eastern Australia, and is described in greater detail below.

The following four veneer processing scales in cubic metres of log volume processed per annum have been evaluated in this case study:

1. 7500 m^3/y;
2. 10,000 m^3/y;
3. 15,000 m^3/y; and
4. 30,000 m^3/y.

Empirical evidence from an existing spindleless rotary veneering operation that is processing hardwood logs in eastern Australia suggests 15,000 m^3/y of log throughput is achievable with one full-time spindleless lathe. The 30,000 m^3/y scale is assumed to be facilitated by operating two spindleless lathes full-time. The 7500 m^3/y and 10,000 m^3/y scales are part-time veneer production operations.

The case study considers the four log types described in Table 17.1; compulsory sawlogs, optional sawlogs, small peeler logs and top logs. Industry does recognise criteria for sweep, ovality, taper, internal defect and external defect for these log types. However, these have not been accounted for in this analysis.

Figure 17.1. The study area for which default model data has been selected to be broadly representative

Table 17.1. Specifications of allowable log types for veneer manufacture in the case study

Criterion	Specifications by log type		
	Compulsory sawlog	Optional sawlog	Small peeler and top logs
Minimum length (m)	2.6	2.6	2.6
Minimum SEDUB (cm)	40	30	16
Maximum SEDUB (cm)	60	60	28

Small peeler logs are typically from small diameter trees. Top logs are small diameter logs that would be left among the residues following a traditional native forest harvest. These logs could be in the bole of a felled tree above a sawlog or pole, but below crown break, or could be within the crown. For the purposes of this study, top logs have the same specifications as small peelers. Because of their high value, it is assumed that logs suitable for electricity distribution poles and bridge girders will not be peeled for veneer. Much of the log volume suitable for fencing is unlikely to meet peeler log requirements for level of defect, log length or minimum small-end diameter under bark, so fencing logs have not been considered in this study.

Mill-delivered log costs and gross margins for a spindleless rotary veneering facility are estimated for six log type scenarios that restrict the utilisation of particular log types for veneer production:

1. Small peeler logs only;
2. Small peeler logs and top logs;
3. Small peeler logs, top logs and optional sawlogs;
4. Small peeler logs, top logs, optional sawlogs and compulsory sawlogs;
5. Optional sawlogs and compulsory sawlogs; and
6. Optimal selection of logs to maximise gross margins.

Log type scenarios 1 to 5 assume the total volume of allowed log types (dictated by the log type scenario) are always harvested when any hectare is harvested in the model. In contrast, scenario 6 permits the picking and choosing of log types to purchase from any hectare in order to maximise the gross margin generated by veneer manufacture. For example, it might be optimal to purchase all log types to up to 50 km from the mill, small peeler and top logs up to 130 km from the mill, and optional sawlogs up to 180 km from the mill.

Case study area

The case study area illustrated in Figure 17.1 is 24.4 M ha, of which approximately 11.4 M ha is forest (canopy cover ≥ 30% and stand height ≥ 2 m) distributed across Crown (7.7 M ha) and private (3.7 M ha) landholdings (Venn and Francis 2018). Much of the Crown estate is national park and other tenures not managed for timber. In the northern New South Wales part of the study area, there are 1.0 M ha of commercial and harvestable (net of all regulatory exclusions) native forest on private land and 0.4 M ha on state-owned land (Venn and Francis 2018).

In the South East Queensland Forest Agreement (SEQFA) area (see Appendix 17.1), the Queensland government is committed to log supply agreements from Crown forests to the end of 2024 (McAlpine et al. 2005). Crown supply from these forests post-2024 is uncertain. Nevertheless, there are hundreds of thousands of hectares of State Forests and Timber Reserves on Crown land within the case study area north and west of the SEQFA area, where harvesting is permitted post-2024. The area of commercially productive forest on these Crown land tenures was not available at the time of publication.

There are 1.9 M ha of commercial (according to industry) and harvestable (after accounting for regulatory restrictions under the accepted development vegetation clearing code (DNRM 2014)) private native forest in the Queensland part of the case study area (Venn and Francis 2018). Although landholder management intent will determine the area of private forest actually managed for timber production, it is notable that private lands have supplied between 50% and 70% of the log resource to the Queensland hardwood industry since the 1950s (Carron 1985, DPI Forestry 1998, State of Queensland 2016).

For case study analysis purposes, it has been assumed that logs would be delivered to a spindleless rotary veneer producer operating out of the Gympie-Maryborough region in southern Queensland. The majority of the study area (Grafton to Rockhampton) is within 400 km of this location. Given existing Queensland government policy regarding hardwood log supply from Crown land, the majority of the commercial hardwood resource proximate to a mill located in this region would be privately owned.

Distribution of the commercial and harvestable native forest resource

The spreadsheet model developed for the case study analysis was designed to accept an estimate of the total area of commercial and harvestable forest within a specified maximum haul distance of the mill, and a mean harvest return interval. The model then used these estimates to populate the following four resource distribution scenarios that provide approximations of how the forest is distributed spatially from the mill to the stipulated maximum haul distance:

A. even distribution of the harvestable resource as a proportion of the landscape from the mill location to the maximum haul distance;
B. no harvestable resource within 50 km of the mill, 50% of the distribution of the resource under Scenario A between 51 km to 100 km, and then evenly distributed thereafter to the maximum haul distance;
C. two times the resource distribution of Scenario A between 0 km and 100 km, and then evenly distributed thereafter to the maximum haul distance; and
D. three times the resource distribution of Scenario A between 0 km and 100 km, and then evenly distributed thereafter to the maximum haul distance.

Scenario A has an even distribution of forest throughout the landscape. Scenario B could reflect resource conditions for an operation in a large city, such as Brisbane. Scenarios C and D are designed to reflect resource conditions for a mill located within an area with high levels of commercial and harvestable forest. Model settings for the resource distributions examined in the case study are now described.

Maximum haul distance, harvest return interval and total harvestable area for the case study

Discussions with three hardwood sawmillers, Private Forestry Service Queensland and DAF employees revealed a maximum haul distance of 400 km is relatively common in the hardwood timber industry in the subtropics of eastern Australia, and this has been adopted as the maximum haul in the case study. A 400 km radius from the Gympie-Maryborough region encompasses all but the northwest of the Queensland part of the study area and extends as far south as Grafton in northern New South Wales.

Native forests in the study area are generally selectively harvested on a 20 to 40 year cycle (Venn and Francis 2018). In the case study analysis, a default average return interval of 30-years has been assumed.

The total area of commercial and harvestable native forest in the study area is about 3.6 M ha, with 2.9 M ha on private land[20]. Most Australian literature has indicated about 50% of private landowners with timber on their properties are interested in timber production, while sawmillers and industry practitioners have suggested that up to about 90% of landholders in Queensland are interested in earning an income from their timber (MBAC Consulting Pty Ltd 2003a). In their estimation of potential future log supply from private native forests in SEQ, Bureau of Rural Sciences (2004) modelled private landholder timber harvesting intentions of

[20] In northern New South Wales, there are 1.0 M ha of private and 0.4 M ha of Crown commercial and harvestable native forest. In the Queensland part of the study area there are 1.9 M ha of commercial and harvestable native forest on private land. Given current policy to cease harvesting in SEQ Crown native forests in 2024, the default data only considers commercial and harvestable Crown native forest in the WHR within the study area. The exact area is uncertain at the time of publication, but has been conservatively estimated at 0.3 M ha.

50%, 70% and 90%. The default total commercial and harvestable native forest area assumed to be managed for timber in this analysis has been set at 1.8 M ha within 400 km of a mill located around Gympie-Maryborough. This is equivalent to 50% of the commercial and harvestable private and Crown native forest, and 16% of the total forest area. The sensitivity of the technical feasibility of supplying sufficient log volume to alternative levels of available forest area and volume per hectare is explored in Appendix 17.2.

Forest resource distribution in the case study

The implication of the maximum haul distance, harvest return interval and total harvestable area by resource distribution scenario is reported in Table 17.2. The total area (forested or not) within a particular haul distance from a spindleless rotary veneering facility located in the Gympie-Maryborough region can be approximated as the area of a semi-circle. A semi-circle with a radius of 400 km has an area of 25.1 M ha. The resource distribution scenario headings A to D in Table 17.2 describe how the resource is distributed on the landscape given the parameters previously described. For example, resource distribution scenario A has an even distribution of the forest resource at 7.1% of the landscape. In contrast, scenario C has two-times the resource of scenario A out to 100 km from the mill (14.2% of the landscape), and then even distribution of the resource thereafter (at 6.6% of the landscape). The 'Total' columns are the total commercial and harvestable native forest area within the haul zone by resource distribution scenario. The 'Annual' columns report annual harvestable area available to the veneer processor, which is described in the following section.

Table 17.2. Commercial and harvestable native forest area by resource distribution scenario and haul zone

Haul zone from veneer processing facility (km)	Total and annual commercial and harvestable native forest area available to the veneer processor by resource distribution scenario and distance from the facility (ha)							
	A: 7.1% of landscape		**B**: 0% < 50 km, 3.55% for 51 to 100 km, 7.3% thereafter		**C**: 14.2% < 100 km, 6.6% thereafter		**D**: 21.3% < 100 km, 6.1% thereafter	
	Total (THA_i)	Annual (AH_i)	Total (THA_i)	Annual (AH_i)	Total (THA_i)	Annual (AH_i)	Total (THA_i)	Annual (AH_i)
0 to 50	27,778	546	0	0	55,556	1093	83,333	1639
51 to 100	83,333	735	41,667	368	166,667	1471	250,000	2206
101 to 200	333,333	917	347,222	956	311,111	856	288,889	795
201 to 300	555,556	712	578,704	742	518,519	665	481,482	617
301 to 400	777,778	570	810,185	594	725,926	532	674,074	494
Total	1,777,778	3482	1,777,778	2660	1,777,778	4617	1,777,778	5752

Competition for the native forest resource and annual harvestable area available to the veneer processor

The method for estimation of competition factors and annual harvestable area available to the mill are now described with reference to the default data. There are 40 hardwood sawmills competing for logs within 300 km of the Gympie-Maryborough region; however, the largest 25 sawmills process 95% of the harvested log volume (Venn and Francis 2018). As indicated in Table 17.3, there are 14.1 M ha within a 300 km semi-circle. Assuming 25 mills are evenly distributed throughout this area and have equal access to the forest resource within this area, this equates to one mill per 0.57 M ha. On this basis, the expected number of hardwood mills by distance from the mill is reported in Table 17.3. The competition factor reported in Table 17.3 for haul zone *i*, CFi, is calculated as follows

$$CF_i = \frac{100\%}{1+NM_i} \qquad \text{[eq. 17.1]}$$

where NM_i is the expected number of hardwood mills in haul zone *i*,; and
the numeral one in the denominator represents the addition of the veneer processing facility.
The competition factor is interpreted as the percent of the forest resource within that haul zone potentially available to the veneer production facility.

Table 17.3. Number of competing hardwood mills and competition factors by haul zone from the veneer production facility

Distance from mill (km)	Total area within distance from mill (M ha)[a]	Expected number of hardwood mills (NM_i) [b,c]	Haul Zone (km)	Competition factor (CF_i, %)
50	0.39	0.7	0 to 50	59
100	1.57	2.8	51 to 100	26
200	6.28	11.1	101 to 200	8
300	14.14	25	201 to 300	4
400	25.13	44	301 to 400	2

Notes: a. Total area within a particular distance from the mill has been calculated as the area of a semi-circle, which approximates the spatial distribution of potential log supply from a mill located in the Gympie-Maryborough region.
b. The expected number of hardwood mills is 'Total area within distance from mill' divided by 0.565 (=14.14 M ha / 25 mills within 300 km).
c. The extrapolation to a total of 44 mills within 400 km is consistent with there being 20 hardwood mills in northern New South Wales (Venn and Francis 2018).

In Table 17.2, the annual harvestable areas available to the veneer processor by haul zone, AH_i, have been calculated as follows

$$AH_i = \frac{THA_i}{HRI} * CF_i \qquad \text{[eq. 17.2]}$$

where THA_i is total harvestable area by haul zone from Table 17.2;
HRI is the harvest return interval, with 30 years being applied in the case study; and
CF_i is as previously defined, and enters the equation as a percentage.

With HRI set at 30 years, only one-thirtieth of the commercial and harvestable forest area in each haul zone is available for harvest in any particular year.

Annual harvestable volume available to the mill

Average harvestable volumes per hectare have been estimated for four log types: compulsory sawlog, optional sawlog, small rounds and top logs. These volumes per hectare are then multiplied by the annual harvestable area within each haul zone (AH_i) for each resource distribution scenario (as reported in Table 17.2) to determine the annual harvestable volume available to the mill. As indicated in the previous section, AH_i assumes all mills are evenly distributed throughout this area and have equal access to the forest resource.

As indicated in Table 17.2, the annual harvestable area available to the mill under all resource distribution scenarios is dominated by forests within 300 km of the mill and, therefore, forests in Queensland. There is uncertainty about future log supply from Crown native forests in Queensland, and the commercial and harvestable area proximate to the Gympie-Maryborough region is dominated by private native forest. Harvestable volume per hectare estimates adopted in this case study are based on MBAC Consulting Pty Ltd (2003a, 2003b) inventories of private native forests in South East Queensland (SEQ) and the Western Hardwoods Region (WHR) of Queensland. These inventories are the best available for private native forest in the study area. Appendix 17.2 reports a comparison of State Forest and private native forest log volumes per hectare, and Appendix 17.1 illustrates the spatial relationship between the study area, SEQ and WHR.

Native forests in SEQ and WHR generally have low yield of merchantable timber of between about 2 m^3/ha to 8 m^3/ha per hectare in dry forests, and 8 m^3/ha to 20 m^3/ha in moist to wet forest types (Queensland CRA/RFA Steering Committee 1997). Table 17.4 reports standing harvestable volume by log type in SEQ and WHR. The log specifications for small round logs[21] in the MBAC Consulting Pty Ltd (2003a, b) inventories were similar to that of small peeler logs adopted in this study. Standing volumes of top logs are from Chapter 2. The case study adopted the mean standing volume estimates reported in the fourth column, which suggests small peeler logs account for about 40% of the potentially harvestable resource in private native forests in the study area that is suitable for veneering. Justification for the standing volumes per hectare of small peeler and top logs is provided in Appendix 17.3.

Table 17.4. Harvestable log volume per hectare for spindleless rotary veneer production in the case study area

Log type	SEQ private native forest inventory (m^3/ha)[a]	WHR private native forest inventory (m^3/ha)[b]	Mean of SEQ and WHR private native forest inventory (m^3/ha)
Compulsory sawlog	1.9	0.4	1.1
Optional sawlog	4.5	2.5	3.5
Small rounds (small peeler logs)	4.8	1.9	3.4
Top logs[c]	0.6	0.6	0.6
Total	11.4	5.7	8.6

Source: a. MBAC Consulting Pty Ltd (2003a).
b. MBAC Consulting Pty Ltd (2003b).
c. Refer to Chapter 2

The annual harvestable area by resource distribution scenario (Table 17.2) was multiplied by the mean of SEQ and WHR volume per hectare by log type (Table 17.4) to estimate maximum annual harvestable volume by resource distribution scenario reported in Table 17.5. The total row is applicable for log type scenarios 4 and 6, where all log types are available for processing. Maximum annual harvestable volume by resource distribution scenario for log type scenarios 1, 2, 3 and 5 can be determined by summing the appropriate rows in Table 17.5. For example, the volume available under log type scenario 1 is reported in the small peeler log row.

[21] Minimum length 2.5 m, minimum small-end diameter under bark 15 cm, and maximum small-end diameter under bark 27.5 cm.

Table 17.5. Harvestable volume by resource distribution scenario for the case study area

Log type	Maximum annual harvestable volume by resource distribution scenario (m^3/y)			
	A: 7.1% of landscape	**B**: 0% < 50 km, 3.55% for 51 to 100 km, 7.3% thereafter	**C**: 14.2% < 100 km, 6.6% thereafter	**D**: 21.3% < 100 km, 6.1% thereafter
Compulsory sawlog	3830	2925	5079	6327
Optional sawlog	12,187	9308	16,159	20,132
Small peeler log	11,839	9042	15,698	19,557
Top log	2089	1596	2770	3451
Total	29,945	22,872	39,706	49,468

Stumpage, harvest and haul costs

Tables 17.6 and 17.7 report the stumpage, cut, snig, load and haul costs provided by industry and adopted in the case study. The parameters in Table 17.6 are used to estimate haul costs as follows. A 150 km log haul would cost \$39.29/m^3, plus \$0.1731/m^3/km, multiplied by 50 km.

Table 17.6. Stumpage, cut, snig and load costs

Log type	Stumpage (\$/m^3) [a]	Cut, snig and load (\$/m^3) [b]
Compulsory sawlog	110	43.5
Optional sawlog	55	43.5
Small peeler log	40	66.0
Top log	40	47.9

Notes: a. Stumpage prices for compulsory and optional sawlogs are the mean of a range provided by Private Forestry Service Queensland (PFSQ) in 2018. Presently, there is a limited market for small peeler logs and top logs in the study area. The stumpage price adopted of \$40/m^3 is informed by anecdotal evidence from PFSQ that fencing logs have stumpage prices from \$25/m^3 to \$45/m^3, and salvage logs from \$10/m^3 to \$30/m^3.

b. Cut, snig and load costs for compulsory and optional sawlogs are industry rates provided by industry in 2018. At a research trial within the study area at Mundubbera, the cut and merchandise time cost per cubic metre of small peeler logs was double that of optional sawlogs. For analysis purposes, the cut rate provided by industry was doubled for small peeler logs before being added to the snig and load cost. Top logs are merchandised from trees that have been felled because their bole met the specifications for a higher quality log (e.g. pole or sawlog). Nevertheless, top logs will be merchandised near and within the crown of felled trees, which is likely to present some inconvenience for timely merchandising and snigging. For analysis purposes, the cut, snig and load rate for top logs has been inflated by 10% over the cost of sawlogs.

Table 17.7. Haul costs

Haul distance (km)	Fixed cost (\$/m^3)	Variable cost (\$/m^3/km)
0 to 30	10.33	0.3856
31 to 50	21.90	0.3153
51 to 80	28.21	0.2355
81 to 100	35.28	0.2007
101+	39.29	0.1731

Volume and value of marketable veneer produced by log type

Before peeling veneer, delivered hardwood logs need to be pre-conditioned (heated) prior to being docked to length, and prepared for peeling in a rounding-debarking lathe (to provide a rounded billet with bark, taper, sweep and ovality removed). Chapter 16 determined how log geometry (taper, sweep and ovality) affected marketable veneer volume recovery per hour from log volume. For case study analysis purposes, mill-delivered logs are assumed to be cylindrical such that minimal wood volume is lost in the rounding-debarking lathe[22].

Table 17.8 summarises log volumes processed and marketable veneer volumes produced per hour by small-end diameter under bark (SEDUB), assuming cylindrical logs and 100% utilisation of the lathe (see Chapter 16)[23]. The case study assumes a maximum SEDUB for processing by the spindleless lathe of 60 cm. The last three columns of the table indicate the assumed proportion of logs by SEDUB for each log type. Limited empirical data was available to inform these proportions. It has been assumed that the volume of small peelers and top logs is evenly distributed between logs ranging from 16 cm to 28 cm SEDUB. Anecdotal evidence suggests the availability of compulsory sawlogs decreases with increasing SEDUB. The proportionate availability of compulsory sawlogs is assumed to decrease at a constant rate from 40 cm to 60 cm SEDUB. Anecdotal evidence suggests most optional sawlogs are between 30 cm and 38 cm SEDUB. The proportionate availability of optional sawlogs greater than 38 cm SEDUB has been assumed to decrease at a constant rate to 60 cm SEDUB.

The final four rows of Table 17.8 summarise important processing characteristics of the log types. Given the assumed proportionate distribution of logs by SEDUB, these rows report the: (a) mean SEDUB; (b) mean log volume processed per hour; (c) mean veneer volume produced per hour; and (d) mean value of veneer produced per hour.

The case study adopts the veneer grade recoveries used in Chapter 16, which were based on empirical studies by McGavin et al. (2014), and Chapter 4. Total marketable veneer recovered from log volume in these studies was high, at up to 58%, but the grade recoveries were dominated by D-grade veneers (the lowest marketable grade) when graded to Australian and New Zealand Standard AS/NZS 2269.0:2012 (Standards Australia 2012). Of the recovered marketable veneer volume, this case study assumes D-grade comprises 80%, C-grade 15%, B-grade 5% and A-grade 0%.

[22] As discussed in Chapter 16, mill-delivered log costs per cubic metre of veneer produced will be marginally higher for 2.6 m logs with a small level (≤ 2 cm) of taper, sweep or ovality. At levels greater than 2 cm, the impact on mill-delivered log costs per cubic metre of veneer increases substantially.

[23] Reporting 100% utilisation of the lathe facilitates simple conversion to a selected industry utilisation rate, which is likely to vary between about 50% and 75%

Table 17.8. Veneer production per hour from a spindleless lathe at a 100% utilisation rate, and distribution of log sizes by log type

SEDUB (cm)	Log volume processed (m^3/h)[a]	Marketable veneer volume produced (m^3/h)[a]	Marketable veneer value ($/h)[b]	Assumed distribution of log sizes by log type (%)		
				Small peelers and top logs	Optional sawlogs	Compulsory sawlogs
16	14.3	7.9	3375	14.3		
18	13.3	7.5	3176	14.3		
20	12.9	7.3	3127	14.3		
22	12.9	7.4	3150	14.3		
24	13.0	7.5	3212	14.3		
26	13.3	7.7	3299	14.3		
28	13.7	8.0	3401	14.3		
30	14.1	8.2	3514		12.0	
32	14.5	8.5	3635		12.0	
34	15.0	8.8	3761		12.0	
36	15.5	9.1	3892		12.0	
38	16.0	9.5	4027		12.0	
40	16.5	9.8	4165		6.8	17.2
42	17.0	10.1	4304		6.1	15.6
44	17.6	10.4	4446		5.5	13.9
46	18.1	10.8	4589		4.9	12.3
48	18.7	11.1	4733		4.3	10.7
50	19.2	11.5	4879		3.6	9.1
52	19.8	11.8	5025		3.0	7.5
54	20.4	12.1	5172		2.4	5.9
56	21.0	12.5	5320		1.8	4.2
58	21.5	12.8	5469		1.1	2.6
60	22.1	13.2	5618		0.5	1.0
Total				100	100	100
Mean SEDUB (cm)				22.00	39.02	46.44
Mean log volume processed per hour (m^3/h)				13.33	16.32	18.27
Mean veneer volume produced per hour (m^3/h)				7.63	9.65	10.86
Mean value of veneer produced per hour ($/h)				3249	4113	4625

Notes: a. 3.2 mm veneer production rates from Chapter 16.
b. This is marketable veneer volume produced per hour multiplied by the weighted mean veneer value of $426/$m^3$.

Commercial dry-graded veneer values are challenging to determine, as veneer producers are typically manufacturing engineered wood products with the veneer, and the costs of production and final market prices for these products vary substantially. Anecdotal information indicates that 3.2 mm and 2.15 mm D-grade veneer in Australia has a wholesale value of about $400/$m^3$. Engineered Wood Products Association of Australasia (2014) asserted that C-grade veneer is about 1.2 times D-grade, B-grade is 1.7 times D-grade, and A-grade is 3 times D-grade. This study has adopted these relative values for C, B and A-grade veneers, which equate to $480/m^3, $680/m^3 and $1200/m^3, respectively. The weighted average marketable veneer value adopted in the case study is $426/m^3 of veneer.

Calculate the mean mill-delivered log cost, marketable veneer revenue and gross margin by resource distribution, log type and veneer processing scale scenarios

The scenarios evaluated consider forest resource and haul costs in 10 km increments from the mill. The spreadsheet model simulates the harvest of logs beginning with the closest forests to the mill and moving progressively further from the mill until the desired annual log volume is reached. The simulation is constrained to allow only 1/HRI of the total commercial and harvestable forest within a haul zone to be harvested in any one year. The mean mill-delivered log cost for each combination of the processing scale, log type and resource distribution scenarios, *MMDLC*, is estimated as follows.

$$MMDLC = \frac{\left(\sum_{i=1}^{N} AH_i * \left(\sum_{l=1}^{4} LV_l * (S_l + CSL_l + HFC_i + (HVC_i * Dist_i * WRF))\right)\right)}{\sum_{i=1}^{N}\sum_{l=1}^{4} AH_i * LV_l} \qquad \text{[eq. 17.3]}$$

where AH_i is annual harvestable area by haul zone i out to haul zone N, which will supply sufficient volume to the mill for the selected processing scale (ha, case study values in Table 17.2);

LV_l is log volume of log type l (m^3/ha, case study values in Table 17.4);

S_l is stumpage price of log type l ($/m^3, case study values in Table 17.6);

CSL_l is cut snig and load cost for log type l ($/m^3, case study values in Table 17.6);

HFC_i is haul fixed cost for haul zone i ($/m3, default case study in Table 17.7);

HVC_i is haul variable cost for haul zone i ($/m3/km, case study values in Table 17.7);

$Dist_i$ is the haul distance from the start of haul zone i (see Table 17.7); and

WRF is a user defined ‘windy road factor’, which accounts for roads not being in straight lines from the forest to the mill (% increase in haul distance relative to a straight-line haul, default is 30%).

For all resource distribution scenarios, the marketable veneer volume (MVV) produced by a spindleless rotary lathe is a function of the processing scale and the log types peeled into veneer.

$$MVV = \sum_{i=1}^{N}\sum_{l=1}^{4} LV_l * RMV_l * AH_i \qquad \text{[eq. 17.4]}$$

where RMV_l is the recovery of marketable veneer from log volume for log type l (case study levels are derived from Table 17.8: the mean veneer volume produced per hour by log type, divided by the mean log volume processed per hour by log type); and

all other variables are as previously defined.

Marketable veneer revenue (MVR) earned from each combination of processing scale and log type scenarios is estimated as follows:

$$MVR = MVV * VP \qquad \text{[eq. 17.5]}$$

where *VP* is the mean veneer price ($/m^3 of veneer, case study value is $426/m^3); and all other terms are as previously defined.

For log type scenarios 1 to 5, the gross margin from sale of veneer per cubic metre of log processed (GM) for each combination of the processing scale, log type and resource distribution scenarios, is defined as the value of marketable veneer produced per cubic metre of log, less the log cost.

$$GM = \frac{MVR}{\left(\sum_{i=1}^{N}\sum_{l=1}^{4} AH_i * LV_l\right)} - MMDLC \qquad \text{[eq. 17.6]}$$

where all terms are as previously defined.

GM accounts for small increases in RMV_l as log diameter increases, but not for the shorter processing time (*i.e*. lower variable veneer processing costs) per cubic metre of veneer as log diameter increases (see Chapter 16). The variable labour and energy costs associated with veneer production are considerable, so the higher mill-delivered log cost of larger diameter logs will be at least partially offset by reduced variable costs of veneer production with larger logs. Fixed and variable costs of veneer production will be examined in a forthcoming report. In this case study, the potential efficiencies of using larger diameter logs are captured by maximising GM per hour of veneer processing in log type scenario 6, where it is assumed the log procurement officer can choose which logs will be purchased for processing into veneer from any given harvest. Equivalently, log type scenario 6 can be thought of as all logs at a harvest being purchased, but logs are sorted at the mill and sub-optimal logs for veneering are utilised (and costed to) another part of the business, such as a sawmill.

For each combination of the processing scale and resource distribution scenarios, the optimal purchase of logs in log type scenario 6 is that which maximises the following

$$Maximise \quad GM \Big/ \frac{LV_l}{LVPH_l} \qquad \text{[eq. 17.7]}$$

Where GM is Equation 17.6;

$LVPH_l$ is log volume processed per hour by log type *l* (m^3/h, case study values in Table 17.8); and
LV_l is as previously defined.

The spreadsheet model solves Equation 17.7 with a linear program. GM for log type scenario 6 is then predicted by inserting the optimal log purchases revealed by solving Equation 17.7, into Equation 17.6. The fact that log volume processed per hour from Table 17.8 is for a theoretical 100% utilisation rate does not bias the optimal purchase of log types solved by Equation 17.7. The optimal purchase of log types at the 100% utilisation is the same as the optimal purchase of log types at any other utilisation rate.

Results

For all combinations of veneer processing scale, resource distribution and log type scenarios examined in the case study, the following will be described:

- technically viable veneer processing scales;
- mean mill-delivered log costs;
- the volume and value of marketable veneer;
- mean gross margins; and
- technical and financial viability of reliance on small peeler logs.

Technically viable veneer processing scales

Shaded cells in Table 17.9 indicate the scales of veneer production by resource distribution and log type scenarios that are technically viable (i.e. sufficient harvestable volume is available) within the study area. The technical feasibility of supplying 7500 m^3/y to a spindleless rotary veneering facility is not sensitive to the resource distribution and log type scenarios assessed. However, all other scales of operation are sensitive to resource distribution and log type scenarios. The 10,000 m^3/y scale cannot be supported by log type scenario 1 (small peeler logs only) for resource scenario B, but is technically feasible for all other log type and resource distribution scenarios. Veneer production at a scale of up to 15,000 m^3/y can be sustained only utilising small peeler logs, but only if the facility is located close to the resource (resource distribution scenarios C and D). In resource scenarios A and B, scales of 15,000 m^3/y are only technically feasible if some sawlog volume is utilised (log type scenarios 3 and 4). The 30,000 m^3/y scale is only feasible when sawlog volume is utilised and only for resource distribution scenarios C and D.

Table 17.9. Technically viable veneer production scales in the study area by resource distribution and log type scenario

Log type scenario [a]	Technically feasible veneer production scales (1000s m^3 of log/y) by resource distribution scenario															
	A: 7.1% of landscape				**B**: 0% < 50 km, 3.55% for 51 to 100 km, 7.3% thereafter				**C**: 14.2% < 100 km, 6.6% thereafter				**D**: 21.3% < 100 km, 6.1% thereafter			
	7.5	10	15	30	7.5	10	15	30	7.5	10	15	30	7.5	10	15	30
1																
2																
3																
4																
5																
6																

Mean mill-delivered log costs

Figure 17.2 illustrates mean mill-delivered log cost (MMDLC) for the 96 scenarios examined. Each panel reflects one resource distribution scenario. Within each panel, log type scenarios 1 to 6 are distributed from left to right along the x-axis, while the individual bars report MMDLC by veneer processing scale. Missing bars indicate that processing scale scenario was not technically feasible.

Figure 17.2 indicates that mean mill-delivered log cost varies substantially. Across all scenarios evaluated, the minimum mill-delivered log cost is \$125/m^3 (resource distribution scenario D, log type scenario 3, 7500 m^3/y) and the maximum is \$175/m^3 (resource distribution scenario B, log type scenario 5, 10,000 m^3/y). Within a particular combination of resource distribution and log type scenarios, MMDLCs increase with processing scale, because maximum haul distance increases as processed log volume increases. For example, for resource distribution scenario C and log type scenario 3, the mill-delivered log cost for 7500 m^3/y is \$127/m^3, while for 30,000 m^3/y is \$147/m^3.

There is always a cost advantage associated with the veneer plant being located proximate to the forest resource. In ascending order of MMDLC, the resource distribution scenarios are D, C, A, and B. The mill-delivered log cost analysis does suggest benefits of between \$20/m^3 of log and \$30/m^3 of log associated with being located close to the resource (resource distribution scenarios C and D), relative to being distant from the resource (scenario B). The cost advantage associated with resource distribution scenarios C and D diminishes as the harvestable volume per hectare increases, a finding that is explored further later in this report.

Mill-delivered log costs also vary substantially between log type scenarios within particular resource distribution and processing scale scenarios. For example, for resource distribution scenario C and a processing scale of 15,000 m^3/y, mean mill-delivered log cost for log type scenario 1 is \$156/m^3, while for log type scenario 3 is \$133/m^3.

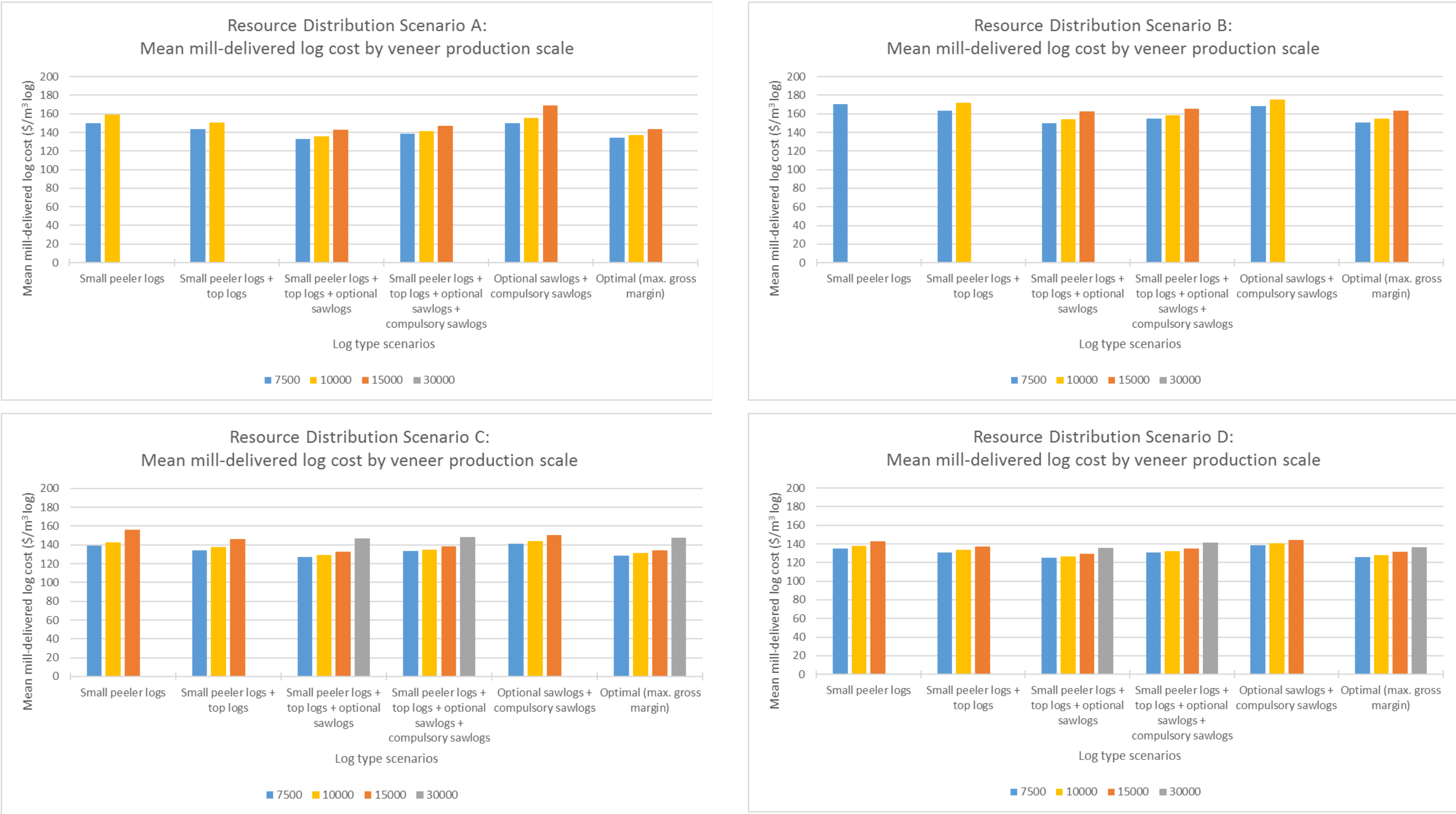

Figure 17.2. Mean delivered log cost by resource distribution scenario, log type scenario and scale of veneer production

Notes: Resource distribution scenario **A**: 7.1% of the landscape. **B**: 0% < 50 km, 3.55% for 51 to 100 km, 7.3% thereafter. **C**: 14.2% < 100 km, 6.6% thereafter. **D**: 21.3% < 100 km, 6.1% thereafter.

For a given haul distance, mill-delivered log costs in ascending order are: (i) top logs; (ii) optional sawlogs; (iii) small peeler logs; and (iv) compulsory sawlogs. This explains why, out of log type scenarios 1 to 5, scenario 3 (small peeler logs, top logs and optional sawlogs) always minimises mill-delivered log costs, irrespective of processing scale and resource distribution scenario. Log type scenarios 4 and 5 utilise high stumpage price compulsory sawlogs. Log type scenarios 1 and 2 have comparatively less harvestable volume per hectare (and thus longer haul distances to supply any particular volume), and the majority of the harvested volume is small peeler logs, which have stumpage, cut, snig and load costs that are $7.50/m^3 higher than the optional sawlogs utilised in log type scenario 3.

Log type scenario 6, which selected logs for processing to maximise gross margin, sometimes (but not always) has lower MMDLC than log type scenario 3. Gross margins are not necessarily maximised by minimising MMDLC.

For the 10,000 m^3 of log/y processing scale scenario, Figure 17.3 illustrates the breakdown in total mill-delivered log costs between stumpage, cut, snig and load, and haul costs. The higher cut, snig and load costs associated with log type scenarios relying on small peeler logs and top logs are evident, as are the reduced haul costs associated with resource distribution scenarios C and D.

Volume and value of marketable veneer

Table 17.10 reports marketable veneer volumes (MVV) by log type scenario and processing scale. Small increases in MVV accompany log type scenarios with larger proportions of optional and compulsory sawlog (from which a higher proportion of log volume can be converted into marketable veneer). Log type scenarios 1 and 2 have exactly the same MVV, because small peeler logs and top logs are assumed to have the same distribution of log sizes and proportion of log volume that can be converted into marketable veneer.

Marketable veneer revenues (MVR) are illustrated in Figure 17.4, and vary from $1.8 M/y at the 7500 m^3/y of log scale to $7.4 M/y for the 30,000 m^3/y of log scale. Within a particular processing scale, MVV and MVR are only marginally affected by log type scenario. In the following section, the MVRs have been converted into gross margins per cubic metre of log (GM), which account for log costs.

Table 17.10. Marketable volume of veneer produced per annum by log type scenario and veneer production scale

Log type scenario	Marketable volume of veneer per year (m^3) by processing scale (m^3 of log)			
	7500	10,000	15,000	30,000
1	4290	5720	8579	
2	4290	5720	8579	
3	4358	5811	8717	17,433
4	4371	5828	8742	17,484
5	4442	5922	8883	
6	4430	5903	8846	17,487

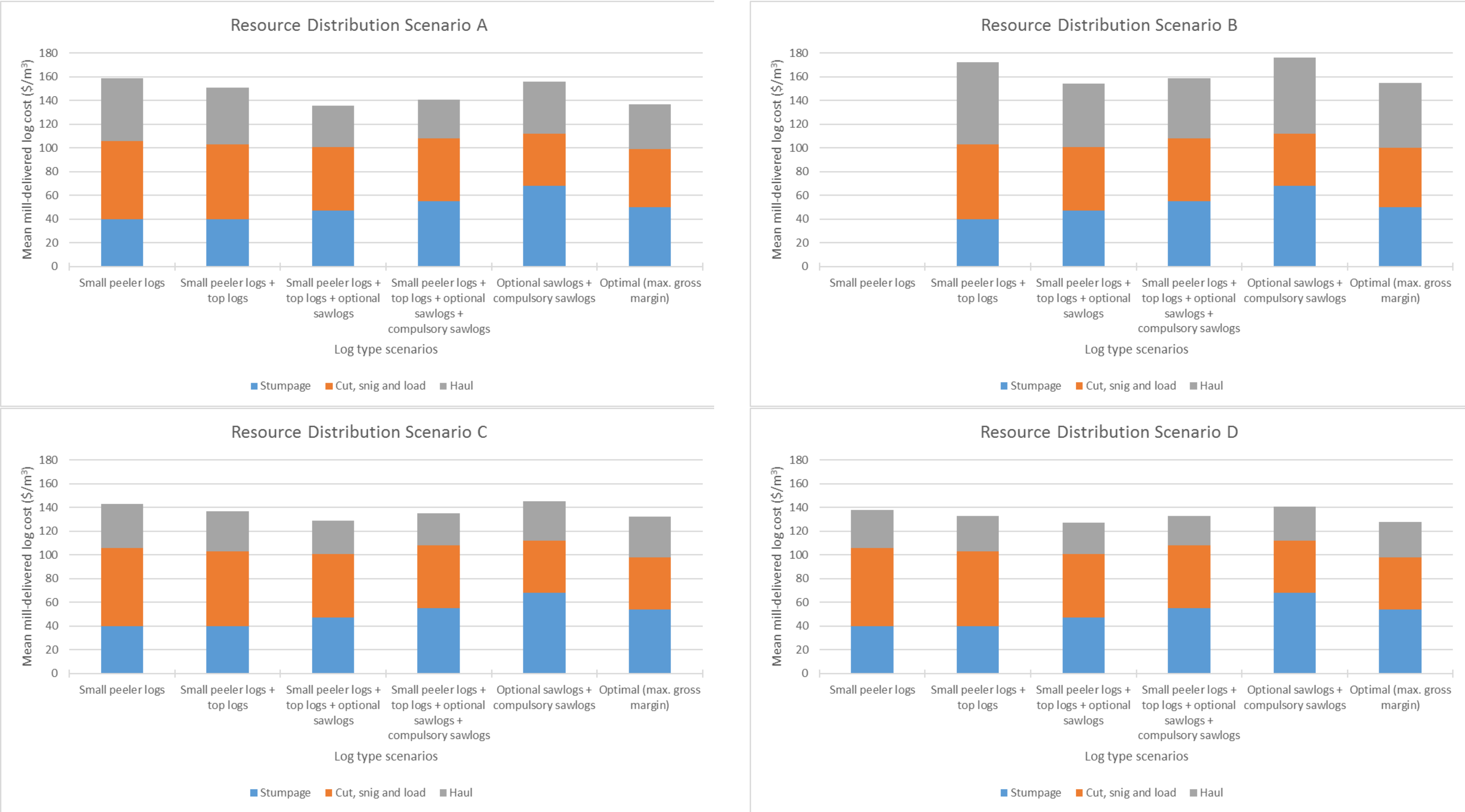

Figure 17.3. Breakdown of mill-delivered log cost for the 10,000 m^3 of log/y processing scale and each resource distribution scenario

Notes: Resource distribution scenario **A**: 7.1% of the landscape. **B**: 0% < 50 km, 3.55% for 51 to 100 km, 7.3% thereafter. **C**: 14.2% < 100 km, 6.6% thereafter. **D**: 21.3% < 100 km, 6.1% thereafter.

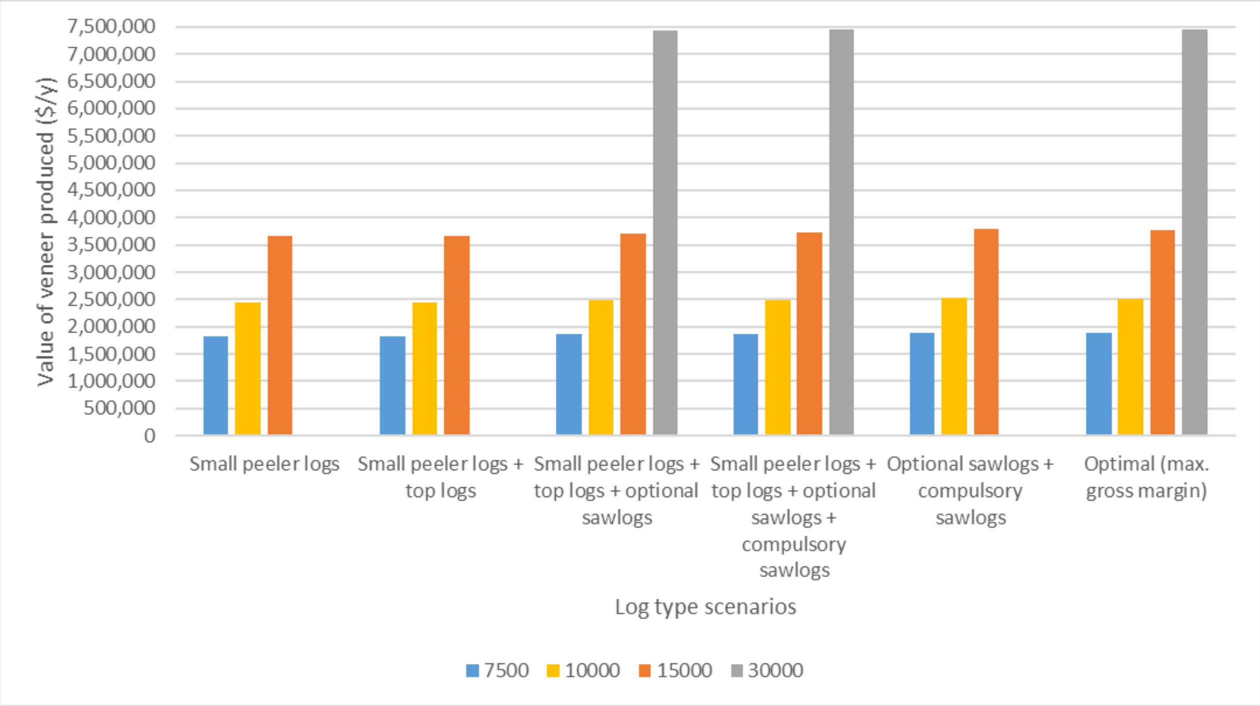

Figure 17.4. Marketable veneer value by log type scenario and veneer processing scale

Mean gross margins

Mean gross margins per cubic metre of log (GM) is the mean value of veneer produced per cubic metre of log, minus mean mill-delivered log cost. In order for veneer production to be financially viable, the mean gross margin must cover all fixed and variable costs of conversion of logs at the mill into dry, marketable veneer, as well as provide a profit on investment. Estimating these fixed and variable costs of veneer production is the focus of a forthcoming report.

Figure 17.5 indicates that GMs vary substantially between resource distribution, log type and processing scale scenarios. GMs range from $72/m^3$ (resource distribution scenario B, log type scenario 2, 10,000 m^3/y) to $126/m^3$ (resource distribution scenario D, log type scenario 6, 7500 m^3/y). Resource distribution scenarios with more resource proximate to the mill, such as C and D, have higher GM because of lower average haul distances. As a result, GM for resource scenarios C and D are always at least $20/m^3$ of log higher than for resource distribution scenario B (distant from the resource). Although MVR rises with increasing veneer processing scale (Figure 17.4), GM falls with increasing processing scale (Figure 17.5), because of increasing mean haul distance to supply sufficient volume.

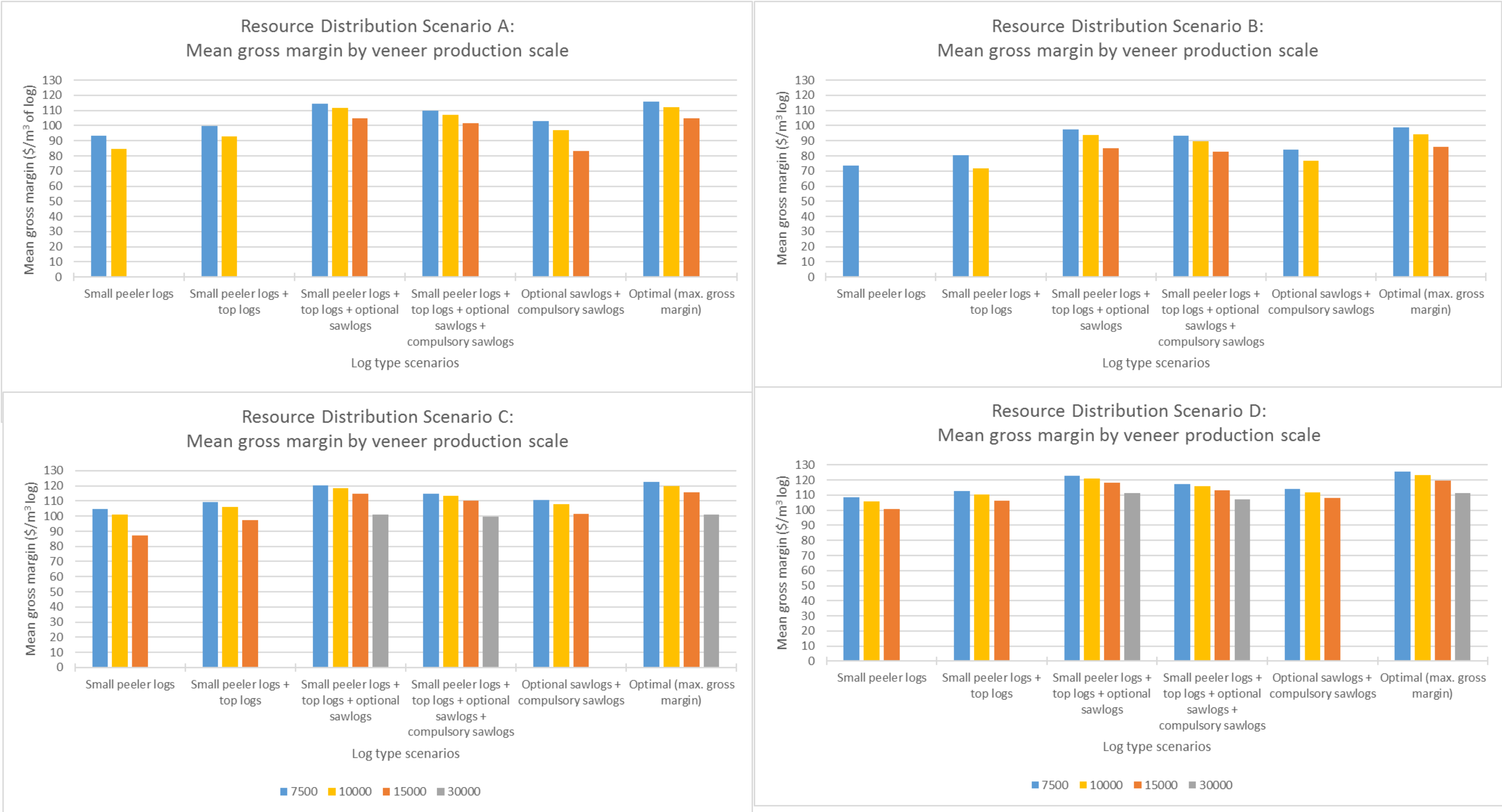

Figure 17.5. Mean gross margins by resource distribution scenario, log type scenario and scale of veneer production *Notes*: Resource distribution scenario **A**: 7.1% of the landscape. **B**: 0% < 50 km, 3.55% for 51 to 100 km, 7.3% thereafter. **C**: 14.2% < 100 km, 6.6% thereafter. **D**: 21.3% < 100 km, 6.1% thereafter

Irrespective of resource distribution scenario and veneer processing scale, the log type scenarios in descending order of GM are 6, 3, 4, 5, 2, and 1. Log type scenario 6 was designed specifically to maximise GM, and scenario 3, utilising small peeler logs, top logs and optional sawlogs, always has the closest GM to scenario 6. The lower GM in log type scenarios 1 to 5, relative to scenario 6, are explained by longer mean haul distances and larger volumes of relatively high cost logs. This is explored for log type scenarios 2, 3, 4 and 6 for resource distribution scenario C at the 15,000 m^3/y processing scale in Figures 17.6 to 17.8 and discussed below. General conclusions drawn from this comparison of log type scenarios are not sensitive to changes in resource distribution and processing scale scenarios.

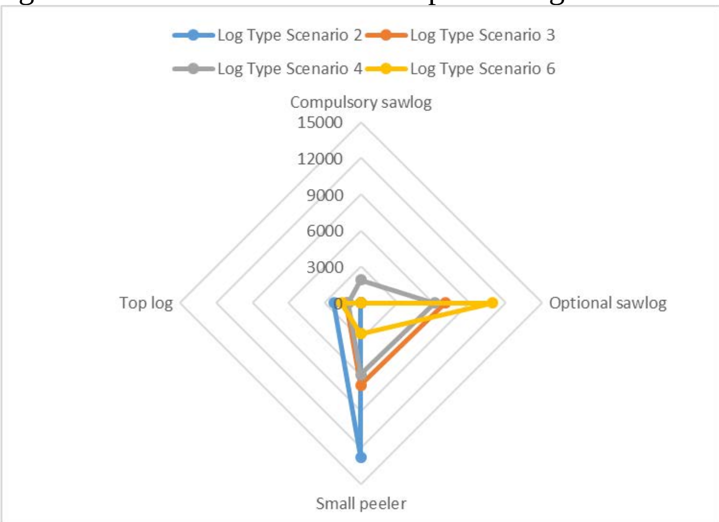

Figure 17.6. Volume of log (m^3) by log type for resource distribution scenario C and veneer production scale of 15,000 m^3/y

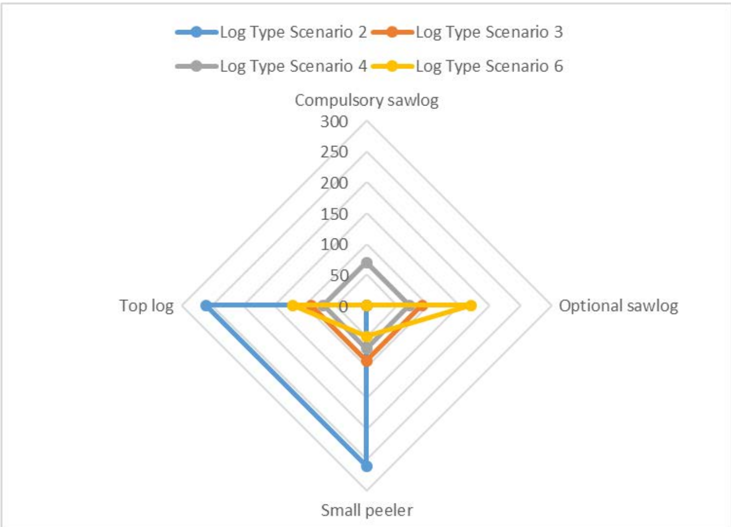

Figure 17.7. Maximum log haul (km) by log type for resource distribution scenario C and veneer processing scale of 15,000 m^3/y

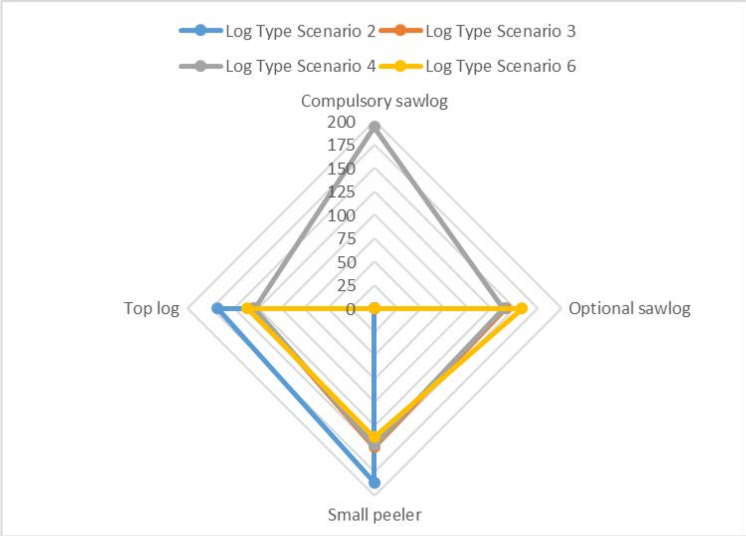

Figure 17.8. Maximum mill-delivered log cost ($/m^3 of log) by log type for resource distribution scenario C and veneer processing scale of 15,000 m^3/y

Recall, log type scenario 2 utilised only small peeler logs and top logs. Log type scenario 3 utilised small peeler logs, top logs and optional sawlogs. Log type scenario 4 utilised small peeler logs, top logs, optional sawlogs and compulsory sawlogs. In log type scenarios 2 to 4, all utilised log types pertinent to that scenario were simulated to be purchased from each harvested hectare and processed into veneer. In contrast, log type scenario 6 permitted the utilisation of small peeler logs, top logs, optional sawlogs and compulsory sawlogs, but it was assumed the log procurement officer could choose from which harvested hectares different log types would be purchased in order to maximise gross margins. For example, small peeler logs might only be purchased from harvests within 100 km of the mill, while optional sawlogs might be purchased from harvested hectares up to 150 km from the mill.

Figure 17.6 reveals that GM has been maximised in log type scenario 6 by using 11,000 m^3 of optional sawlogs, which is substantially more than any other scenario. Only 2500 m^3 of small peeler logs were processed in log type scenario 6, which is substantially less than any other scenario. The linear program arrived at the distribution of logs illustrated for scenario 6 in Figure 17.6, because:

(a) the sum of stumpage, cut, snig and load costs for small peeler logs in this case study are $7.50/m^3 higher than for optional sawlogs;
(b) a larger volume of veneer can be produced per hour of lathe operation from larger diameter logs than smaller diameter logs (Table 17.8); and
(c) larger logs yield a higher recovery of marketable veneer volume from log volume (see Chapter 16)[24].

The last two points imply that variable costs of veneer production will be lower with larger diameter logs.

Given uncertainty about what the stumpage price, and cut, snig and load costs for small peeler logs and top logs may be if a market develops, a break-even analysis was performed to determine the difference in mill-delivered log cost at which the gross margin per cubic metre of log is the same for small peelers and top logs, versus optional sawlogs and compulsory sawlogs. The default settings in the model assumed the mean small-end diameter under bark of small peeler logs and top logs is 22 cm, while for optional and compulsory sawlogs, it is 39 cm and 46 cm, respectively. The analysis revealed that gross margins are maximised by using

[24] This assessment performed in Chapter 16 assumed the quality of veneer produced does not vary by log type.

optional and compulsory sawlogs when they can be delivered to the mill at a cost of no more than $\$20/m^3$ to $\$25/m^3$ more than small peeler logs and top logs. It was also found that gross margins are maximised using compulsory sawlogs (over small peeler and top logs) only when they can be delivered to the mill at a cost of not more than $\$25/m^3$ to $\$30/m^3$ higher than the mill-delivered cost of small peeler and top logs. That is, the veneer processing efficiency gains arising from utilising larger logs have a value of $\$20/m^3$ to $\$30/m^3$ of log processed, and minimising log costs does not necessarily maximise gross margins[25].

Given the much higher stumpage price for compulsory sawlogs, it is not surprising that gross margins are maximised by not utilising compulsory sawlogs at the 15,000 m^3/y processing scale assessed in Figures 17.6 to 17.8. It would only be optimal to utilise compulsory sawlogs at a short haul from the veneer processing facility when optional sawlogs, small peeler logs and top logs are being hauled over long distances (at high cost).

Figure 17.7 highlights that it is optimal (in log type scenario 6) to haul optional sawlogs up to 170 km, but small peeler logs only up to 50 km. At these maximum haul distances, the maximum mill-delivered cost for optional sawlogs is $\$158/m^3$, and for small peeler logs is $\$138/m^3$ (Figure 17.8). In contrast, in log type scenario 2, small peeler logs are being hauled up to 260 km (Figure 17.7) to obtain sufficient log volume at a maximum mill-delivered cost of $\$186/m^3$ (Figure 17.8). In log type scenario 4, haul distances are only 70 km (Figure 17.7), but compulsory sawlogs are being supplied at up to $\$194/m^3$ of log, and small peelers at up to $\$146/m^3$ (Figure 17.8).

Technical and financial feasibility of reliance on small peeler logs

Table 17.11 reports mean mill-delivered log cost for small peeler logs (log type scenario 1) for alternative levels of harvestable volume per hectare, veneer processing scales and each of the four resource distribution scenarios (A to D). Cells without mean mill-delivered log costs indicate scenarios where it is not technically feasible to supply sufficient log volume. Table 17.9 revealed that the base case estimate of standing harvestable volume of small peeler logs of 3.4 m^3/ha is sufficient to supply 7500 m^3/y under all resource distribution scenarios, and sufficient to supply 10,000 m^3/y under all resource distribution scenarios, except scenario B. Resource distribution scenarios C and D can supply 15,000 m^3/y at the base case small peeler log volume per hectare. Table 17.11 indicates that for resource distribution scenarios A and B, the 15,000 m^3/y scale can only be supplied by small peelers if there are least 5 m^3/ha and 6 m^3/ha available, respectively. The 30,000 m^3/y scale does not become technically feasible for any resource distribution scenario until harvestable volumes of small peeler logs are at least 6 m^3/ha.

[25] This result is not sensitive to the lathe utilisation rate.

Table 17.11. Mean mill-delivered log cost for small peeler logs only (log type scenario 1)

Small peeler volume (m^3/ha)	Mean mill-delivered small peeler log cost (\$/m^3) by veneer processing scale and resource scenario															
	7500 m^3 log/y				10,000 m^3 log/y				15,000 m^3 log/y				30,000 m^3 log/y			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
2			149	140				147								
3	154	175	140	136	165		146	139				147				
4	147	166	137	134	154	175	140	136			149	140				
5	143	161	135	132	148	167	138	134	160		143	138				
6	140	158	134	131	144	163	136	133	154	175	140	136				147
7	139	156	133	130	142	160	135	132	149	169	139	135			155	142
8	137	154	132	130	140	158	134	131	147	166	137	134			149	140
9	136	153	131	129	139	156	133	130	144	163	136	133	165		146	139
10	135	152	130	129	138	155	132	130	143	161	135	132	160		143	138
11	134	151	130	128	137	154	132	129	141	159	134	132	156		141	137
12	134	150	130	127	136	153	131	129	140	158	134	131	154	175	140	136

Note: cells without a mean mill-delivered log cost indicate it is not technically feasible to supply sufficient volume.

A separate issue to technical feasibility is the financial viability of utilising small peeler logs only. Figure 17.2 revealed that MMDLC to maximise gross margins (log type scenario 6) were generally between \$125/m^3 and \$145/m^3 for resource distribution scenarios A, C and D. If this range is considered a target MMDLC for the competitiveness of a spindleless rotary veneering facility, then Table 17.11 reveals that utilising only small peeler logs under resource distribution scenario B is never financially viable. Resource distribution scenario A is financially viable for the 7500 m^3/y and 10,000 m^3/y scales, but only with minimum standing harvestable volumes of at least 5 m^3/ha to 6 m^3/ha. The 15,000 m^3/y scale is financially viable for resource distribution scenario A when there are at least 9 m^3/ha of small peeler logs, and the 30,000 m^3/y scale would require harvestable volumes of small peeler logs greater than 12 m^3/ha.

Utilising only small peeler logs under resource distribution scenarios C and D at processing scales up to 10,000 m^3/y is financially viable given harvestable volumes of 3 m^3/ha to 4 m^3/ha (Table 17.11). A processing scale of 15,000 m^3/y requires small peeler log volumes of 4 m^3/ha to 5 m^3/ha. The 30,000 m^3/y processing scale is only financially viable for resource distribution scenarios C and D at minimum peeler log volumes between 7 m^3/ha and 10 m^3/ha.

If the cut, snig and load costs for small peeler logs are the same as for optional and compulsory sawlogs, then all reported mean mill-delivered log costs in Table 17.11 can be reduced by \$22.50/m^3. This would result in few changes to the financial viability of utilising only small peeler logs in resource distribution scenarios A and B. For example, resource distribution scenario B remains unviable (MMDLC exceeding about \$145/m^3) at any processing scale, unless harvestable volumes are at least about 6 m^3/ha to 7 m^3/ha. A processing scale of 15,000 m^3/ha would become financially viable for resource distribution scenario A at a minimum harvestable volume of 5 m^3/ha of small peelers. However, MMDLC for small peeler logs under resource distribution scenarios C and D would fall to around \$125/m^3 for processing scales up to 15,000 m^3/y at standing harvestable volumes of 3 m^3/ha to 4 m^3/ha. This is at the minimum MMDLC level illustrated in Figure 17.2, suggesting the operation could be highly competitive.

Table 17.11 also highlights how increasing harvestable volume per hectare reduces the effect of resource distribution scenario on mill-delivered log cost. For example, at the 10,000 m^3/y scale and 4 m^3/ha, the difference between the resource distribution scenarios with the highest and lowest mill-delivered log cost for small peeler logs is \$39/m^3. If harvest volume trebles to 12 m^3/ha, the difference between the resource distribution scenarios with the highest and lowest mill-delivered log cost reduces by \$15/m^3 (38%) to \$24/m^3.

Conclusions

The aim of this report was to estimate the cost of delivering logs to a spindleless rotary veneering facility and to estimate gross margins (per cubic metre of log input) from the sale of veneer. This was performed for a case study area in the subtropics of eastern Australia. The analysis evaluated the technical feasibility and financial viability of four scales of veneer production (between 7500 m^3 of log per annum and 30,000 m^3 of log per annum), for four resource distribution scenarios (that affected the harvestable forest area and mean haul distance to the veneer processing facility), and six log type scenarios that dictate which logs can be processed into veneer (out of top logs, small peeler logs, optional sawlogs and compulsory sawlogs). The combination of resource distribution and log type scenarios resulted in 24 potential levels of annual harvestable log volume, ranging from 9042 m^3/y to 49,468 m^3/y. With four processing scales examined, a total of 96 scenarios were evaluated that produced between 4300 m^3 and 17,500 m^3 of veneer per annum, with a market value of between \$1.8 and \$7.4 M.

The 7500 m^3/y scale was found to be technically feasible in the study area for all scenarios evaluated. The 10,000 m^3/y scale is technically feasible for almost all scenarios evaluated. The feasibility of the 15,000 m^3/y and 30,000 m^3/y scales requires resource distribution scenarios that have the veneer production facility located proximate to the forest resource, and log type scenarios that permit utilising sawlogs.

Production of veneer at scales of up to 15,000 m^3/y relying solely on small peeler logs does appear technically viable in resource distribution scenarios where the mill is proximate to the resource. However, relatively high mill-delivered log costs mean the financial viability of small peeler log only production at scales exceeding 10,000 m^3/y is questionable, unless mill-delivered log costs could be about \$20/m^3 lower than the levels assumed in this case study analysis. Small peeler and top logs are presently not marketed in southern Queensland, and there is only limited utilisation in northern New South Wales. Potential stumpage, cut, snig and load costs for these log types have been estimated for analysis (rather than obtained from industry), so reported costs and gross margins for small peelers and top logs should be interpreted with caution.

The case study revealed that mean mill-delivered log costs for spindleless lathe veneering within the study area would likely vary between \$125/m^3 of log and \$175/m^3 of log, and that gross margins would be between \$72/m^3 of log and \$126/m^3 of log[26]. The analysis produced findings consistent with expectations that mill-delivered log costs per cubic metre rise (and gross margins per cubic metre fall) with increasing processing scale and distance of the resource from the mill. If the veneering facility was located at least 50 km from any log resource (e.g. in Brisbane), mean mill-delivered log costs were up to about \$30/m^3 of log higher than for a facility located proximate to the resource.

The mix of log types being processed also had a large impact on mean mill-delivered log cost, with some combinations examined being up to about \$20/m^3 of log higher than others (when all other variables were held constant). The lowest mill-delivered log costs, and highest gross margins were always achieved in scenarios when the spindleless rotary veneering facility was

[26] This range in mill-delivered log costs and gross margins is due to differences in processing scale, forest resource distribution and log type scenarios.

utilising optional sawlogs, small peeler logs and top logs, while being located close to the resource. Because of their relatively low stumpage price and relatively large log diameter, optional sawlogs were identified by the model as the optimal log type for veneer production.

A key finding was the quantification in dollars of the veneer processing efficiencies from utilising optional and compulsory sawlogs in veneer production, which arise due to higher recovery of veneer from log volume and faster production of veneer per unit time of operation, relative to small peeler logs and top logs. These efficiency gains were found to be worth between \$20/m^3 and \$25/m^3 of log for optional sawlogs, and between \$25/m^3 and \$30/m^3 of log for compulsory sawlogs. That is, sawlogs are better value for purchase for veneering when they can be delivered to the mill at no more than \$20/m^3 to \$30/m^3 of log more than the cost of small peeler and top logs. If the difference in mean diameters between small peelers and sawlogs is greater than assumed in the case study, so too will be the value of the efficiency gains associated with utilising the larger logs. This analysis assumed veneer grade recovery does not vary with log SEDUB. If larger logs yield higher proportions of higher grade veneer, the efficiency gain from utilising sawlogs in this report will have been underestimated. Therefore, minimising mill-delivered log costs will not necessarily maximise profitability of a veneer producer.

The default inventory data utilised in the model suggests small peeler logs account for about 40% of the potentially harvestable resource in native forests in the study area that is suitable for veneering. Prior research has highlighted that the productive condition of private native forests in the case study area forests would greatly benefit from silvicultural treatment that would remove stems in the small peeler size class. Spindleless rotary veneering does potentially provide a market for this material, which could help facilitate silvicultural treatments in the landscape. Further research is necessary to ascertain small peeler log stumpage, cut, snig and load costs acceptable to industry (and landholders), and update mill-delivered log cost and gross margin estimates in this report.

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Appendices:

Appendix 17.1: Study areas for published private native forest inventories relative to the case study area adopted in this report

The study area for this report relative to published private native forest inventories is illustrated in Figure A.17.1. The South East Queensland Forest Agreement (SEQFA) study area is referred to as simply SEQ in the body of this report. Private native forest inventories in SEQ and the Western Hardwoods Region (WHR) were performed by MBAC Consulting PTY LTD (2003a, 2003 b). Private Forestry Service Queensland (PFSQ c2015) classified commercial forest types on private land in southern Queensland.

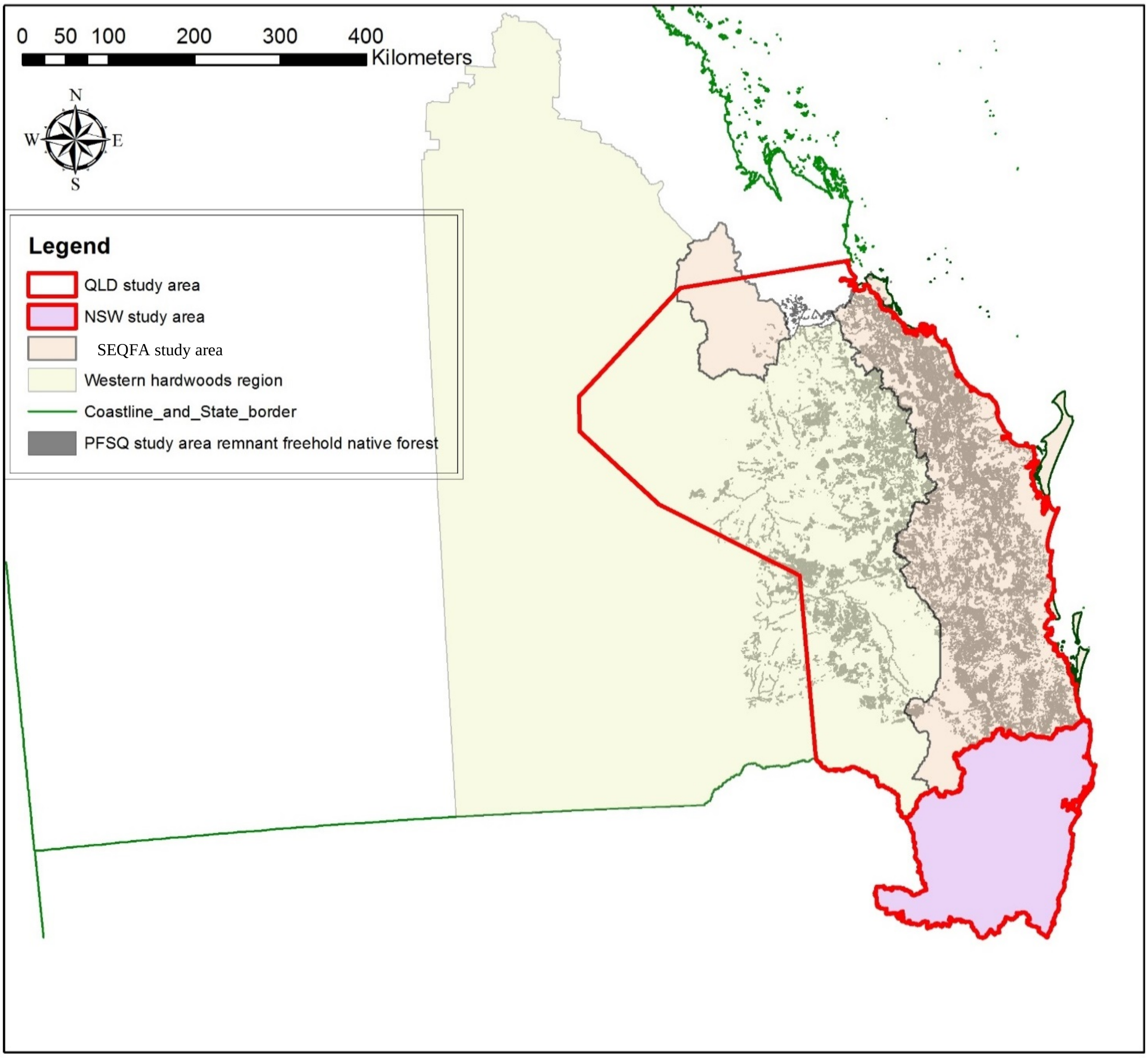

Figure A.17.1. Study areas for published private native forest inventories

Appendix 17.2: Justification of case study levels of volume per hectare and commercial and harvestable forest area

The analysis performed with default data for the study area considers four resource distribution scenarios, but only one estimate of commercial and harvestable forest managed for timber production and one estimate of standing merchantable volume per hectare. A second level for forest area and volume per hectare would increase the number of scenarios analysed from the present 96 to 384 (=96*2*2). This was deemed impractical. This appendix provides a partial sensitivity of the technical feasibility of alternative scales of veneer production to justifiable alternative levels of commercial and harvestable forest managed for timber production, and harvestable volume per hectare in southern Queensland.

For the four resource distribution scenarios described in the report (A to D), three probable levels of availability of commercial and harvestable native forest within a 400 km radius of the Gympie-Maryborough region in the study area are considered:

a) 1.78 M ha (50% of the total harvestable and commercial resource under the code, and the level used in case study);
b) 1.44 M ha (40% of the total harvestable and commercial resource under the code); and
c) 1.08 M ha (30% of the total harvestable and commercial resource under the code).

To test the sensitivity of the technical feasibility of spindleless rotary veneering to volume per hectare, the harvested volume per hectare in State Forests in the Queensland part of the study area was estimated as reported in Table A.17.2.1. Volumes by log type differ between State Forests and private forests. For example, State Forests have substantially higher compulsory sawlog volumes per hectare than private native forests.

Table A.17.2.1. Harvestable volume per hectare by log type in State Forest and private native forest in the Queensland part of the case study area

Log type	Mean of private native forests in SEQ and WHR (m^3/ha) [a]	State Forests (m^3/ha) [b]
Compulsory sawlog	1.1	6
Optional sawlog	3.5	2
Small peeler log	3.4	2
Top log	0.6	0.6
Total	**8.6**	**10.6**

Notes: a. Volumes for private native forests are as reported in Table 17.4 in the body of the report.

b. Mean annual harvested volumes of compulsory and optional sawlogs from State Forests and Timber Reserves for the years 2006-07 to 2010-11 were supplied by the Queensland Department of Agriculture and Fisheries (DAF), Forest Products. These volumes were divided by the annual area of Crown forest harvested to estimate volume per hectare for each of these years (ABARES 2013). This revealed a mean of 8 m^3/ha of sawlog, but did not partition the log volume into compulsory and optional sawlog. This break-down has been based on the Queensland CRA/RFA Steering Committee (1998b) estimate that standing commercial log volume in State Forests comprised 50% compulsory sawlogs, 15% optional sawlogs and 35% non-sawlog standard 'fibre' logs. That is, in State Forests, there are approximately 3 m^3 of compulsory sawlog for every 1 m^3 of optional sawlog. Small round logs for peeling are not a traditional log specification that DAF Forest Products has sold, and there are limited data on availability of this log type from State Forests. In three more probable integrated harvesting scenarios examined in Chapter 2 for Gurulmundi State Forest, where small rounds might be harvested as part of an integrated harvest of poles and sawlogs, available volumes of small rounds was estimated at 0.3 m^3/ha, 0.8 m^3/ha and 5.0 m^3/ha. In this analysis, the mean of those three scenarios, 2 m^3/ha, has been adopted. There is no inventory data available for top logs in State Forests, so the estimate adopted in this report for private native forests, 0.6 m^3/ha, has been adopted for State Forests.

Figure A.17.2.1 illustrates the annual log volume available to a spindleless rotary veneering facility in the study area for the three alternative levels of forest area, and the State Forest and mean private native forest total volume per hectare estimates from Table 17.2.1. The columns in the figure represent log volume potentially available to the facility per year, given assumptions about the resource described in the body of the report.

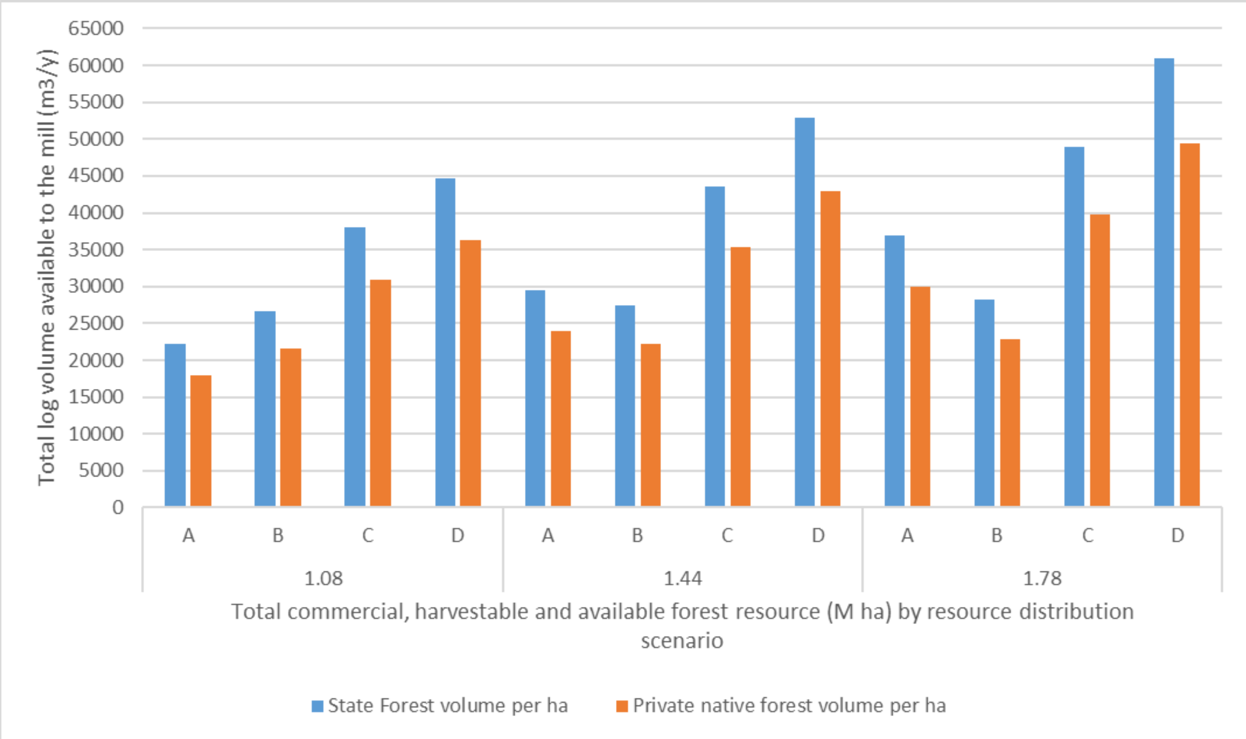

Figure A.17.2.1. Commercial and harvestable volume available per annum by resource distribution scenario

The processing scales examined in this case study are 7500, 10,000, 15,000 and 30,000 m^3/y. The technical feasibility of these 4 processing scales is not highly sensitive to total commercial, harvestable and available forest resource area (1.08 M ha, 1.44 M ha or 1.78 M ha) or volume per hectare (State Forest vs private native forest). The only case where technical feasibility was affected is resource distribution scenario A, where the 30,000 m^3/y scale is feasible at 1.78 M ha of commercial and harvestable forest resource with the State Forest standing volumes, but not for any other area of forest or for private native forest standing volumes. Therefore, the levels adopted in the case study analysis in the body of this report are sound for general assessment in the study area.

Appendix 17.3: Justification for the case study volumes per hectare for small peeler logs and top logs

There is strong demand for traditional hardwood sawlogs and poles in the study area; however, there are few markets for small peeler logs. There is much interest in the potential for spindleless rotary veneering to utilise small peeler logs, because it would facilitate expansion of the timber industry by utilising logs that are not presently considered merchantable, while also facilitating silvicultural treatments necessary to improve the productive condition of large areas of private native forest.

Private native forest inventories conducted in the South East Queensland Forest Agreement area and the Western Hardwoods Region (MBAC Consulting Pty Ltd 2003a, b), which overlap the case study area adopted for this analysis (Appendix 17.1), reported volumes for small round logs of 4.8 m^3/ha and 1.9 m^3/ha, respectively. The log specifications for these small round logs[27] were similar to that for small peeler logs adopted in this study (Table 15.1).

Ryan (2018) described an exceptional private native forest demonstration site at Nanango, where the original stand carried 608 stems/ha with an average DBH of 18 cm, and was thinned to 120 stems/ha, yielding 12 m^3/ha of small round logs. In post-harvest sites on one private property west of Kingaroy, there was found to be an average of 13.8 m^3/ha suitable for small peelers (see Chapter 2). However, the authors acknowledged additional assessments would need to be undertaken to determine how representative this property is of the larger private native forest resource, as well as how the code of practice and a desire to retain dominant and co-dominant trees to grow onto more valuable product classes (e.g. poles and sawlogs) in 15 to 30 years would affect the volume that could actually be cut.

At a silvicultural treatment research trial conducted on a property at Mundubbera, Queensland in 2017, small peeler log volume harvested in two plots was 1.3 m^3/ha and 5 m^3/ha, respectively (PFSQ unpublished data). On the plot with 5 m^3/ha, average log volume was 0.1 m^3. Chapter 2 examined six scenarios regarding the availability of small peeler logs using pre-harvest data from Gurulmundi State Forest, with estimates ranging from 0.3 m^3/ha to 10.5 m^3/ha[28]. Three of these scenarios, with estimated yields of 0.3 m^3/ha, 0.8 m^3/ha and 5 m^3/ha, are more realistic in practice, given regulatory constraints and a rational desire of landholders to grow and harvest higher value logs. Ryan (2018) asserted that 4 m^3/ha would be a typical harvestable standing volume of small peelers in private native forest in SEQ. The mean of the harvestable volumes of small rounds estimated by MBAC Consulting Pty Ltd (2003a, 2003b), 3.4 m^3/ha, as reported in Table 17.4, appears sound and has been adopted as the default volume of small peelers in the study area.

Top logs are small diameter logs that are traditionally left among residues following a native forest harvest. These logs could be in the bole of a felled tree above a sawlog or pole, but below crown break, or could be within the crown. For the purposes of this study, top log volumes have been estimated assuming the same specifications as small peelers (see Table 17.1). Fieldwork in post-harvest sites at one State Forest found an average of 0.6 m^3/ha of residual logging residue that would meet the top log specification (see Chapter 2). There do not appear to be any other published estimates of top log volumes, and the estimate from Chapter 2 has been adopted in this report.

[27] Minimum length 2.5 m, minimum small-end diameter under bark 15 cm, and maximum small-end diameter under bark 27.5 cm.

[28] The low estimate is based on current tree marking practices by the Department of Agriculture and Fisheries, Forest Products. The high estimate assumed the code of practice did not have to be followed and all trees are potentially available for small peelers, even if the tree has excellent form and crown, and would likely grow into a pole or sawlog.

Chapter 18: Financial performance of veneer and laminated veneer lumber (LVL) production using sub-optimum quality log resources

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Introduction

Research by the Queensland Department of Agriculture and Fisheries (DAF) has demonstrated the potential to use emerging spindleless rotary veneering technologies to process hardwood plantation and native forest logs of sizes and qualities previously considered unmerchantable (i.e. less than 30cm diameter and 2.6m length) (McGavin *et al.* 2014a, b; McGavin *et al.* 2015a, b; McGavin and Leggate 2019). That research has shown that spindleless rotary veneering can recover much higher proportions of marketable product from smaller sized logs than can be achieved through conventional sawing. Indeed, for small native forest *Corymbia citriodora* logs, spindleless rotary veneering produced double the marketable product recovery of sawing, and the resulting veneer contained visual qualities and mechanical properties well suited to the manufacture of veneer-based engineered wood products (McGavin and Leggate 2019).

Currently, the majority of Queensland's private native forests are in a state of low productivity due to decades of poor management that has resulted in a high stocking of trees that do not meet traditional product specifications for sawlogs, electricity distribution poles and bridge girders (Queensland CRA/RFA Steering Committee 1998, MBAC Consulting Pty Ltd. 2003a, b, Bureau of Rural Sciences 2004, Burgess and Catchpoole 2016). A major reason these forests are not being silviculturally treated to increase productivity is the cost of thinning small and large diameter trees that do not have logs that meet these traditional product specifications and, therefore, little or no value can be recovered to offset the thinning costs. Spindleless lathe rotary veneering could offer a financially viable manufacturing opportunity to utilise these under-utilised hardwood logs and facilitate the necessary silvicultural treatment in native forests to increase their productivity and ensure future supplies of traditional sawlogs, poles and girders.

The purpose of this report is to investigate the financial viability of producing rotary veneer and veneer-based engineered wood products (EWP) in the Queensland wood-processing sector. This study forms part of the Queensland Government, Forest and Wood Products Association (FWPA) and industry funded project, entitled— "Increasing the value of forest resources through the development of advanced engineered wood products". The main objective of this project is to investigate the feasibility of using rotary-veneer produced from sub-optimal quality native forest logs in combination with other wood-based feedstock to manufacture high performance 'next generation' engineered wood products, suitable for structural and appearance applications.

Research objective and the manufacturing process evaluated

The objective of this study was to determine the financial performance of utilising spindleless lathe technology to produce veneer, and then using the veneer in the manufacture of engineered wood products (EWPs). There is a strong focus on evaluating the technical feasibility and financial viability of producing veneer from small-diameter peeler logs to provide a market for small-diameter logs.

Figure 18.1 illustrates the veneer and EWP manufacturing process evaluated in this report. Hardwood logs delivered to the veneer processing facility are pre-conditioned (heated) prior to being docked to 2.6 m length billets. The billets are then prepared for peeling in a rounding-debarking lathe to produce a rounded billet with bark, taper, sweep and ovality removed. Logs are then processed through a spindleless lathe to produce green veneer ribbons at the desired thickness, and clipped to a desired length. This green veneer could be packaged for freight to an EWP manufacturer or proceed on-site to a drying facility.

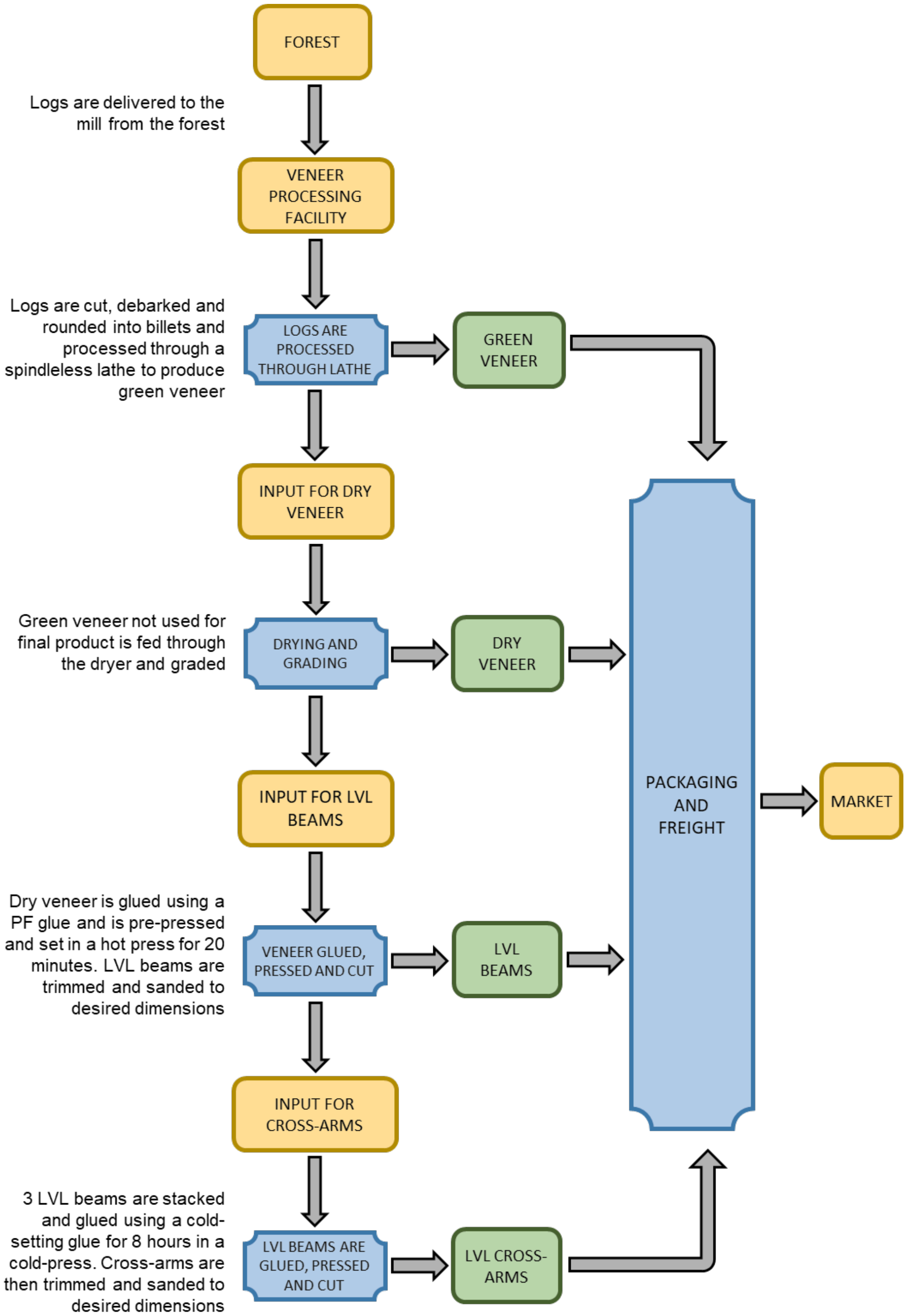


Figure 18.1. Schematic diagram of the evaluated veneer and EWP manufacturing process

The model assumes a conventional jet-box dryer is used to dry the veneer sheets to a moisture content of approximately 5%. The analysis investigated the financial viability of utilising one three deck (small) dryer, one five deck (large) dryer, or two three-deck dryers for alternative scales of production. The dried and graded veneer could then either be clipped to remove any damage that may have occurred during the drying process and packaged for freight to market, or proceed on-site to short-length laminated veneer lumber (LVL) manufacture.

The short-length LVL manufacture has been modelled assuming traditional plywood production equipment is utilised, therefore restricting LVL section length to <2.6 m (minus any necessary end-trimming), in line with the peeler billet length. Dry veneer sheets are first glued together using a phenol formaldehyde-based glue (PF), then pressed in a cold press for six minutes, before being placed in a hot press for twenty minutes to cure the adhesive. The LVL panels are then assumed to be sawn and sanded to the specific product dimensions of a one-stage LVL product. This one-stage LVL product could then be packaged for freight to market, or proceed on-site to be manufactured into a two-stage LVL product.

Two-stage LVL products are produced by gluing together one-stage LVL products in a cold press for eight hours with a resorcinol formaldehyde-based glue (RF) to form a larger dimension product that is unable to be manufactured in a conventional one-stage process (e.g. cross arms and railway sleepers). They are then sanded to the desired dimensions, and packaged for freight to market.

Research method

A discounted cash flow spreadsheet model has been developed to estimate the costs, revenues and profitability of veneer and EWP product manufacture. The model has been populated with production and cost parameters that are likely to be broadly representative of veneer processing facilities in eastern Australia, having been collated from a literature review, quotes from equipment suppliers, and discussions with key informants within the industry. Following development of the model, three separate meetings were held with different industry experts to review and validate model parameters.

Case study scenarios evaluated

The spreadsheet model permits the comparison of 36 veneer and EWP product manufacturing scenarios: three processing scales, three log diameter sizes, and four final products. The veneer-processing scales in cubic metres of log per annum are:

1. 7500 m^3/y;
2. 15,000 m^3/y; and
3. 30,000 m^3/y.

Empirical evidence from an existing spindleless rotary veneering operation that is processing hardwood logs in eastern Australia suggests 15,000 m^3/y of log throughput is achievable with one full-time spindleless lathe. The 30,000 m^3/y scale is assumed to be facilitated by operating two spindleless lathes full-time. The 7500 m^3/y scale is a part-time veneer production operation.

The three log diameter sizes considered in this study in centimetres small-end diameter under bark (SEDUB) are:

1. 25;
2. 35; and
3. 45.

The specifications for the four final products evaluated in this analysis are indicated in Table 18.1. Green veneer is assumed to be sold ungraded. As detailed below, dry veneer is assumed to be graded in accordance with AS/NZS 2269.0:2012 (Standards Australia 2012). LVL beams are a one-stage LVL product sawn from LVL panels produced by gluing together 12 sheets of dry veneer. The LVL panels are then sawn and sanded into the desired dimensions. These beams are assumed to substitute for structural softwood timber in applications where high strength is required (e.g. in multi-storey construction). LVL cross-arms (or similar) are a two-stage LVL product, where three LVL panels produced in the first stage of LVL manufacture are glued together in a cold press in the second stage of product manufacture. Cross-arms are then sawn from these large LVL panels and sanded to the desired dimensions. Cross-arms are expected to substitute for solid wood and fibre glass cross-arms for electricity distribution.

Table 18.1. Final product dimensions

Marketable product	Length (m)	Width (m)	Thickness (mm)
Green veneer	2.55	1.40	3.2
Dried veneer	2.45	1.27	3.0
LVL beams	2.40	0.12	35.0
LVL cross-arms	2.40	0.15	100.0

Case study data

To facilitate evaluation of the financial performance of veneer and EWP manufacture, the following cost, revenue and production parameter estimates have been collated for southern Queensland:

1. mill-delivered log costs;
2. recovery of marketable product from log volume;
3. equipment utilisation and productivity rates;
4. capital costs;
5. labour costs;
6. non-labour operating costs; and
7. market prices.

Mean mill-delivered log costs

Chapter 17 determined the cut, snig and haul costs of delivering hardwood logs from private native forests in southern Queensland to a log processing facility. The mean mill-delivered log costs (MMDLC) adopted in this analysis are reported in Table 18.2, and have been taken from resource distribution scenario A in Chapter 17. That scenario assumed an even distribution of harvestable private native forest equivalent to 7.1% of the landscape radiating out from the processing plant. As a facility’s log throughput volume increases; the mean mill-delivered log cost (MMDLC) increases due to a longer average haul distance to obtain sufficient logs. As explained in Chapter 17, the 25 cm SEDUB logs are more costly to deliver to the processing facility than 35 cm logs, because of higher fell and merchandise costs per cubic metre of log for these small logs.

Table 18.2. Mean mill-delivered log costs for the different log sizes and scales

Log processing scale (m^3/y)	Mean mill-delivered log cost ($/$m^3$) by log SEDUB (cm)		
	25	35	45
7500	$137	$129	$184
15,000	$145	$138	$193
30,000	$167	$159	$214

Recovery of marketable product from log volume

Typically, logs arriving at the veneer processing plant are not cylindrical. Rather, they are affected by geometrical irregularities such as sweep, taper and ovality. Chapter 16 determined how these irregularities affected marketable veneer volume recovery from log volume. For purposes of this case study analysis, values of sweep and taper have been set to 0.005 m/m and 0.0075 m/m respectively, which are average levels for small-diameter *Eucalyptus* and *Corymbia* native forest and plantation logs processed in multiple recent veneering studies (e.g. McGavin *et al.* 2014a; McGavin and Leggate 2019). Logs are fed into a rounding-debarker lathe to remove such irregularities and produce a cylindrical billet prior to veneering (Leggate *et al.* 2017).

Green veneer can be recovered from the rounded billet until the residual cylindrical peeler core at the centre of the billet is reached. The peeler core typically has a diameter between 4 cm and 5 cm. This case study analysis assumes a peeler core diameter of 4.5 cm with a volume of $1.59 \times 10^{-3} m^3$/m of log length. The green veneer recovery from log volume reported in Table 18.3 has been estimated from the ungraded green veneer recovery equations reported in Chapter 16. This accounts for the waste due to log geometry (the effects of the sweep and taper described in the previous paragraph) and the peeler core.

Table 18.3. Final product recovery from log volume

Marketable product	Recovery of marketable product (%) from log volume by SEDUB		
	25cm	35cm	45cm
Green veneer	69	79	84
Dry veneer	52	59	63
LVL beams	43	49	52
LVL cross-arms	42	48	51

Empirical studies by McGavin *et al.* (2014a, b), and McGavin and Leggate (2019) revealed that approximately 75% of green veneer is recovered as dry, graded veneer. This is reflected in the recovery from log volume parameters in Table 18.3, which are 75% of the green recoveries. The volume loss from green veneer is due to defects in the veneer sheets (from imperfections inside the log), trimming veneer to marketable dimensions, and shrinkage during drying. These same studies found that *Eucalyptus* and *Corymbia* dry veneer grade recoveries are about 80% D-grade, 15% C-grade, 5% B-grade, and 0% A-grade.

Recoveries of short-length LVL beams and cross-arms from log volume have been estimated as follows. First, the volume in cubic metres of an untrimmed LVL panel (*VU*), with the specifications listed in Table 18.1, was determined.

$$VU = LU \times WU \times TU \qquad \text{[eq. 18.1]}$$

where *LU* is the length of the untrimmed dry veneer used to manufacture the LVL panel (m);

WU is the width of the untrimmed dry veneer used to manufacture the LVL panel (m); and
TU is the thickness of the untrimmed dry veneer used to manufacture the LVL panel (m).

Following pressing and trimming the edges, the dimensions of the LVL panel are assumed to be 2.4 m x 1.2 m x 0.035 m. The number of products of product type *p* (NP_p) that can be cut from the LVL panel has been estimated as follows

$$NP_p = \frac{1.2}{W_p + SK} \quad \text{[eq. 18.2]}$$

where 1.2 is the width of the trimmed LVL panel (m);
W_p is the width of product *p* (m); and
SK is the saw kerf (m);

NPp is rounded down to the nearest whole integer. This analysis has adopted a saw kerf of 0.003 m. That is, for every product cut out of the LVL panel, 3 mm of width becomes sawdust. The volume of LVL product *p* that can be produced from an LVL panel ($VLVL_p$) is

$$VLVL_p = NP_p \times L_p \times W_p \times T_p \quad \text{[eq. 18.3]}$$

where L_p is the length of product *p* (m);
W_p is the width of product *p* (m);
T_p is the thickness of product *p* (m); and
all other variables are previously defined.

The recovery of LVL product *p* from log volume of log diameter *l* ($RLVL_{pl}$), is

$$RLVL_{pl} = DR_l \times \frac{VLVL_p}{VU} \quad \text{[eq. 18.4]}$$

where DR_l is the dry veneer recovery from log volume of log diameter *l* from Table 18.3; and all other variables are as previously defined.

Using the case study data, LVL beam and LVL cross-arm recoveries from untrimmed LVL panel volume were found to be 83.3% and 81% (*i.e.* $VLVL_p/VU$), respectively.

Equipment utilisation rates and productivity

Equipment utilisation rate and productivity parameters adopted in the case study analysis are reported in Table 18.4. Spindleless lathe utilisation is typically well below 100% due to issues such as delays in log loading, waste removal, and lathe knife changes for sharpening. Other factors affecting the utilisation rate include labour skill and processing automation (see Chapter 16). Industry experts assert that utilisation rates for spindleless lathes of between 50% and 75% are plausible; 65% has been adopted for this study. Productivity level for a spindleless lathe was determined from a time and motion study with a spindleless lathe. Chapter 16 fit a regression model to estimate peeling time from empirical data collected from a commercial spindleless lathe facility where the operating speed was 40 lm/minute. Green veneer productivity levels for three log diameters are reported in Table 18.4. Productivity rises with log diameter due to the reduced log loading time per cubic metre of green veneer produced.

Table 18.4. Productivity per machine per hour of veneers and veneer-based EWPs

Inputs	Output	Hourly processing of input (m^3/h)		
		Utilisation rate	Not adjusted for utilisation rate	Adjusted for utilisation rate
Log	Green veneer			
25cm SEDUB		0.65	13.15	8.55
35cm SEDUB		0.65	17.25	11.21
45cm SEDUB		0.65	18.27	11.88
Green veneer	Dry veneer from small dryer	0.85	4.8	4.08
	Dry veneer from large dryer	0.85	7	5.95
Dry veneer	LVL beams	0.5	5	2.5
LVL beams	Cross-arms	0.8	0.5	0.4

Production of dry veneer is constrained by the drying capacity, which is influenced by the number of decks feeding into the dryer; more decks yielding greater dry veneer volumes. This case study has assessed the production of dry veneer from a small dryer (three decks), a large dryer (five decks), and two small dryers. Veneer dryers are assumed to operate 24 hours per day regardless of whether or not it is drying material 24 hours per day, due to the high cost of getting the dryer back to drying temperature. The dryer will shut down for one eight-hour period each week to perform routine maintenance, and there are likely to be unplanned break-downs, such as for clearing veneer jams. Industry experts suggest utilisation rates for dryers range between 75% and 95%; this analysis has adopted the midpoint at 85%. Dryer productivities are based on typical industry production rates for small and large dryers.

The rates at which LVL can be produced is determined by the time required for the adhesive to cure, in addition to the capacity of the hot press[29]. The utilisation rate of the hot press is dependent on the charging and unloading time for the glued veneer sheets, as well as the time the glued veneer is in the press. LVL cross-arm manufacture requires a second gluing phase where three LVL beams are glued together and clamped in a cold press for eight hours. In the LVL cross-arm scenario, it is assumed that LVL cross-arm production will utilise all LVL beams produced. Typically, this will require three charges of cross-arms loaded into the cold presses per day. The first at the beginning of the first eight-hour shift, the second at the beginning of the second shift, and the third at the end of the second shift. Anecdotal evidence from an eastern Australian plywood mill suggests utilisation rates for hot and cold presses are typically about 50% and 80% respectively and these levels have been adopted in this analysis. The production of LVL beams in Table 18.7 has been estimated on the basis of an adhesive cure time of 20 minutes and a hot press capacity of 1.67 m^3 per charge. LVL cross-arms are glued with RF glue that requires an eight-hour period in a cold press to cure, with a maximum charge of 4 m^3 of LVL in each cold press.

[29] The hot press is the bottleneck for the LVL beams, as the glued veneer sheets are pressed for 20 minutes. The preliminary clod press of the veneer sheets is only for six minutes.

Capital and fixed costs

Following discussions with industry experts and equipment suppliers, the equipment necessary to produce each of the four marketable products evaluated have been listed in Tables 18.5 to 18.8. Land costs are not accounted for in the model, but building costs have been included. The equipment needs are cumulative. For example, in order to produce short-length LVL beams for market, the equipment listed in Table 18.5 (green veneer), Table 18.6 (dry veneer) and Table 18.7 (LVL beams) are necessary.

Table 18.5. Capital and fixed costs for green veneer production

Item	Unit cost with installation	Asset life (years)	Units by log scale (m^3/y) 7,500 & 15,000	30,000
Water storage	$82,500	20	1	2
Log steaming/ bathing chamber	$75,000	15	1	2
Biomass boiler	$3,105,000	20	1	2
Log docking saw	$23,000	10	1	2
Log charger	$7095	15	1	2
Log conveyer	$15,893	15	1	2
Log debarker/ rounder	$52,000	5	1	2
Waste chipper	$230,000	15	1	1.5
Waste wood conveyer	$20,700	15	2	4
8-foot spindleless lathe	$130,743	5	1	2
Veneer conveyor	$20,700	15	1	2
Veneer stacker	$67,741	10	1	2
Veneer clipper	$58,029	10	1	2
Knife grinder	$33,000	20	1	1
Control room	$90,000	30	1	1
Veneer trolleys	$10,000	5	2	4
Wrapping machine	$17,250	5	1	1
Industrial bin	$5000	10	1	2
Forklift (second hand)	$30,000	4	1	2
Buildings (360m^2)	$270,000	30	1	2
Fuel bin for boiler	$5000	10	1	2
Total up-front capital costs for green veneer production			**$4,379,351**	**$8,503,452**
Annual maintenance costs (5% of capital)			$218,968	$425,173
Annual insurance costs (1.5% of capital)			$65,690	$127,552
Annual fixed costs for green veneer production			**$284,658**	**$552,724**

Table 18.6. Capital and fixed costs for dry veneer production

Item	Unit cost with installation	Asset life (years)	Small dryer scenario	Large dryer scenario
Jet dryer (small)	$417,185	20	1	0
Jet dryer (large)	$678,500	20	0	1
Automatic feeder	$69,000	7	1	1
Dry veneer conveyer	$20,700	5	1	1
Trolleys	$10,000	5	1	2
Forklift	$30,000	4	1	1
Buildings (360m^2)	$270,000	30	1	2
Total up-front capital costs for dry veneer production			**$816,885**	**$1,358,200**
Annual maintenance costs (5% of capital)			$40,844	$67,910
Annual insurance costs (1.5% of capital)			$12,253	$20,373
Annual fixed costs for dry veneer production			**$53,098**	**$88,283**

Table 18.7. Capital and fixed costs for LVL beam manufacture

Item	Unit cost with installation	Asset life (years)	Units by log scale (m^3/y)	
			7,500 & 15,000	30,000
Glue spreader	$41,045	5	1	1
Glue mixer	$15,202	5	1	1
Glue/resin storage	$133,000	25	1	1
Trim saw	$25,843	5	1	1
Sanding machine	$139,856	6	1	1
Cold press	$110,000	15	1	1
Hot press	$117,700	20	2	3
LVL conveyers	$19,800	5	1	1
LVL assembly	$30,404	7	1	1
LVL stacker	$67,740	5	2	2
Hydraulic lifter	$4104	5	1	1
Dust extraction and briquette machine	$187,000	20	1	1
Waste conveyer	$19,800	5	1	1
Waste chipper	$220,000	30	1	1
LVL storage	$44,000	8	1	2
Buildings (360m^2)	$270,000	30	1	2
LVL testing machine	$19,762	10	1	1
Lab equipment for oven, viscometer, hot plates, specific gravity etc.	$4400	10	1	1
Product development	$22,000	10	1	1
Total up-front capital costs for LVL beam manufacture			**$1,947,097**	**$2,648,797**
Annual maintenance costs (5% of capital)			$97,355	$132,440
Annual insurance costs (1.5% of capital)			$29,206	$39,732
Annual fixed costs for LVL beam manufacture			**$126,561**	**$172,172**

Table 18.8. Capital and fixed costs for LVL cross-arm manufacture

Item	Unit cost with installation	Asset life (years)	Units by log scale (m^3/y)	
			7,500 & 15,000	30,000
Glue spreader	$41,045	5	1	1
Glue mixer	$15,202	5	1	1
Glue/resin storage (15,000L)	$133,000	25	1	1
Trim saw	$25,843	5	1	1
Cold press	$110,000	15	4	7
Plywood conveyers	$19,800	5	1	1
LVL assembly	$30,404	7	1	1
Beam saw	$165,000	10	1	1
Product development	$22,000	10	1	1
Total up-front capital costs for cross-arm manufacture			**$892,293**	**$1,222,293**
Annual maintenance costs (5% of capital)			$43,515	$61,115
Annual insurance costs (1.5% of capital)			$13,384	$18,334
Annual fixed costs for cross-arm manufacture			**$56,899**	**$79,449**

Tables 18.5 to 18.8 each list the items, unit costs (including delivery and installation), asset life, and number of units of equipment required. At the 7500 m^3/y and 15,000 m^3/y scales, the number of units is interpreted as the physical number of units. At the 30,000 m^3/y scale, smaller equipment items are also interpreted as the physical number of units (e.g. veneer trolleys and forklifts in Table 18.5). However, for analysis purposes, the number of units of large equipment items (e.g. log steaming or bathing chamber, the biomass boiler, the waste chipper, and buildings in Table 18.5) are sometimes better interpreted as a cost scale with still only one physical unit of equipment.

The up-front capital costs of veneer and EWP manufacture are substantial. In this analysis, it has been assumed that 70% of the necessary funds will be borrowed from a bank at an interest rate of 6% for a loan term of 10 years. Maintenance costs in this section are for parts only, and this is set equal to 5% of the total capital cost. Insurance costs are assumed to be 1.5% of the total capital cost. At the end of an asset's life, a replacement is assumed to be purchased with cash. Assets are estimated to have a 5% residual value at the end of the project.

Labour costs

Table 18.9 presents the labour salaries and on-costs adopted in this case study. Salaries have been estimated to reflect typical industry wages with on-costs being determined in accordance with the Timber Industry Award 2010. To account for any employees who may not be present on a given day (e.g. away due to sickness or approved leave) a labour contingency cost of 10% has been added on top of the hourly labour on-cost to account for a labour hire arrangement. The annual hours worked in Table 18.9 is effectively the minimum number of hours that can be worked by a full-time employee under the Timber Industry Award 2010.

Table 18.10 highlights the necessary number of full-time equivalent workers at each stage of production, as estimated by industry experts. The 7500 m^3/y scale assumes that veneer and EWP production is a part-time operation, perhaps attached to an existing sawmill. The 15,000

m^3/y and 30,000 m^3/y scales are fulltime operations. However, when veneering takes place at the 7500 m^3/y scale, it is assumed to process the same volumes per day as the 15,000 m^3/y scale. For this reason, these scales have similar employment levels for the hours they are operating.

Table 18.9. Salaries, on-costs and annual hours worked by each full-time equivalent employee

Position	Annual salary	On-cost (% salary) [a]	Total annual cost of position	Annual hours worked [b]	Total cost of labour per hour
Manager	$150,000	27.15%	$193,725	1566	$114.16
Senior administration	$80,000	27.15%	$103,320	1566	$60.88
Supervisor/ Maintenance	$80,000	27.15%	$103,320	1566	$60.88
Machine operators	$55,000	27.15%	$71,033	1566	$41.86
Machine assistants	$45,000	27.15%	$58,118	1566	$34.25
Administration	$45,000	27.15%	$58,118	1566	$34.25

Notes: a. 27.15% on-cost represents 12% paid to compulsory superannuation, 10% labour contingency cost, 4.75% to payroll tax and 0.4% for workers' compensation insurance.
b. Hours worked are set to 38 hours per week, less 20 annual leave days, 12 personal leave days, 20 holidays where the mill is closed and 2 days off for other leave per year (e.g. long service, and parental).

The number of workers is generally a function of the scale of log throughput; however, the number of workers required during the drying phase is dependent on the dryer scenario. Labour requirements for a facility are cumulative. Regardless of which final product is manufactured, administration is required. If LVL beams are produced, then total labour needs at the facility will be the sum of administration, green veneer, dry veneer and LVL beam employment in Table 18.10. Note that any non-integer in Table 18.10 reflects a part-time role.

The additional number of workers required for LVL cross-arm manufacture is low because transforming LVL beams into cross-arms only requires the gluing of three LVL beams together and stacking them in a cold press for eight hours. It is assumed that some labour accounted for in LVL beam manufacture can assist with charging the cold presses for LVL cross-arms manufacture.

In the model, work shifts have been fixed at eight hours each for 48 weeks per year, for a total of 1920 hours per year. The model determines the number of shifts required for all scenarios on the basis of the productivity of equipment (Table 18.4). Up to three shifts per day are permitted in the model for all labour, except administration[30]. If necessary, the third shift operates throughout the late night and early morning and requires a payment of a 30% penalty rate over the labour costs listed in Table 18.9.

[30] Only one administration shift is required.

Table 18.10. Number of workers required at specified levels of throughput

Position	Number of workers per shift at each log scale (m^3/y)		
Administration	7500m	15,000	30,000
Manager	0	1	1
Senior administration	0	1	1
Supervisor	1	0	1
Quality control supervisor	0	1	1
Administration support	1	1	2
Total number of employees for administration	**2**	**4**	**6**
Green veneer	7500	15,000	30,000
Vehicle operators	1	1	2
Machine operators	2	2	4
Machine assistants	2	2	3
Maintenance	0.25	0.25	0.5
Total number of employees for green veneer production	**5.25**	**5.25**	**9.5**
Dry veneer	1 small dryer	2 small dryers	1 large dryer
Maintenance	0.25	0.25	0.25
Machine assistants	3	6	4
Total number of employees for dry veneer production	**3.25**	**6.25**	**4.25**
LVL Beam	7500	15,000	30,000
Supervisor	1	1	1
Maintenance	0.25	0.25	0.25
Machine operators	5	5	8
Billet processing and packaging and stacking	3	3	3
Total number of employees for LVL beam manufacture	**9.25**	**9.25**	**12.25**
LVL Cross-arms	7500	15,000	30,000
Machine operators	1	1	2
Total number of employees for cross-arm manufacture	**1**	**1**	**2**

Non-labour operating costs

Non-labour operating costs have been estimated through discussions with industry experts about costs for a 15,000 m^3 of log throughput facility. For some non-labour operating costs, it was challenging for the experts to justify changes in annual costs due to marginal changes in log volume input or final product output. These costs are presented in Table 18.11. Other non-labour costs could be estimated per unit volume of outputs from a production process, and these are reported in Table 18.12.

Table 18.11. Annual consumption of non-labour operating costs that do not vary with marginal changes in input or output volume (15,000 m^3 of log scale)

			Unit consumption per annum at 15,000 m^3/y log processing scale by processing stage			
Operating cost	Unit	Unit cost ($/unit)	Green veneer	Dry veneer	LVL beams	LVL cross-arms
Electricity	kWh	0.2	200,000	500,000	300,000	
Water	kl	1.56	6600			
Boiler feedstock	t	30	2160			
Consumables	1 unit	1000	10	2	1.5	1.5
Compliance	1 unit	1000	2	3	2	3
Sales cost	1 unit	15,000			1	1

Consumption of non-labour operating costs in Table 18.11 are listed for each stage of production and are cumulative across the processing stages. For example, annual electricity consumption to produce dry veneer is 200,000 kWh to process 15,000 m^3 of logs into green veneer, plus 500,000 kWh to dry the veneer. The consumption of all non-labour operating costs listed in Table 18.11 for the 15,000 m^3 of log scale are assumed to be half and double for the 7500 m^3 of log and 30,000 m^3 of log scales, respectively.

Table 18.12. Consumption of non-labour operating costs that do vary with marginal changes in output volume (15,000 m^3 of log scale)

			Unit consumption per 1000 m^3 of marketable product by processing stage			
Operating cost	Unit	Unit cost ($/unit)	Green veneer	Dry veneer	LVL beams	LVL cross-arms
Hot glue	t	800			73 [a]	75 [b]
Cold glue	t	800				5.9 [b]
Machine wrapping	1 roll	70.69	9.1	9.1		
Bearers and strapping	1 unit	10			24	24
Pallets	1 pallet	50	27 [c]	27 [c]		
Freight						
7500m^3/y	1 unit	60	1000	1000	1000	1000
15,000m^3/y	1 unit	55	1000	1000	1000	1000
30,000m^3/y	1 unit	50	1000	1000	1000	1000

Notes: a. In LVL beams production (either as a final product or as an input to produce of LVL cross-arms), PF hot glue is applied to one side of 11 of the 12 veneer sheets at a rate of 200 g/m^2, which equates to 61 kg/m^3 of LVL panel. Trimming and waste from sawing reduces LVL beam recovery to 83% of panel volume resulting in glue consumption of 73 kg/m^3.

b. LVL cross-arms require three LVL panels glued together with two cold glue lines applied at 250 g/m^2, which equates to 4.8 kg/m^3 of LVL panel. When the LVL panels are trimmed and sawn into LVL cross-arms, 81% of panel volume is recovered as product. Thus, PF hot glue consumption is 75 kg/m^3 of cross arms (61 kg/m^3 / 0.81) and cold glue consumption is 5.9 kg/m^3 of LVL cross-arms.

c. Pallet consumption per 1000 m^3 of final product assumes a 4-week turn-around for pallets to be returned to the plant following product delivery, and that half of the pallets need to be replaced each year.

Electricity consumption was estimated at 1 million kWh for a facility with a woody biomass boiler (for log steaming and veneer drying) that is producing engineered wood products. It was asserted by key informants from industry that energy would be allocated approximately 20% to green veneering, 50% to drying and 30% to engineered wood product manufacturing (for either LVL beam or LVL cross-arm production). Experts considered it unlikely that energy costs would vary with marginal changes in production, because most of the equipment will draw electricity for a similar period. For example, the jet drier will typically only be shut down once per week for maintenance, irrespective of the actual throughput of green veneer.

When recoveries of final products exceed about 40% of input log volume, as it does in all scenarios evaluated, additional biomass feedstock for the boiler must be purchased to supplement on-site wood waste. Generally, the boiler needs to operate 24 hours per day irrespective of output volume.

Consumables include costs such as lathe knives, personal protective equipment, sandpaper and other items that may regularly need replacing. Items that ensure the veneer products are compliant with regulatory standards such as moisture metres, measuring tapes and thickness gauges have been included under ‘compliance’ cost. Presently in Australia, LVL is not being used in the markets this analysis assumes it will be sold into. It is anticipated there will be market development costs. The analysis accommodates sales costs for travel, accommodation and per diem for a sales representative to market the LVL.

Table 18.12 reports consumption of non-labour operating costs per 1000 m^3 of marketable product. Unlike Table 18.11, these costs are not cumulative across the processing stages. All the relevant non-labour operating costs that vary with marginal changes in output are listed in the column for the marketable final product. Machine wrapping (plastic), bearers and strapping, and pallets costs are incurred only when the product is prepared for freight to market.

Freight charges reported in Table 18.12 are based on the mean cost of delivering timber product to major markets throughout Australia from Brisbane, as provided by key informants from the industry. Freight companies are assumed to provide a discount with increasing scale.

Market prices

Market prices for final products adopted in this analysis are reported in Table 18.13. Commercial green and dry-graded veneer values are challenging to determine, as veneer producers are typically manufacturing engineered wood products with the veneer they produce, and the costs of production and final market prices of engineered wood products vary substantially. Anecdotal information indicates that 3.2 mm and 2.15 mm dry D-grade exotic pine veneer in Australia has a wholesale value of about \$400/m^3. Engineered Wood Products Association of Australasia (2014) asserted that C-grade veneer is about 1.2 times D-grade, B-grade is 1.7 times D-grade, and A-grade is 3 times D-grade. This study has adopted these relative values for C, B and A-grade veneers, which equate to \$480/m^3, \$680/m^3 and \$1200/m^3, respectively. The price of marketable dry veneer adopted in the case study of \$426/m^3 was determined by multiplying the proportion of veneer recovered by grade by the grade price.

Industry experts asserted purchasers of green veneer would expect the cost of drying to be about \$100/m^3. On this basis, a mean price of \$300/m^3 for green veneer has been adopted. It is assumed that green veneer would be sold ungraded.

Retail prices of LVL beams and cross-arms were estimated by industry experts to currently be \$1000 and \$2750, respectively. Anecdotal evidence suggested the wholesale price of an LVL cross-arm would be about 50% of the retail price to account for additional value-adding necessary to prepare the cross-arm for installation on an electricity pole.

Table 18.13. Market prices of final products

Marketable product	Market price ($/m^3 of final product)
Green veneer	$300
Dry veneer	$426
LVL beams	$1000
LVL cross-arms	$1375

Analysis methods to estimate financial performance of veneer and EWP manufacture

This section describes the estimation of costs, revenues and investment performance for 36 veneer and engineered wood product manufacturing scenarios: three processing scales (*k*); three log diameter sizes (*l*); and four marketable products produced from different processing stages (*j*). A discounted cash flow analysis has been performed at a 7% real (net of inflation) discount rate over a 30-year project period to determine the net present value (NPV), internal rate of return (IRR) and payback period for each scenario. The standard Australian company tax rate of 30% has been applied to determine profit after tax; however, tax benefits of claiming depreciation on equipment have not been accommodated.

All necessary capital expenditure for a particular processing scale to produce a particular marketable product (as listed in Tables 18.5 to 18.8) is assumed to be made in year zero. The 70% of capital expenses that is borrowed is assumed to be paid back in 10 equal annual instalments. Equipment with an asset life of less than 30 years is discarded for zero return at the end of its useful life, and a new piece of equipment is purchased out of operating revenues. At the end of the project period, equipment is sold for 5% of the asset's original value, irrespective of the age of the asset.

Annual mill-delivered log costs for logs of diameter *l* at processing scale *k* ($AMDLC_{kl}$) have been estimated with Equation 18.5.

$$AMDLC_{kl} = V_l \times C_{kl} \quad \text{[eq. 18.5]}$$

where V_l is the volume of logs purchased of log diameter *l* (m^3/y); and
C_{kl} is the cost of mill-delivered logs of log diameter *l*, for processing scale *k* ($/m^3).

Annual labour costs (ALC_{klj}) for processing stage *j* (administration, green veneering, drying, LVL beam manufacture, and LVL cross-arm manufacture) at processing scale *k* when processing logs of diameter *l*, has been estimated as follows:

$$ALC_{klj} = \sum_{s=1}^{S} \sum_{i=1}^{I} NE_{ksji} \times LC_{is} \times H_{kslj} \quad \text{[eq. 18.6]}$$

where NE_{ksji} is the number of employees per shift in role *i* employed at processing stage *j*, in labour shift *s*, at processing scale *k* (from Table 18.10);
LC_{is} is the cost of labour per hour for one employee in role *i* (from Table 18.9) in labour shift *s*; and
H_{kslj} is the hours of operation at each processing stage *j*, when processing logs of diameter *l*, in labour shift *s*, at processing scale *k* (further defined below).

The number of employees in each shift of each processing stage are identical for the hours worked. Each shift is assumed to be for a maximum of 8 hours, with each worker contributing

1566 hours per year to production (Table 18.9). If hours of operation at a processing stage (H_{kslj}) exceeds 1566 hours, then a second shift is required. If hours of operation at a processing stage exceeds 3132, a late night, third shift will be required, with workers earning a penalty rate of 30% above the hourly rates listed in Table 18.9.

Determination of H_{kslj} required estimation of the annual marketable volume of output produced by processing stage *j* (MV_{klj},), from logs of diameter *l* at log processing scale *k*.

$$MV_{klj} = MDLV_{kl} \times R_{lj} \qquad \text{[eq. 18.7]}$$

where $MDLV_{kl}$ is the mill-delivered log volume of log diameter *l* at log processing scale *k*;

R_{lp} is the recovery rate (%) from log volume of product from processing stage *j* from logs of diameter *l* (from Table 18.3).

MV_{klj} was then used to estimate hours of operation at a processing stage (H_{klj}) for each processing stage, *j*, as described by equations 18.8 to 18.11.

$$H_{kslGreen\ veneer} = \frac{MDLV_{kl}}{VLH_l \times NSL} \qquad \text{[eq. 18.8]}$$

$$H_{kslDry\ veneer} = \frac{MV_{klGreen\ veneer}}{VGVH_d \times ND} \qquad \text{[eq. 18.9]}$$

$$H_{kslLVL\ beams} = \frac{MV_{klDry\ veneer}}{VDVH \times NHP} \qquad \text{[eq. 18.10]}$$

$$H_{kslLVL\ cross-arms} = \frac{MV_{klLVL\ beams}}{VLBH \times NCP} \qquad \text{[eq. 18.11]}$$

where VLH_l is the volume of logs processed per hour of log diameter *l* adjusted for the utilisation rate of the spindleless lathe (from Table 18.4);

NSL is number of spindleless lathes;

$MV_{klGreen\ veneer}$ is the volume of marketable green veneer produced from logs of diameter *l* at processing scale *k*, (determined in eq. 18.7);

$VGVH_d$ is the volume of green veneer dried per hour by drier size *d* adjusted for the utilisation rate (from Table 19.4);

ND is number of driers;

$MV_{klDry\ veneer}$ is the volume of marketable dry veneer produced from logs of diameter *l* at processing scale *k*, (determined in eq. 18.7);

VDVH is the volume of dry veneer glued and pressed into LVL beams per hour, adjusted for the utilisation rate (from Table 18.4);

NHP is the number of hot presses;

$MV_{klLVL\ beams}$ is the volume of marketable LVL beams produced from logs of diameter *l* at processing scale *k*, (determined in eq. 18.7);

VLBH is the volume of LVL beams glued and pressed into LVL cross-arms per hour, adjusted for the utilisation rate (from Table 18.4);

NCP is the number of cold presses; and

All other variables are previously defined.

Administration labour hours at the 15,000 m^3/y and 30,000 m^3/y scale has been set to 1566 hours, with 7500 m^3/y scale being equal to 783 (half of a full-time equivalent).

Annual non-labour operating costs ($ANLOC_{klj}$) have been estimated as follows

$$ANLOC_{klj} = SF_k \left[\sum_{n=1}^{N}\left(U_{jn} \times UC_n\right) + \sum_{m=1}^{M}\left(\frac{MV_{klj}}{1000} \times U_{jm} \times UC_m\right)\right] \qquad \text{[eq. 18.12]}$$

where SF_k is the processing scale factor (0.5 when k=7500; 1.0 when k = 15,000; 2.0 when k = 30.000);

U_{jn} is the number of units consumed of non-labour operating cost, *n*, that does not vary with marginal changes in output volume due to log size, when producing marketable product from processing stage *j* (Table 18.11);

UC_n is the unit cost of non-labour operating cost, *n*, that does not vary with marginal changes in output volume due to log size ($/unit) (Table 18.11);

U_{jm} is the number of units consumed per 1000 m^3 of non-labour operating cost, *m*, that does vary with marginal changes in output volume due to log size, when producing marketable product from processing stage j (Table 18.12);

UC_m is the unit cost of non-labour operating cost, *m*, that does vary with marginal changes in output volume due to log size ($/unit) (Table 18.12); and

All other variables are previously defined.

Annual packaging and freight costs (APF_{klj}) have been estimated with Equation 18.13.

$$APF_{klj} = \left(\frac{P_j}{1000} + F_k\right) MV_{klj} \quad \text{[eq. 18.13]}$$

where P_j is the packaging cost per 1000 m^3 of marketable product for the product produced by processing stage *j*;

F_k is the freight cost to market per cubic metre of final product by processing scale *k*; and

All other variables are previously defined.

Annual revenues (AR_{klj}) have been estimated with Equation 18.14.

$$AR_{klj} = MV_{klj} \times MP_j \quad \text{[eq. 18.14]}$$

where MP_j is the market price per cubic metre of the product produced by processing stage *j*; and

All other variables are previously defined.

The after tax NPV of the production scenarios assessed over a 30 year project period at a 7% discount rate have been estimated as

$$NPV_{klj} = \sum_{t=1}^{30} \frac{\left[\left(AR_{klj} - \left(AMDLC_{klj} + ALC_{klj} + ANLOC_{klj} + APF_{klj} + AFR_{klj}\right)\right) - \sum_{e=1}^{E} EC_{kje} \times NE_{kjet}\right] \times (1 - TAX)}{1.07^t} - C_{kj} + \frac{RSC_{kj}}{(1.07^{30})}$$

[eq. 18.15]

where AFR_{klj} is the annual finance repayment costs for time period 1 to 10 years to repay the loan to finance the purchase of equipment and buildings in year zero;

EC_{kje} is the equipment cost of piece of equipment *e* from processing stage *j* at scale of production *k;*

NEk_{jet} is the number of pieces of equipment bought in time period *t* of equipment *e* from processing stage *j* at scale of production *k;*

TAX is the company tax rate in percent (Australian company tax rate of 30 % adopted in this analysis);

C_{kj} is the cash paid in year zero to purchase equipment and buildings for processing stage *j* at processing scale *k* (Tables 18.5 to 18.8);

RSC_{kj} is the resale value of equipment at the end of the project period for processing stage *j* and processing scale *k*; and

All other variables are previously defined constant annual revenues or expenses.

The internal rate of return for each scenario (IRR_{klj}) has been determined by solving for the discount rate that sets the NPV in Equation 18.15 to zero. The payback period (PBP_{klj}) is the number of years of operation required to recover the cash invested in the project in year zero, C_{kj}. All revenues and expenses, other than finance repayment costs and equipment purchase costs after year zero, are constant in real dollars each year for the 30-year project life. Finance repayment costs are only for the first 10 years. Equipment purchase costs after year zero are only incurred periodically, as indicated in Tables 18.5 to 18.8.

$$PBP_{klj} = T \qquad \text{[eq. 18.16]}$$

where T is the value of time period t that satisfies the following condition

$$C_{kj} - \left[t\left(AR_{klj} - \left(AMDLC_{klj} + ALC_{klj} + ANLOC_{klj} + APF_{klj}\right)\right) - t \times AFR_{klj} - \sum_{e=1}^{E}\sum_{t=1}^{T} EC_{kje} \times NE_{kjet}\right] = 0 \qquad \text{[eq. 18.17]}$$

where all variables are previously defined and the maximum value t can take on when being multiplied by AFR_{klj} is 10. This condition has deliberately ignored the time value of money, as is standard for estimation of the payback period.

The average gross profit after tax per cubic metre of marketable product over the 30 year investment period, AP_{klj}, has been estimated as follows

$$AP_{klj} = \left[\frac{NPV_{klj} \times 0.07\left(1.07^{30}\right)}{1.07^{30} - 1}\right] \Big/ MV_{klj} \qquad \text{[eq. 18.18]}$$

where all variables have been previously defined, and the term in square brackets coverts NPV_{klj} into an annualised equivalent at a 7% discount rate over 30 years. The term gross profit has been adopted because, while it does account for tax, there are likely to be some overhead costs not accounted for in the analysis, such as administration office expenses.

The average costs of production per cubic metre of marketable product, AC_{klj}, over the 30 year investment period has been estimated as follows

$$AC_{klj} = \left[\sum_{t=1}^{30} \frac{AMDLC_{klj} + ALC_{klj} + ANLOC_{klj} + APF_{klj} + AFR_{klj} + \sum_{e=1}^{E} EC_{kje} \times NE_{kjet}}{1.07^{t}} + C_{kj}\right] \times \left[\frac{0.07\left(1.07^{30}\right)}{1.07^{30} - 1}\right] \Big/ MV_{klj} + \left[\frac{AP_{klj}}{1 - TAX} \times TAX\right] \quad ; \forall\, AP_{klj} > 0$$

[eq. 18.19]

where all variables have been previously defined. The first term in square brackets calculates the present value of the costs of production. Multiplying this term by the second term in square brackets converts the present value of the costs into an annualised equivalent at a 7% discount rate over 30 years. This is then divided by the annual production volume to determine costs per cubic metre of marketable product. The last term in square brackets adds the average company tax paid per cubic metre of marketable product.

Mixed LVL production

Recognising that there may be scale limitations on a potential LVL cross-arm market in Australia, mixed LVL production scenarios, where 70% of output was short-length LVL beams and 30% was LVL cross-arms, were also examined. The costs of these scenarios are effectively the LVL cross-arms scenario costs (for all scale of production and log SEDUB scenarios) with full administration, green veneering, drying and short-length LVL beam manufacturing costs, but with only approximately 30% of the LVL cross-arm stage of production capital and operating costs. The analysis has adopted a weighted market price of \$1113/m^3 (0.7 x \$1000/m^3 + 0.3 x \$1375/m^3).

Financial performance of veneer and EWP production

This section presents the financial performance of the 36 log processing scale, log type and final product scenarios examined, as determined from the data and methods described in earlier sections. The following characteristics and financial performance metrics are described for each scenario:

- annual production and hours of operation;
- up-front capital costs;
- annual costs of production;
- annual revenues;
- after tax net present value, internal rate of return and payback period; and
- costs and after tax gross profit per cubic metre of final product.

Reporting of the financial performance of the mixed short length LVL beams and cross-arms manufacturing concludes this section of the report.

Annual production and hours of operation

Annual volume of marketable product (MV_{klj}) is reported in Table 18.14. Although not highlighted in Table 18.14, the evaluation of scenarios assumes production in the first year of operation is only half the volumes indicated to account for establishment and commissioning of the manufacturing facilities. Table 18.15 reports the hours of operation (H_{kslj}) at each processing stage to manufacture particular products. Figure 18.2 displays the green veneer information in Tables 18.15 and 18.16 to clearly illustrate the effect of log SEDUB on hours of veneer processing time and volume of green veneer produced by scale of operation. In Figure 18.2, at the 30,000 m^3 scale, total hours peeling logs through both spindleless lathes is reported, while Table 18.15 reports only the hours that veneering is taking place at the manufacturing facility, which reflects the two lathes operating at the same time to produce twice the hourly output of one lathe.

Consistent with recovery from log volume estimates (Table 18.3), the volume of marketable product increases with log diameter. An increase in SEDUB from 25 cm to 35 cm will produce 14.1% more product volume, and an increase in SEDUB from 35 cm to 45 cm will yield 6.5% more product volume from the same volume of logs. Consistent with the productivity of the spindleless lathe (Table 18.4), larger logs result in more veneer volume produced per hour of production compared to peeling smaller logs. Both of these factors make working with larger logs more desirable, although these benefits need to be compared against potentially higher mill-delivered log costs and opportunity costs associated with diverting logs from more profitable manufacturing processes.

Table 18.14. Volume of marketable product produced per annum by log scale and SEDUB

	Annual volume of marketable product (m^3/y product) by scale of production (m^3/y log) and SEDUB (cm)								
	25			35			45		
Product	7500	15,000	30,000	7500	15,000	30,000	7500	15,000	30,000
Green veneer	5184	10,367	20,734	5917	11,835	23,669	6301	12,602	25,203
Dry veneer	3888	7775	15,551	4438	8876	17,752	4726	9451	18,902
LVL beam	3239	6477	12,954	3697	7394	14,788	3937	7873	15,746
LVL cross-arm	3149	6297	12,595	3594	7189	14,377	3827	7655	15,309

Table 18.15. Annual processing hours for each product by SEDUB and log processing scale

	Annual production hours by scale of production (m^3/y log) and SEDUB (cm)								
	25			35			45		
Product	7500	15,000	30,000	7500	15,000	30,000	7500	15,000	30,000
Green veneer	833	1667	1667	731	1461	1461	628	1256	1256
Dry veneer	1270	2541	3485	1450	2901	3978	1544	3089	4236
LVL beams	778	1555	2073	888	1775	2367	945	1890	2520
LVL cross-arm	1574	3149	3936	1797	3594	4493	1914	3827	4784

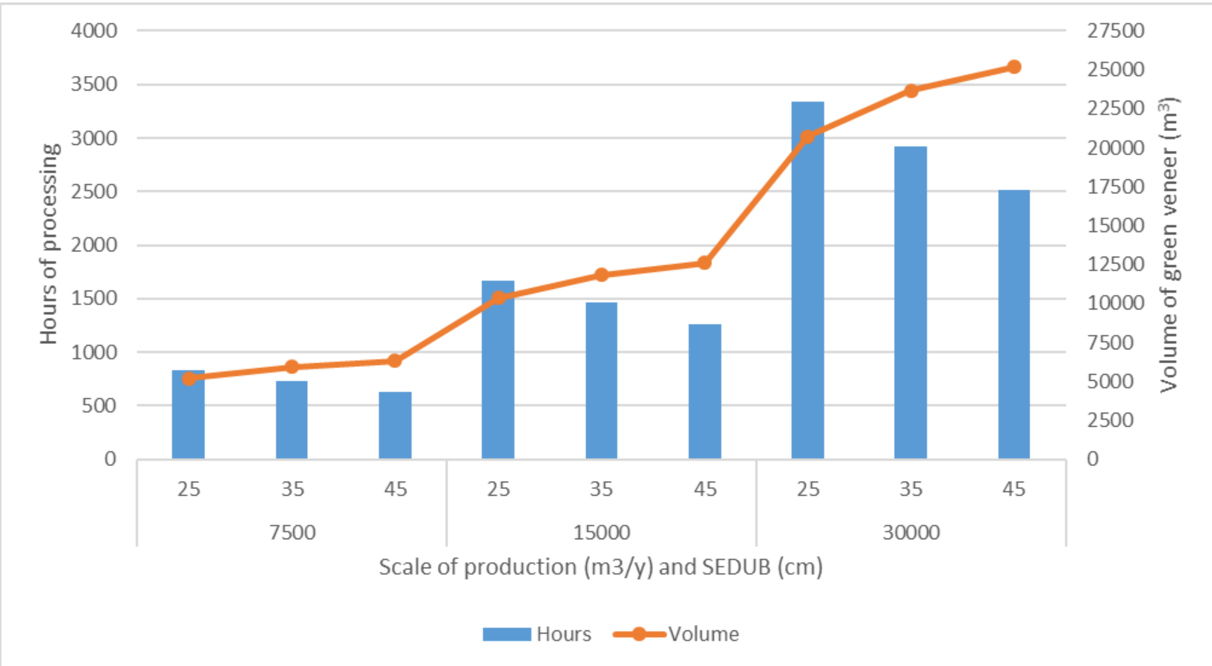


Figure 18.2. Relationship between log size, processing hours and green veneer volume

Table 18.15 reports the hours of operation (H_{kslj}) at each processing stage to manufacture particular products. For example, veneering 15,000 m^3 of 35 cm SEDUB logs will require 1461 hours at the spindleless lathe, and drying the green veneer will require 2901 hours with the jet dryer. These hours of operation drive labour costs in the model.

Hours of operation for veneer drying was determined for the least cost drying method out of one small jet dryer, two small jet dryers and one large jet dryer. One small dryer was the least cost drying method for all log SEDUBs for the 7500 m^3/y and 15,000 m^3/y log processing scales. One large dryer was most cost-effective for all SEDUBs when processing scale was 30,000 m^3/y. Despite having the greatest drying capacity, two small dryers was never the most cost-effective drying method because of the high capital and operating costs, relative to one large dryer.

From the annual production hours in Table 18.15, and given 1920 hours per year in one shift, the number of shifts can be determined. It is assumed that all administration employees work one shift per day. However, at the 7500 m^3/y scale, all administration employees are assumed to only be employed for 50% of the working days in the year supporting the veneer and EWP manufacturing part of the business.

Only at the 30,000 m^3/y scale, and only for veneer drying, is a third shift per day required. Therefore, the 30% penalty rate has been applied to the third drying shift when appropriate. The high number of hours for LVL cross-arm manufacture at the 30,000 m^3 of log scale suggests the need for three labour shifts, but it actually represents total glue setting time. Three 8-hour charges of LVL cross-arms can be achieved by setting one at the beginning of shift one, the second at the end of shift one, and the third at the end of shift two. Therefore, LVL cross-arm manufacture never requires more than two shifts of labour.

Capital costs of production

Figure 18.3 displays the total up-front capital expenditure necessary to commence operation for the 7500, 15,000 m^3/y and 30,000 m^3/y log processing scales. Capital costs are cumulative to the product being manufactured for market. For example, if dry veneer is being produced at the 15,000 m^3 of log scale, total up-front capital costs are $5.2 M ($4.38 M + $0.82 M). The capital costs of drying veneer reflect the most cost-effective arrangement, as described previously. The analysis assumes that 70% of all up-front capital costs will be borrowed from a bank, with 30% paid by the investors in cash. Asset replacement costs, when pieces of equipment come to the end of their useful life, are accounted for in the estimation of NPV.

Annual costs of production

Table 18.16 reports the annual costs of production by processing stage for all scenarios, as estimated by Equations 18.5 to 18.13. With the exception of packaging and freight, costs of production are cumulative. For example, the annual costs of producing short-length LVL beams for market is the sum of administration, green veneer, dry veneer and LVL expenses. However, the only packaging and freight costs applicable for the sale of LVL beams are the packaging and freight costs listed for LVL beams. Annual finance repayments were determined using the loan parameters described. The loan is paid off at the end of year 10. All other annual costs continue for the 30-year project life.

Table 18.16. Annual costs by production stage

Cost type by production stage	Annual cost ($ millions) by SEDUB and log processing scale (m^3 of log)								
	25 cm			35 cm			45 cm		
	7500	15,000	30,000	7500	15,000	30,000	7500	15,000	30,000
Administration									
Labour	0.082	0.433	0.596	0.082	0.433	0.596	0.082	0.433	0.596
Green veneer									
Mill-delivered logs	1.028	2.175	5.010	0.968	2.070	4.770	1.380	2.895	6.420
Labour	0.192	0.384	0.705	0.168	0.336	0.618	0.145	0.289	0.531
Non-labour operating	0.064	0.127	0.254	0.064	0.127	0.254	0.064	0.127	0.254
Finance	0.416	0.416	0.751	0.416	0.416	0.751	0.416	0.416	0.751
Pack and freight	0.321	0.591	1.078	0.366	0.674	1.229	0.390	0.717	1.309
Dry veneer									
Labour	0.180	0.360	0.640	0.210	0.410	0.730	0.220	0.440	0.780
Non-labour operating	0.053	0.105	0.210	0.053	0.105	0.210	0.053	0.105	0.210
Finance	0.052	0.052	0.078	0.052	0.052	0.078	0.052	0.052	0.078
Pack and freight	0.241	0.443	0.809	0.275	0.506	0.923	0.293	0.539	0.983
LVL beams									
Labour	0.351	0.703	1.224	0.401	0.802	1.397	0.427	0.855	1.487
Non-labour operating	0.222	0.444	0.887	0.249	0.497	0.995	0.263	0.526	1.051
Finance	0.185	0.185	0.252	0.185	0.185	0.252	0.185	0.185	0.252
Pack and freight	0.203	0.373	0.681	0.230	0.423	0.773	0.245	0.450	0.821
LVL cross-arms									
Labour	0.036	0.072	0.095	0.041	0.082	0.109	0.044	0.087	0.116
Non-labour operating	0.015	0.030	0.059	0.016	0.031	0.063	0.016	0.032	0.065
Finance	0.085	0.085	0.116	0.085	0.085	0.116	0.085	0.085	0.116
Pack and freight	0.197	0.363	0.663	0.224	0.412	0.752	0.238	0.438	0.799

Figure 18.4 highlights total employment at the facility by log size processed and log processing scale, given the required number of employees per shift (Table 18.10) and the number of shifts (derived from Table 18.15). Annual labour costs in Table 18.16 reflect the number of employees illustrated in Figure 18.4. Labour costs for green veneer manufacture from a particular log volume decrease with increasing log diameter, as less time is required to process a given log volume comprising larger logs. At the 30,000 m^3/y scale, green veneer labour costs are 25% lower for 45 cm SEDUB logs than for 25 cm SEDUB logs. As log

diameter increases, volume of green veneer recovered increases, which raises annual processing time, and therefore cost of labour, for all stages of production after veneering.

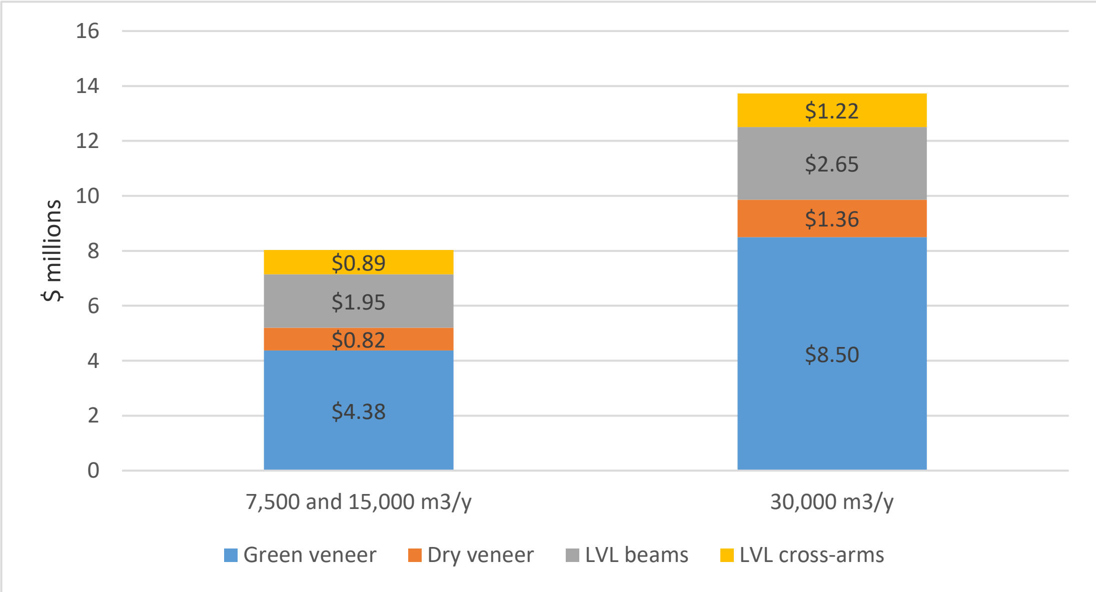


Figure 18.3. Total up-front capital costs by scale of production ($ millions)

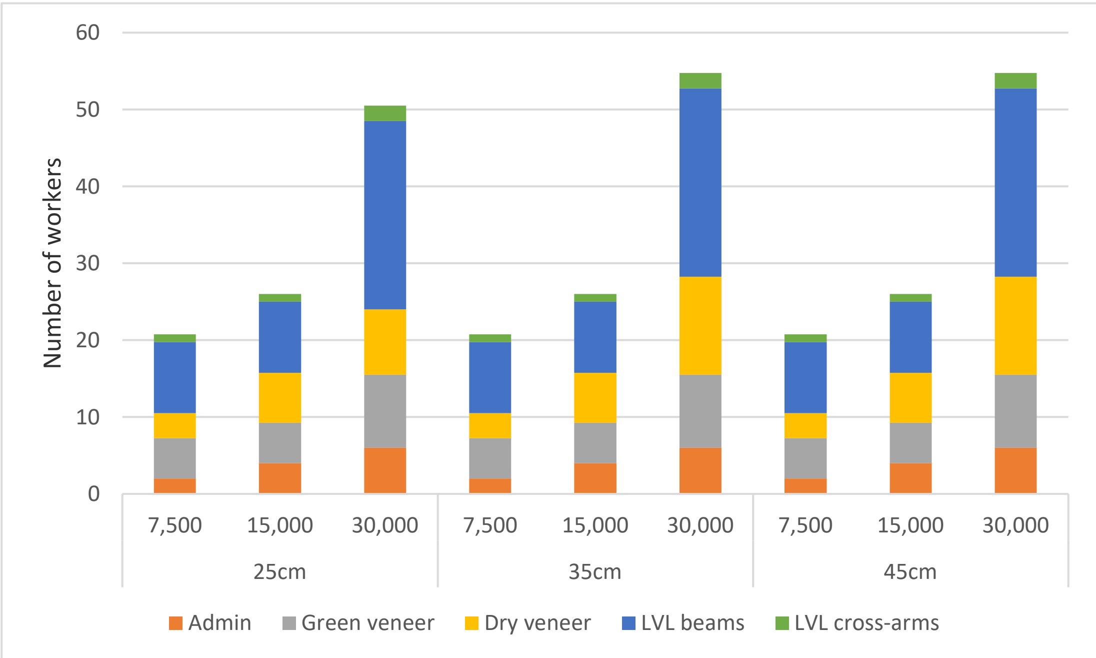


Figure 18.4. Total employment by stage of production for each log size (cm) and log processing scale (m^3/y) scenario

Figure 18.5 displays the composition of non-labour operating costs for each stage of production reported in Table 18.16. For purposes of analysis, feedstock for the boiler is costed to green veneer production (used for peeler billet pre-conditioning), even though the heat is also used for veneer drying (if the veneer is dried). Industry experts were unable to provide estimates of the marginal energy cost of producing LVL cross-arms from LVL beams. For analysis purposes, all energy costs for LVL production are accounted for in the costs of LVL beam manufacture.

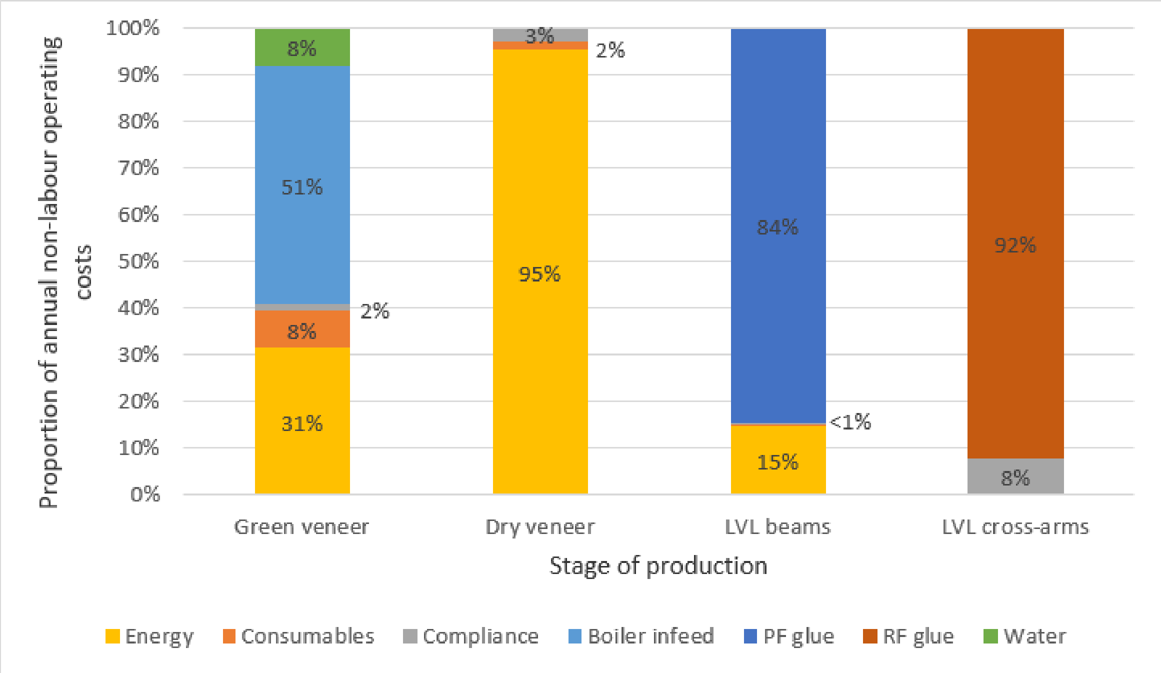


Figure 18.5. Composition of non-labour operating costs by stage of production

Annual revenues

Annual revenues before tax determined from Equation 18.14 are reported in Table 18.17. Revenues increase substantially with increasing log size because of higher product recovery from log volume. Despite the $126/m^3 higher market price of dry veneer over green veneer, there is only a small increase in revenue because of the relatively large reduction in marketable volume (Table 18.14). There may be other technical benefits of producing dry veneer rather than green veneer, such as mould management, and reduced product weight for transportation.

Table 18.17. Annual revenues before tax

	Annual revenues ($ millions) by log SEDUB (cm) and log processing scale (m^3/y)								
	25			35			45		
Marketable product	7500	15,000	30,000	7500	15,000	30,000	7500	15,000	30,000
Green veneer	1.56	3.11	6.22	1.78	3.55	7.10	1.89	3.78	7.56
Dry veneer	1.66	3.31	6.62	1.89	3.78	7.56	2.01	4.03	8.05
LVL beams	3.24	6.48	12.95	3.70	7.39	14.79	3.94	7.87	15.75
LVL cross-arms	4.33	8.66	17.32	4.94	9.88	19.77	5.26	10.52	21.05

Annual profit after tax has not been reported because it varies yearly with periodic equipment replacement expenditure not summarised in Table 18.16. The following sections do account for all costs of the projects over the 30-year project life, including tax.

After tax net present value, internal rate of return and payback period

Figure 18.6 illustrates the NPV after tax from manufacturing the four marketable products over a 30-year project period at a 7% real (net of inflation) discount rate. The periodic replacement of equipment has been accommodated in this analysis. Given the market prices for veneer assumed in this analysis, production of green and dry veneer for market are not financially viable for any log SEDUB or log processing scale scenario. Annual revenues never exceed annual costs of production for both of these products. Consequently, investment losses increase with manufacturing scale. The green and dry veneer scenarios had large negative IRRs and did not payback the investor within 30 years.

LVL beams generated positive NPVs from 35 cm and 45 cm logs when the scale was at least 15,000 m^3/y. Only the 30,000 m^3/y scale generated positive returns when 25 cm logs were processed into LVL beams. LVL cross-arms are the most profitable product evaluated, with all LVL cross-arm scenarios generating positive NPVs. For example, processing 35 cm SEDUB logs at the 15,000 m^3/y scale generated a NPV of $25 million, and at the 30,000 m^3/y scale earned $57 million.

Figure 18.7 presents the internal rate of return (IRR) for LVL beams and LVL cross-arms. Key informants from industry suggested IRRs of at least about 20% are required to encourage investment to diversify production into new markets. On this basis, most LVL cross-arm scenarios are attractive, including when 25 cm SEDUB logs are processed. Larger scale LVL beam scenarios utilising logs with SEDUB of at least 35 cm also earn IRRs exceeding 20%.

Figure 18.8 presents the payback periods for establishing manufacturing facilities for these products. LVL beams manufacture at the 7500 m^3/y scale with 25 cm or 45 cm SEDUB logs will not payback the investor within 30 years. Scenarios providing at least 20% IRR have payback periods not exceeding four to five years, which should be encouraging for industry.

Costs and after tax gross profit per cubic metre of product

Figure 18.9 highlights costs of production by stage of production per cubic metre of final product, as estimated with Equation 18.19. Since net losses were earned from the sale of green and dry veneer, no tax is payable for these scenarios. Costs at each stage of production per cubic metre of final product rise as more processing occurs (and value is added), because of progressively lower recovery of marketable product from log volume. For example, the costs of green veneering at the 15,000 m^3/y scale with 35 cm SEDUB logs is $143/$m^3$ of green veneer, but $233/$m^3$ of LVL cross-arms for the same processing scale and log diameter.

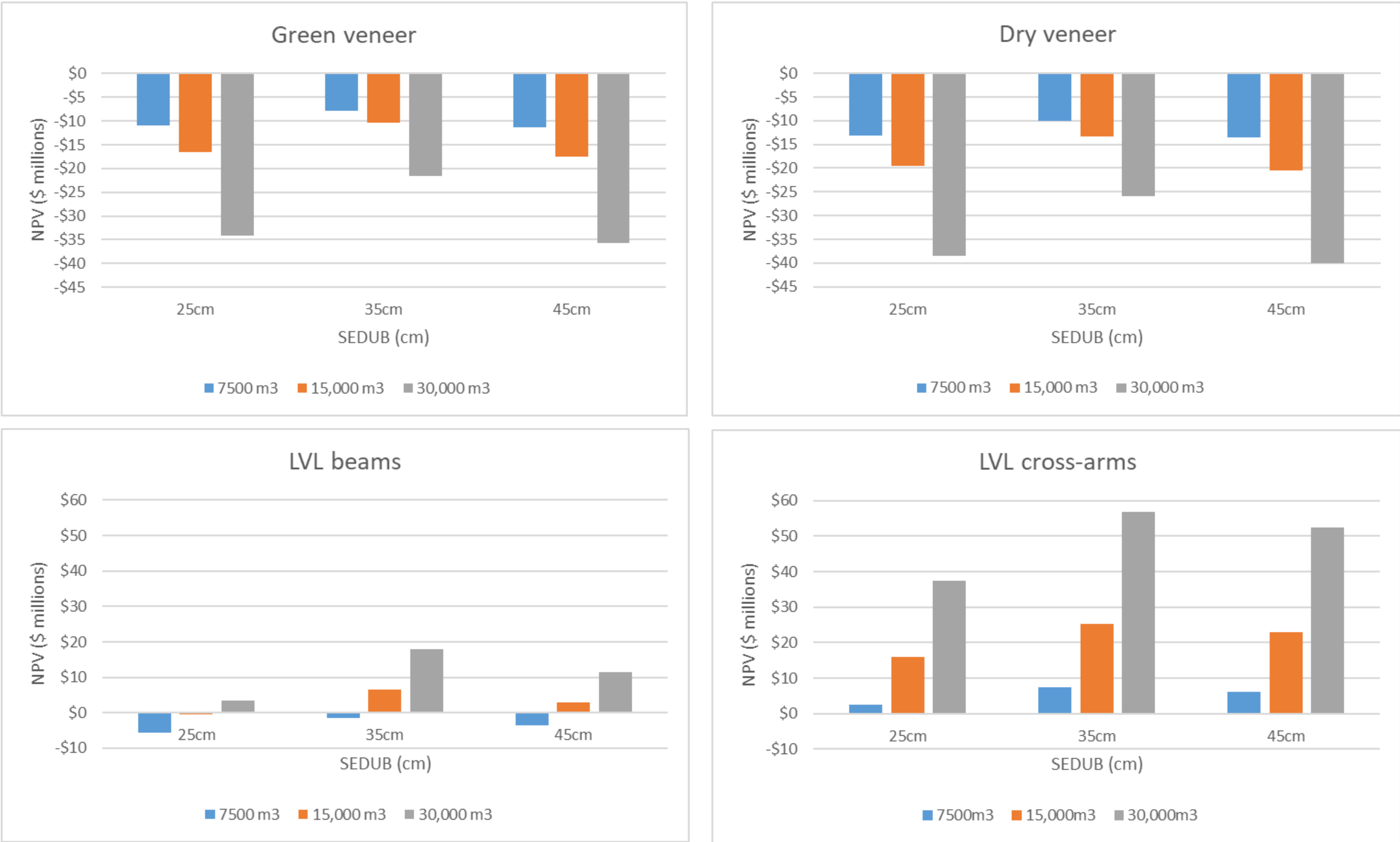
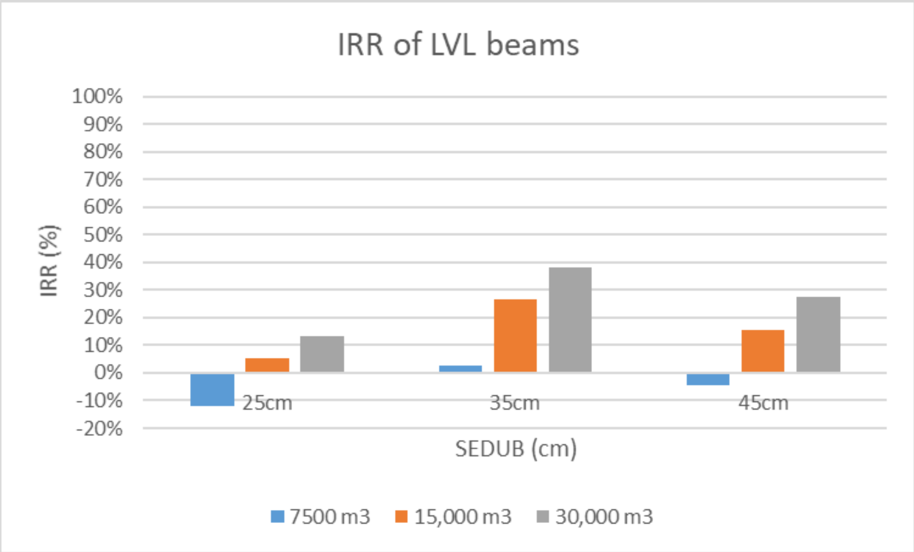


Figure 18.6. After tax NPV for veneer and EWP manufacturing over 30 years at a 7% discount rate (30% standard company tax rate)



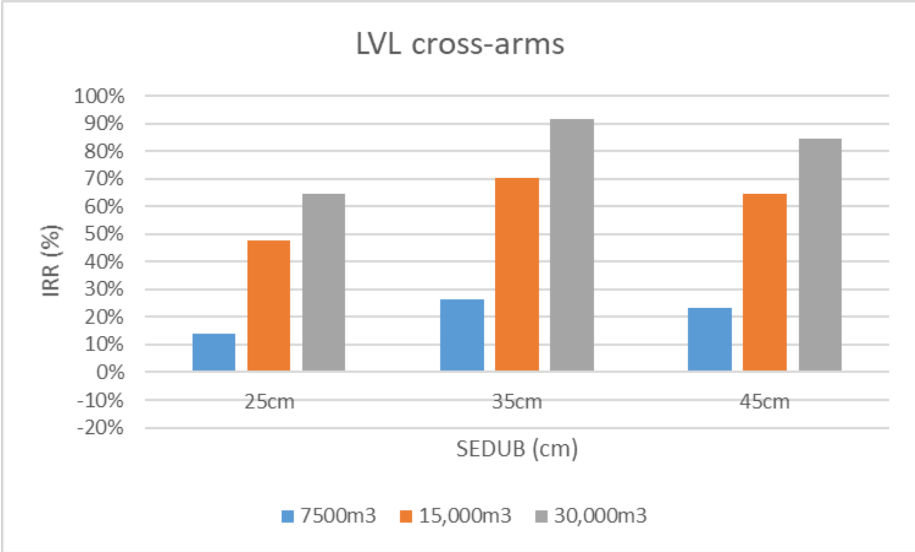
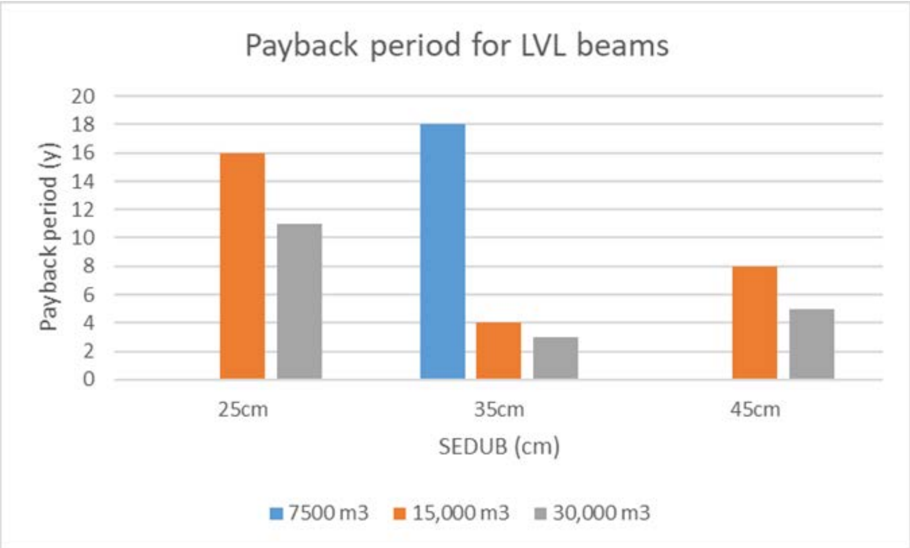


Figure 18.7. After tax internal rate of return for LVL products



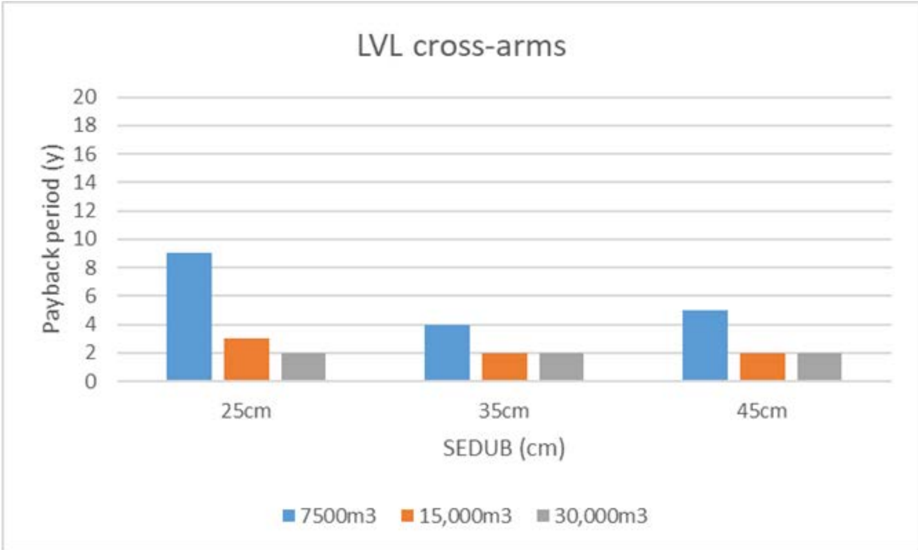


Figure 18.8. After tax payback period for LVL products

Figure 18.9. Costs of veneer and engineered wood product manufacturing by stage of production per cubic metre of final product

Figure 18.9 reveals economies of scale in the manufacture of dry veneer, short-length LVL beams and LVL cross-arms. That is, for all log diameters, costs of production per cubic metre of final product fall with increasing scale. The 15,000 m^3 of log scale has a slighly lower cost of production than the 30,000 m^3 of log scale when manufacturing green veneer for market. This is because higher average log costs at the larger scale are not fully offset by reduced capital expenditure per cubic metre of log processed and assumed potential efficiencies in production.

Although revenues are highest when processing 45 cm SEDUB logs (Table 18.17), NPV is maximised by processing 35 cm SEDUB logs into all four products (Figure 18.6), because log costs per cubic metre of final product were minimised with these logs (Figure 18.9). This finding can be explained with reference to Table 18.18, which articulates the difference in value of marketable product manufactured from logs of alternative SEDUB. Given the market prices adopted for veneer and EWP products (Table 18.13) in this analysis, and the assumed recoveries of product from log volume (Table 18.3), the numbers in Table 18.18 can be interpreted as the minimum discount in mill-delivered log cost for 25 cm and 35 cm logs to be more cost-effective inputs to production than 45 cm logs[31]. For example, 35 cm logs are a better feedstock for the production of LVL cross-arms so long as they can be delivered to the mill at a cost that is at least $\$43/m^3$ of log lower than a 45 cm log. In this report, the mill-delivered cost of 35 cm logs is always at least $\$43/m^3$ less than 45 cm logs, which explains the higher financial performance of scenarios utilising 35 cm logs.

Table 18.18. Difference in value of marketable product recovered from logs of alternative SEDUB

Product	Reduced marketable product value relative to processing a 45 cm SEDUB log ($\$/m^3$ of log)	
	25 cm SEDUB log	35 cm SEDUB log
Green veneer	45	15
Dry veneer	48	16
LVL beams	93	32
LVL cross-arms	124	43

When manufacturing LVL cross-arms, 25 cm logs are a profitable feedstock (Figures 18.6 and 18.7). However, in order to be as profitable as 45 cm logs, 25 cm logs would need to be delivered to the mill at a cost of at least $\$124/m^3$ of log lower than a 45 cm log. As indicated in Table 18.2, in this analysis at the 15,000 m^3/y scale, 25 cm SEDUB logs are only $\$48/m^3$ less costly than 45 cm logs.

The difference between 25 cm and 35 cm logs in Table 18.18 determines the approximate break-even point between these log sizes[32]. From Table 18.2, at the 15,000 m^3/y scale, 25 cm SEDUB logs have mill-delivered log costs that are $\$7/m^3$ more than 35 cm logs. However, given the mean LVL cross-arm price price of $\$1375/m^3$, 25 cm logs would be a more cost-effective feedstock for LVL cross-arm production than 35 cm logs if they could be delivered to the facility at a cost at least $\$81/m^3$ ($\$124/m^3$ - $\$43/m^3$) less than 35 cm logs.

Figure 18.10 illustrates the proportion of manufacturing costs for each product that are log costs, labour costs, energy costs, other operating costs, capital costs (initial and asset

[31] Table 18.18 only accounts for the difference in value of marketable product recovered per cubic metre of log. Larger logs are also more efficient to peel, resulting in slightly lower variable costs at the lathe (i.e. labour) per cubic metre of green veneer. This results in higher labour costs of veneering of $\$7/m^3$ of log for 25 cm SEDUB logs, and $\$3/m^3$ of log for 35 cm SEDUB logs, relative to 45 cm logs.

replacement over time), and packaging and freight costs. These have been displayed for 35 cm SEDUB logs processed at the 15,000 m^3/y scale. This is broadly representative of all log diameter and processing scale scenarios for each product, although capital coists are proportionately larger at the 7500 m^3/y scale and proportionately lower for the 30,000 m^3/y scale. Figure 18.10 reveals that the largest cost item for green and dry veneer manufacture is the mill-delivered log cost (MDLC). In contrast, labour costs are the largest cost item in short-length LVL beam and LVL cross-arm manufacture. 'Other operating' costs are substantial for LVL beam manufacture, and this is predominantly the cost of adhesive. Except when dry veneer is produced for market, energy costs are the smallest cost component.

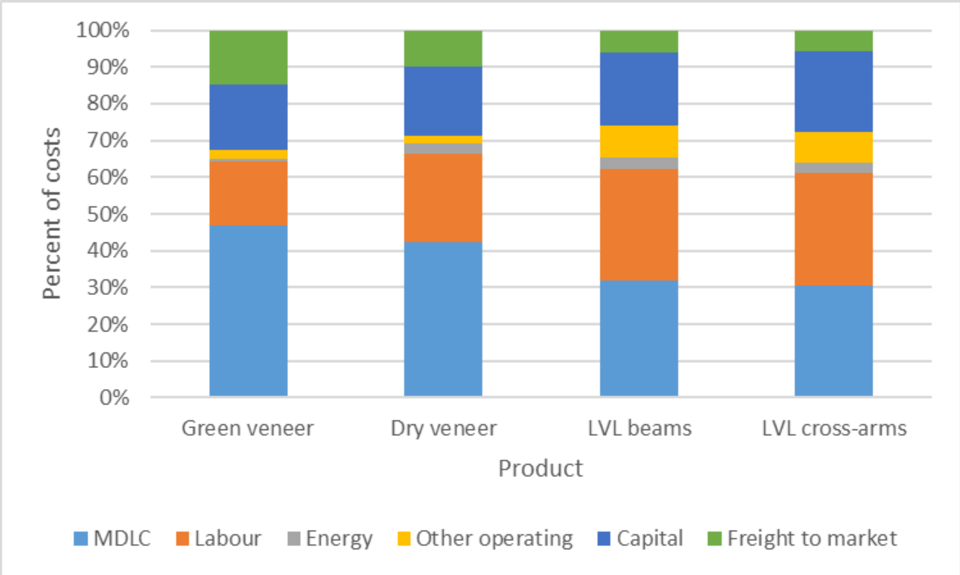


Figure 18.10. Composition of total costs for each product for 35 cm SEDUB logs at the 15,000 m^3/y scale

Figure 18.11 presents after tax gross profit per cubic metre of final product, as estimated by Equation 18.18. The sum of cost from Figure 18.9 and gross profit from Figure 18.11 equals the market price of the product from Table 18.13.

Losses per cubic metre of green veneer vary from \$71/m^3 to 174/m^3, depending on the processing scale and log SEDUB scenario. That is, costs must fall and revenues rise by at combined total of at least \$71/m^3 of green veneer for the manufacture and sale of green veneer to cover costs and make 7% per annum on invested funds. Depending on scale of operation and log resource being processed, markets willing to pay between \$371/m^3 and \$474/m^3 for green veneer are required to earn 7% per annum over inflation on invested capital (i.e. NPV =\$0).

Losses per cubic metre of dry veneer vary from \$119/m^3 to 277/m^3, depending on the processing scale and log SEDUB scenario. This is worse than the financial performance of green veneer manufacture because the increased value of the product did not make up for the combination of reduced marketable volume (relative to green veneer) and the higher capital and operating costs associated with producing dry veneer. Given the costs of production adopted in the analysis, the market price of dry veneer would need to rise from the assumed level of \$426/m^3 to between \$545/m^3 and \$703/m^3 in order earn 7% per annum over inflation on invested capital.

Figure 18.11. After tax gross profit per cubic metre of veneer or engineered wood product (30% company tax rate)

The negative financial performance at the 7500 m^3/y scale for short length LVL beam manufacture suggests investment in the manufacture of this product is only warranted at larger scales, where gross profits of up to \$113/m^3 could be earned. Alternatively, markets willing to pay about \$1126/m^3 for short length LVL beams are necessary to make the small-scale production financially viable. LVL cross-arm manufacture returned high after tax gross profits of \$105/m^3 to \$342/m^3. Logs with SEDUB of 35 cm and 45 cm generated higher gross profits per cubic metre of final product than 25 cm SEDUB logs.

Mixed LVL production

The financial performance of mixed production of short-length LVL beams (70% of production) and LVL cross-arms (30% of production) is illustrated in Figures 18.12 to 18.15. Interpretation of the costs and after tax gross profits per cubic metre of marketable product in Figures 18.15 and 18.16 is facilitated knowing that the mean market price of outputs from mixed production is \$1113/m^3. Relative to the LVL cross-arms scenarios in the previous section, NPVs and IRRs are typically about 50% lower. Nevertheless, returns are substantially higher than for LVL beam production only, and the industry IRR threshold of 20% is achieved with mixed LVL production at log processing scales of at least 15,000 m^3/y. Mixed LVL production is financially viable, even with 25 cm SEDUB logs. This evaluation suggests that modest levels of production of two-stage LVL products, coupled with larger volumes of one-stage LVL products is a financially viable business model.

Limitations of the analysis

This report has not presented extensive sensitivity analyses to test the robustness of findings against changes in important model parameter levels. This is because many parameter levels will vary with the facility location (e.g. mill-delivered log cost) or type of equipment used (e.g. capital costs, production rates and number of employees), and in some cases it has been difficult to verify parameters due to a reluctance or genuine difficulty of key informants from industry to provide estimates (e.g. energy costs). Given these factors, it was not clear that extensive sensitivity analyses could be meaningfully interpreted.

Figure 18.10 highlights the relative importance of different types of costs in the scenarios examined, indicating that financial performance is particularly sensitive to parameters affecting mill-delivered log costs, labour costs (number of employees at different stages of production, salaries, equipment utilisation rates and processing rates), and capital costs for buildings and equipment (including asset life). Financial performance is also sensitive to market prices. The financial model has been developed to allow adjustment of all model parameters. An investor should carefully consider whether the levels adopted in this analysis reflect their own circumstances, and modify them when warranted.

In addition to the need for caution regarding assumptions made about particular parameter levels in the evaluation, three assumptions made in designing the scenarios will inflate the NPVs and IRRs for LVL manufacture. First, the scenarios examined assume an expansion of activity at an existing processing facility (e.g. a sawmill). Consequently, the analysis does not consider land acquisition costs and, while the analysis does account for administration labour costs, it does not account for associated non-labour costs of administration (e.g. office space, stationery, telecommunications) on the assumption that these would be minor additional costs for an existing operation.

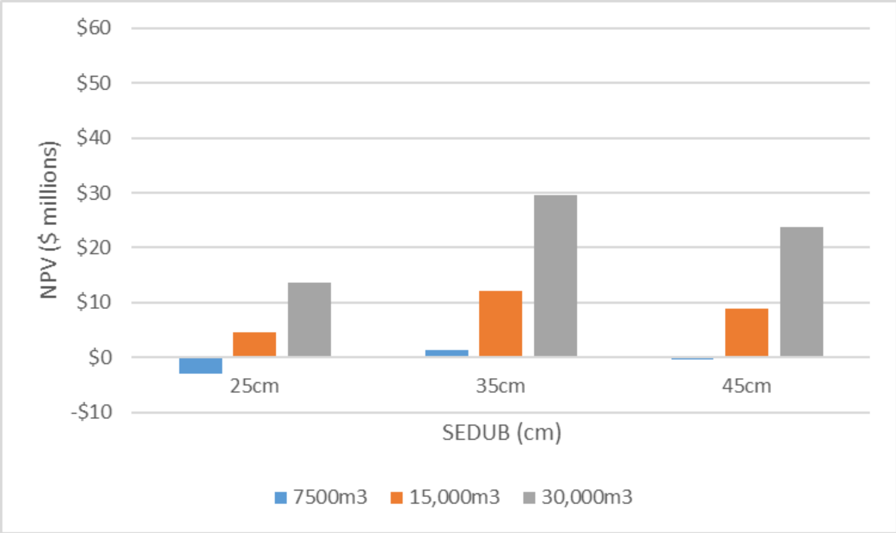


Figure 18.12. After tax NPV of mixed LVL production

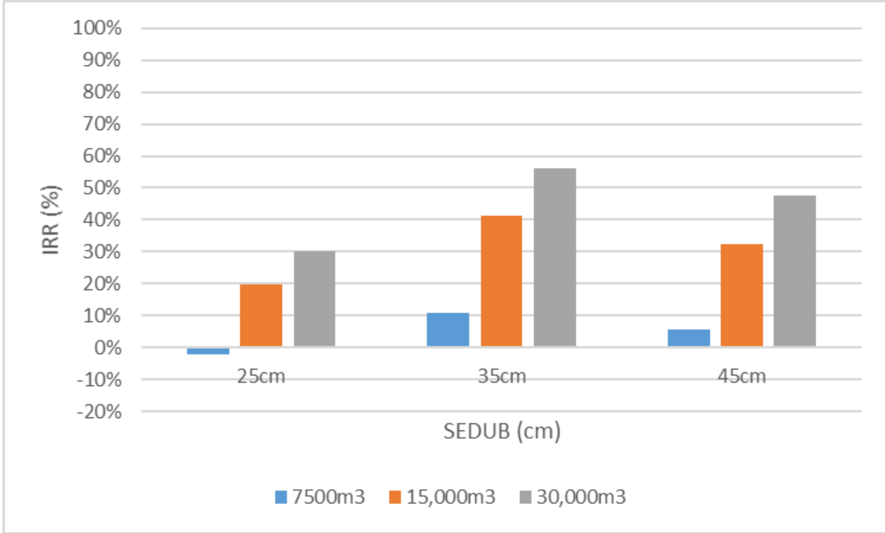


Figure 18.13. After tax IRR of mixed LVL production

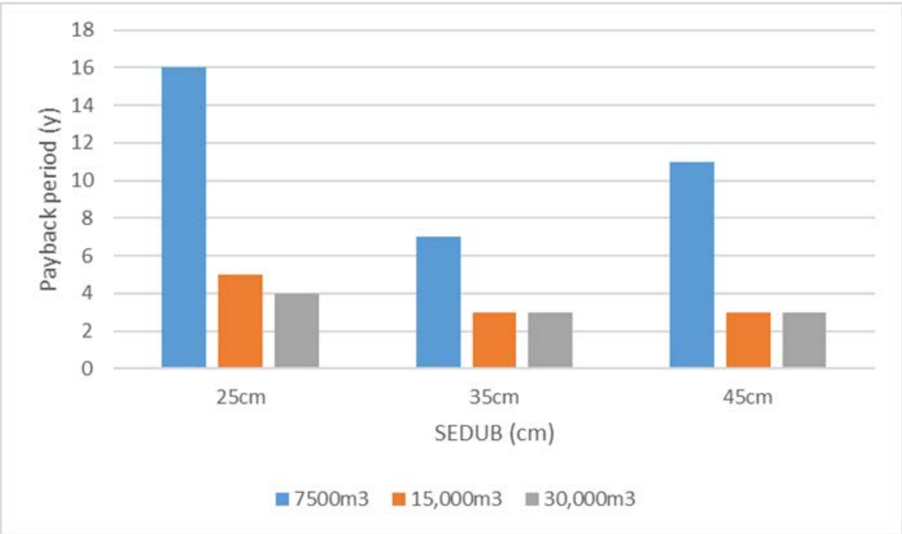


Figure 18.14. After tax payback period for mixed LVL production

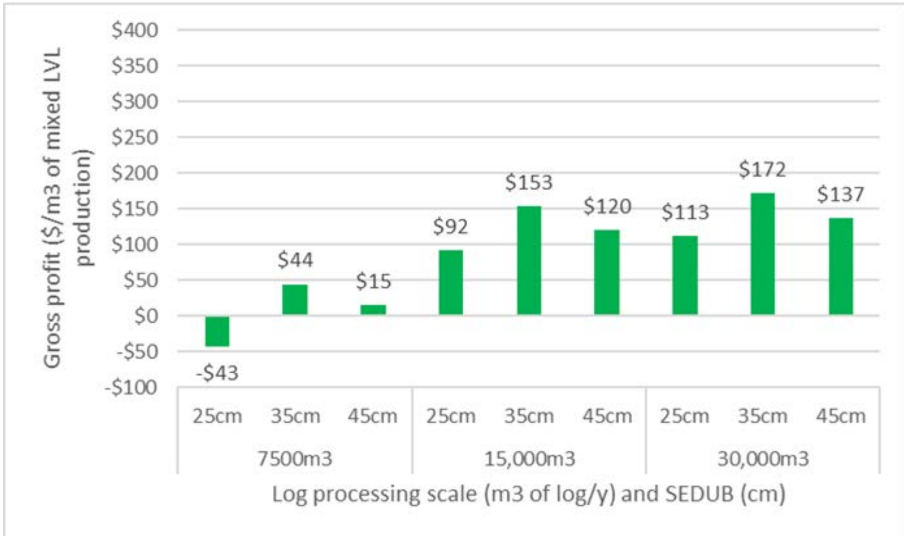


Figure 18.15. After tax gross profit per cubic metre of mixed LVL

Figure 18.16. Costs of mixed LVL production by stage of production per cubic metre of final product

Second, the manufacturing facility is assumed to use a biomass boiler that is largely (although not entirely) supplied by on-site waste to generate the heat necessary for log steaming and veneer drying. If electricity or natural gas had to be used to generate the heat instead, this would be expected to add substantially to annual energy costs, although there would be potential capital savings in not requiring a biomass boiler.

Third, the analysis may not have adequately accounted for costs associated with developing and marketing new hardwood LVL products. All outputs are assumed to be in demand from year 1, although in reality, it may take years to gain market acceptance.

The assumed prices for LVL products examined were based on existing market prices for substitute or similar goods that LVL manufacturers would aim to compete with. However, there is presently essentially no trading of subtropical Australian hardwood veneer. The market prices adopted in this analysis are indicative of exotic pine veneer markets in Australia, and these were found to not be high enough to justify the manufacture and sale of subtropical Australian hardwood green or dry veneer. If veneer markets develop that value the mechanical properties and natural durability of subtropical Australian hardwoods, then higher prices may be achieved and justify the manufacture of veneer for market.

Across all scenarios examined, the 7500 m^3/y scenarios were rarely financially viable. This result needs to be interpreted with caution, because this scale was deliberately examined as a part-time operation with the hourly processing capacity of a 15,000 m^3/y operation. For example, it might represent an add-on to a sawmill where logs less suited to sawmilling are accumulated and, when a threshold log volume is reached, veneering commences. The financial performance of a full-time operation at 7500 m^3/y has not been investigated and it is challenging to hypothesise whether such an operation (presumably utilising lower cost, but also lower processing capacity equipment) would be viable.

The financial performance of veneer and EWP manufacture has been estimated independently for the utilisation of 25 cm, 35 cm and 45 cm SEDUB logs. This was done to determine the effect of log size on financial performance. In reality, a veneering facility is likely to process a range of log sizes, with representation across the diameter ranges influenced by the available log resource, the cost of getting that resource to the mill, and the competition from alternative utilisation options (e.g. sawmilling and roundwood products). Although this analysis revealed 35 cm logs and 45 cm logs generate the highest returns from veneer and EWP manufacture, the reality may be that the opportunity cost of using 35 cm and 45 cm logs for veneering outweigh the benefits. It would be useful for future research to compare the financial performance of manufacturing veneer and EWP products against roundwood and sawnwood products to determine optimal log allocation at a processing facility.

The analysis did consider the impact of company tax on financial performance, but did not account for tax benefits arising from asset depreciation. This would suggest the financial performance of LVL manufacturing scenarios that generated a positive return have been slightly underestimated.

Conclusions

The financial performance of manufacturing four veneer and LVL products from subtropical Australian hardwoods from native forests was investigated for three scales of production (7500 m^3/y, 15,000 m^3/y and 30,000 m^3/y of log) and three log sizes (25 cm, 35 cm and 45 cm SEDUB). The production of one-stage (short-length LVL beams) and the two-stage (cross-arms) LVL products was found to be financially viable, particularly at the 15,000 m^3/y and 30,000 m^3/y scales. The return on investment in LVL cross-arm manufacture was particularly high, with IRRs after tax between 45% and 70% at the 15,000 m^3/y scale. However, large scale manufacture of LVL cross-arms may saturate the Australian market, so a mixed LVL production scenario, where 70% of the output was short-length LVL beams and 30% LVL cross-arms, was also evaluated. This was found to have solid after tax IRRs of 20% to 40% at the 15,000 m^3/y scale.

In contrast, the production of green and dry veneer for market was not financially viable using the market prices adopted for the analysis. The analysis revealed that market prices would have to be higher (or costs lower) by at least \$71/m^3 of green veneer and \$119/m^3 of dry veneer for the best case veneer manufacturing scenarios to cover costs of production, including a 7% per annum real rate of return on investment. Therefore, market price would need to be in the order of \$371/m^3 and \$545/m^3 for green and dry veneer, respectively. Such increases in the market price could arise if veneer markets develop that value the positive attributes of native Australian hardwoods such as mechanical and natural durability properties.

The analysis revealed that the manufacture of LVL products, even from 25 cm SEDUB logs is profitable, which suggests spindleless lathe veneering provides an opportunity to process small diameter logs from private native forests. However, modest increases in green veneer recovery from log volume with increasing SEDUB results in substantial increases in marketable product value per cubic metre of log processed. For example there is a 15 percentage point greater recovery of green veneer from log volume for 45 cm logs versus 25 cm logs, which amounts to an increase in marketable product value of \$48/m^3 of log processed for dry veneer, and \$124/m^3 of log processed for LVL cross arms. That is, assuming the veneer quality from 25 cm logs and 45 cm logs is identical, it is more cost effective to use 45 cm logs rather than 25 cm logs for the manufacture of dry veneer or LVL cross-arms unless the costs to deliver 25 cm logs to the processing facility are at least \$48/m^3 of log or \$124/m^3 of log lower than 45 cm logs, respectively. Given the mill-delivered log costs and veneer recovery from log volume estimates adopted in this study, 35 cm SEDUB logs were found to be optimal for veneer and LVL manufacture. In practise, a veneering operation would be expected to have a range of log diameters available to process. Nevertheless, the most profitable products manufactured from larger logs may be sawnwood or other non-LVL products that were not investigated in this study. Consequently, large volumes of larger logs may not be available as feedstock for veneering.

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Chapter 19: Financial performance of integrated and distributed veneer and laminated veneer lumber (LVL) manufacturing opportunities in sub-tropical eastern Australia

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Introduction

In subtropical eastern Australia, the timber industry is seeking information to support their tactical and strategic veneer and engineered wood product manufacturing investment decisions, including:

- which log types should be procured?;
- where should processing facilities be located?;
- what scale of production should be targeted?; and
- which final products should be produced (i.e. how much value-adding)?

The aim of the research reported in this chapter was to enhance the financial model reported in Chapter 18 and perform financial analyses to support these kinds of investment decisions. The financial performance of integrated (one facility location) veneer and LVL manufacture has been evaluated for the following 144 scenarios:

- three log procurement scenarios, as defined in Chapter 17 (2; 4; and 6);
- four facility locations, as defined in Chapter 17 (A; B; C; and D);
- three processing scales, as defined in Chapter 18 (7500 m^3/y of log; 15,000 m^3/y of log; and 30,000 m^3/y of log); and
- four final product types, as defined in Chapter 18 (green veneer; dry veneer; LVL beams; LVL cross-arms).

In this chapter more generic terminology for LVL products has been adopted. In Chapter 18, LVL beams were an example of one-stage LVL. One-stage LVL is manufactured by gluing together sheets of dry veneer. LVL cross-arms were an example of two-stage LVL in Chapter 18. Two-stage LVL is manufactured by gluing together one-stage LVL panels.

Financial evaluations reported in earlier chapters have assumed one processing facility receives the logs and processes them into the final product. This avoids handling costs associated with shipping intermediate products from one facility to another. If availability and costs of labour, equipment, non-log materials and energy are similar spatially throughout a region, then having all processing performed at one facility will maximise profitability of an operation. However, there may be technical or logistical reasons why distributed production may, in fact, be profit maximising. For example, there may be insufficient labour proximate to the proposed facility to support processing at a particular scale. In such cases, a distributed production model, where some processing is performed at one location, and the remainder at a second and possibly third location may be financially justified. Therefore, in addition to the 144 scenarios outlined above, 36 distributed production scenarios have been assessed in this chapter, where veneering would occur at a location proximate to the log resource and dry veneer would be shipped to an alternative facility for LVL production.

Methods

Assumptions made about the forest area available for harvesting, log volumes per hectare, and stumpage, cut, snig, load and haul costs in Chapter 17 have been adopted here. Mill-delivered log costs for log procurement scenarios 2, 4 and 6 at facility locations A, B, C and D have been estimated according to the methods described in that chapter. The methods for evaluating the financial performance of veneer and LVL manufacturing facilities are as described in Chapter 18. Non-labour financial model parameters for evaluation of veneer and LVL manufacture have been summarised in Table 19.1. These are the same parameter levels adopted in Chapter 18, although some costs listed in total dollars in Chapter 18 have been reported below in dollars per cubic metre.

All buildings and equipment constructed or installed at the beginning of the investment period are assumed to have been purchased with 30% cash and the remainder borrowed at 6% per annum over 10-years. Details about capital costs and asset life of individual building and equipment items are provided in Chapter 18. Capital costs are cumulative with value-adding. For example, the total capital costs of manufacturing one-stage LVL is the sum of the capital costs of green veneer, dry veneer and one-stage LVL. When the asset life is reached for any particular piece of equipment, the asset has zero residual value and requires replacement at its listed capital cost. All equipment purchased in later years to replace items that have reached the end of their useful life are paid from operating cash in the year of acquisition. At the end of the project (30 years), all capital items that are not at the end of their asset life are assumed to have a residual value of 5% of its purchase cost. To account for building construction, and equipment acquisition, delivery and installation, only half the log volume applicable for the processing scale is assumed to be processed in the first year of production. Profits have been taxed at 30%. Scenarios have been evaluated over 30 years at a 7% real (net of inflation) discount rate.

The remainder of this section describes the methods for assessment of distributed production scenarios.

Distributed production

Costs of distributed production of veneer and LVL are likely to be higher than for one integrated facility. There will be increased handling costs at the veneering facility in preparing the dry veneer for shipping to the LVL facility, as well as the shipping costs and handling costs of the intermediate product at the LVL facility. There may also be higher costs associated with requiring equipment and buildings at multiple locations. However, distributed production has the potential to reduce average mill-delivered log costs relative to a single, larger scale veneer plant. Distributed production may also overcome limitations of log supply in some facility location scenarios (e.g. facility location B). Thus, distributed production has the potential to expand the range of technically feasible production scenarios and lower costs of production.

Distributed production has been evaluated for 36 scenarios. Two final product types (one-stage and two-stage LVL), three log procurement scenarios (2, 4 and 6), two veneering facility location scenarios (C and D), and three processing scales for veneering:

1. one 15,000 m^3/y of log veneering facility;
2. one 30,000 m^3/y of log veneering facility; and
3. two separate 15,000 m^3/y of log veneering facilities.

Table 19.1. Veneer and LVL utilisation, processing and recovery rates, non-labour production costs and market prices

Parameter	Final product			
	Green veneer	Dry veneer	One-stage LVL	Two-stage LVL
Utilisation rate of equipment and machinery (%)	65 (Lathe)	85 (Dryer)	50 (Hot press)	80 (Cold press)
Processing rates of input (m^3/h)	9.0 m^3/h of 25 cm SEDUB logs, 10.27 m^3/h of 35 cm SEDUB logs, or 11.94 m^3/h of 45 cm SEDUB logs per lathe	4.08 m^3/h of green veneer per small dryer or 5.95 m^3/h of green veneer per large dryer	2.5 m^3/h of dry veneer per hot press	0.4 m^3/h of one-stage LVL per cold press
Recovery of final product (% of log volume)				
Small peeler and top logs	69	52	43	42
B-grade sawlog	79	59	49	48
A-grade sawlog	84	63	52	51
Capital costs in year zero ($ millions)				
7500 & 15,000 m^3/y scale	4.38	0.82	1.95	0.89
30,000 m^3/y scale	8.50	1.36	2.65	1.22
Annual maintenance parts and insurance per year (% of capital costs in year zero)	5 and 1.5	5 and 1.5	5 and 1.5	5 and 1.5
Non-labour operating costs that vary by processing scale ($/$m^3$ of log processed)				
Electricity	2.67	6.67	4.0 [a]	
Water	0.69			
Boiler feedstock	4.32			
Consumables, compliance and marketing	0.80	0.33	1.23	1.30
Non-labour operating costs that vary by marketable output ($/$m^3$ of final product)				
PF glue			58.40	60.00
RF glue				4.72
Packaging	1.99	1.99	0.24	0.24
Freight to market ($/$m^3$ of final product)				
7500 m^3/y	60	60	60	60
15,000 m^3/y	55	55	55	55
30,000 m^3/y	50	50	50	50
Market price ($/$m^3$)	300	426	1000	1375

Note: a. Industry experts were unable to segregate energy consumption for one-stage and two-stage LVL manufacture. The additional energy cost of converting one-stage LVL into two-stage LVL is marginal, because the additional processing is limited to gluing one-stage LVL in a cold press for eight hours. In the analysis, regardless of whether one-stage or two-stage LVL is produced, the electricity cost of $4/$m^3$ of log is applied once. This electricity cost is cumulative with the drying and veneering electricity costs.

Costs per cubic metre of dry veneer production for each of the 36 scenarios have been taken from the appropriate facility location, log procurement and processing scale scenario for integrated dry veneer production. As described in Chapter 18, these costs do include packaging the dry veneer at the veneering facility. Freight to, and handling costs at the receiving LVL plant have been considered over the range of $20/m^3 of dry veneer to $40/m^3 of dry veneer. Costs of one-stage and two-stage LVL production, and freight of the final product to market, have been taken from the integrated LVL production scenarios (Chapter 18). For each distributed production scenario, costs at the facilities have been summed, and gross profit (revenues minus costs of production), tax payable (gross profit multiplied by the tax rate of 30%), and after tax profit (gross profit minus tax payable) have been calculated.

Results

Optimal mixes of log types for log procurement scenario 6 to maximise NPV are reported in Table 19.2. Table cells with zero indicate that log type was not procured for the particular combination of processing scale and log procurement scenarios. Table cells with 'n.a.' were combinations of processing scale and log procurement scenarios that were not technically feasible due to insufficient log volume over the 30 year investment life. Much higher proportions of small peeler and top logs are utilised in facility location scenarios A and B, relative to C and D, because less forest area was available for harvest close to the facility. It was therefore optimal to procure more low-processing efficiency small logs to reduce mill-delivered log costs. Small volumes of A-grade sawlogs are procured at processing scales of at least 15,000 m^3/y. In contrast to Table 19.2, the constant proportions of log types under log procurement scenarios 19.2 and 19.4, irrespective of processing scale and facility location, were 100% small peeler and top logs for the former, and 12.8% A-grade sawlog, 40.7% B-grade sawlog and 46.5% small peeler and top logs for the latter[33].

Table 19.2. Optimal proportion of log types in log procurement scenario 6 by processing scale and facility location

Log type	Proportion (%) of logs by log type to maximise NPV by processing scale (m^3/y of log) and facility location											
	7500				15,000				30,000			
	A	B	C	D	A	B	C	D	A	B	C	D
A-grade sawlog	0.0	0.0	0.0	0.0	2.6	5.6	0.3	0.0	n.a.	n.a.	9.4	2.2
B-grade sawlog	80.8	73.9	94.4	95.3	58.6	54.6	73.1	90.7	n.a.	n.a.	48.0	55.3
Small peeler or top log	19.2	26.1	5.6	4.7	38.8	39.8	26.6	9.3	n.a.	n.a.	42.6	42.5

Despite large differences in log mixes between log procurement scenarios 2, 4 and 6, Table 19.3 reveals that average mill-delivered log costs for each log procurement scenario were similar for any particular combination of facility location scenario and processing scale. However, there are large differences in mill-delivered log costs between processing scales and facility location scenarios. For example, average mill-delivered log cost for log procurement scenario 4 at the 15,000 m^3/y of log processing scale was $166/m^3 for facility location B and $135/m^3 for facility location D. Cells in Table 19.3 with 'n.a.' were not technically feasible due to insufficient log volume over the 30 year investment life.

[33] For log procurement scenario 4, the proportions are consistent with the harvestable volumes per hectare for each log type reported in Table 19.1.

Table 19.3. Average mill-delivered log cost by processing scale, facility location and log procurement strategy

Log procurement scenario	Average mill-delivered log cost ($/m^3) by processing scale (m^3/y of log) and facility location											
	7500				15,000				30,000			
	A	B	C	D	A	B	C	D	A	B	C	D
2	144	163	135	131	n.a.	n.a.	147	138	n.a.	n.a.	n.a.	n.a.
4	138	155	133	131	147	166	138	135	n.a.	n.a.	149	141
6	135	152	129	126	144	164	134	132	n.a.	n.a.	148	137

Financial performance of integrated processing facilities

The after tax NPVs for the manufacture and sale of green veneer, dry veneer, one-stage LVL and two-stage LVL are illustrated in Figures 19.1 to 19.4, respectively. The four panels within each figure report the NPVs for each facility location scenario and, within each panel, a bar represents a combination of log procurement and facility scale scenarios. Missing bars in the figures indicate that log procurement scenario and processing scale was not technically feasible. Notably, the sale of green and dry veneer always generated negative NPVs, with the production of dry veneer consistently generating the lowest returns out of the four veneer and LVL products evaluated. One-stage LVL production was financially viable at processing scales of at least 15,000 m^3/y for log procurement scenarios 4 and 6 at all facility location scenarios, although this was marginal for location B. Facility location D was the only location where one-stage LVL production with log procurement scenario 19.2 generated a positive NPV, although this was also marginal. Two-stage LVL production was profitable for all log procurement, processing scale and facility location scenarios evaluated.

Figures 19.1 to 19.4 suggest strong returns to increasing level of value-adding. For example, for facility location C at the 30,000 m^3/y scale, the NPVs of one-stage and two-stage LVL were $16 million and $53 million, respectively. There are also economies of scale for LVL manufacture. For example, a doubling of processing scale for one-stage and two-stage LVL manuacture from 15,000 m^3/y to 30,000 m^3/y for facility location C and log procurement scenario 4, increased NPV by factors of 3.8 and 2.4, respectively. Figures 19.1 to 19.4 also highlight that for any combination of facility location and processing scale scenarios, NPV is greatest for log procurement scenario 6 and lowest with scenario 2. NPV is also affected substantially by facility location scenario (proximity to the forest resource), with the expected result that NPV decreases with declining order of proximity of the processing facility to the forest resource (D, C, A, and B).

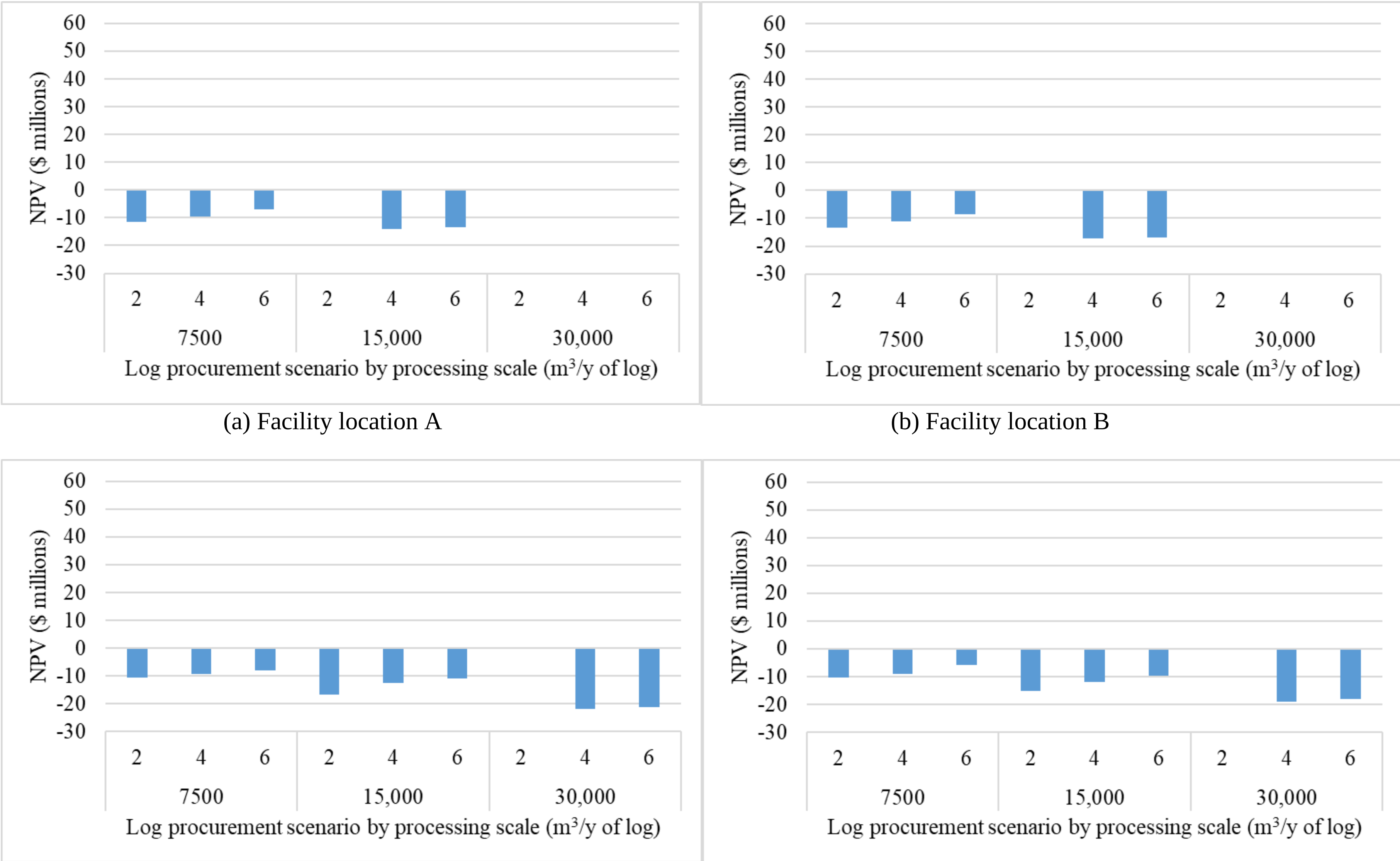
Figures 19.5 to 19.8 illustrate average costs of production by processing stage, market price and profit after tax per cubic metre of final product for green veneer, dry veneer, one-stage LVL and two-stage LVL, respectively. For any combination of facility location, processing scale and log procurement scenarios, average costs rise with increasing value-adding from production of green veneer to two-stage LVL, because of progressively lower recovery of marketable product from log volume. This explains why the losses from dry veneer manufacture are greater than for green veneer manufacture, despite the dry veneer market price being $126/m^3 greater than green veneer. Although veneer drying costs are comparatively small (ranging from $65/m^3 to $93/m^3 in Figure 19.6), the lower recovery of dry veneer from log volume substantially increased mill-delivered log costs and green veneering costs per cubic metre of dry veneer (compare Figures 19.5 and 19.6).

Figures 19.5 to 19.8 highlight the extent to which value-adding can increase profitability per cubic metre of final product. For example, profit per cubic metre of final product for log procurement scenario 4 at the 15,000 m^3/y processing scale and facility location C, ranges from -\$139/m^3 for dry veneer to \$293/m^3 for two-stage LVL. The losses per cubic metre for green and dry veneer illustrated in Figures 19.5 and 19.6 are equivalent to the increases in market price or decreases in costs of production necessary for a veneering operation to break-even over 30 years at a 7% discount rate. For example, for facility location scenario C, the minimum market price for profitable manufacture of green veneer and dry veneer would be about \$370/m^3 and \$541/m^3, respectively.

Figures 19.5 to 19.8 highlight the increasing returns to scale (higher profits or lower losses per cubic metre) that are achievable with all final products. For LVL manufacture, it is the combination of the increasing profitability per cubic metre of final product and the increasing volume of product that results in the large increases in NPV with scale that are illustrated in Figure 19.3 and 19.4.

Figures 19.5 to 19.8 indicate that the effect of log procurement scenario on costs of production can be substantial. For example, for two-stage LVL production at facility location C and a processing scale of 15,000 m^3/y of log, profit ranged from \$236/m^3 to \$307/m^3 of two-stage LVL, depending on the log procurement scenario. The relatively small difference in mill-delivered log costs between the log procurement scenarios (\$134/m^3 to \$147/m^3 of log; Table 19.3) suggests effects of log procurement strategy on financial performance are driven more by rates at which alternative log types can be processed and the recovery of marketable product from log volume. The benefit of optimal log procurement (scenario 6) is greater at smaller processing scales and for higher levels of value-adding. The benefit diminishes with increasing scale, because haul costs increase and capital costs are distributed over larger final product volumes.

Figures 19.5 to 19.8 also provide another measure of the impact of facility location on the financial performance of an operation. For example, the profitability of two-stage LVL manufacture for log procurement scenario 4 at the 15,000 m^3/y processing scale was \$46/m^3 greater at facility location D than location B.



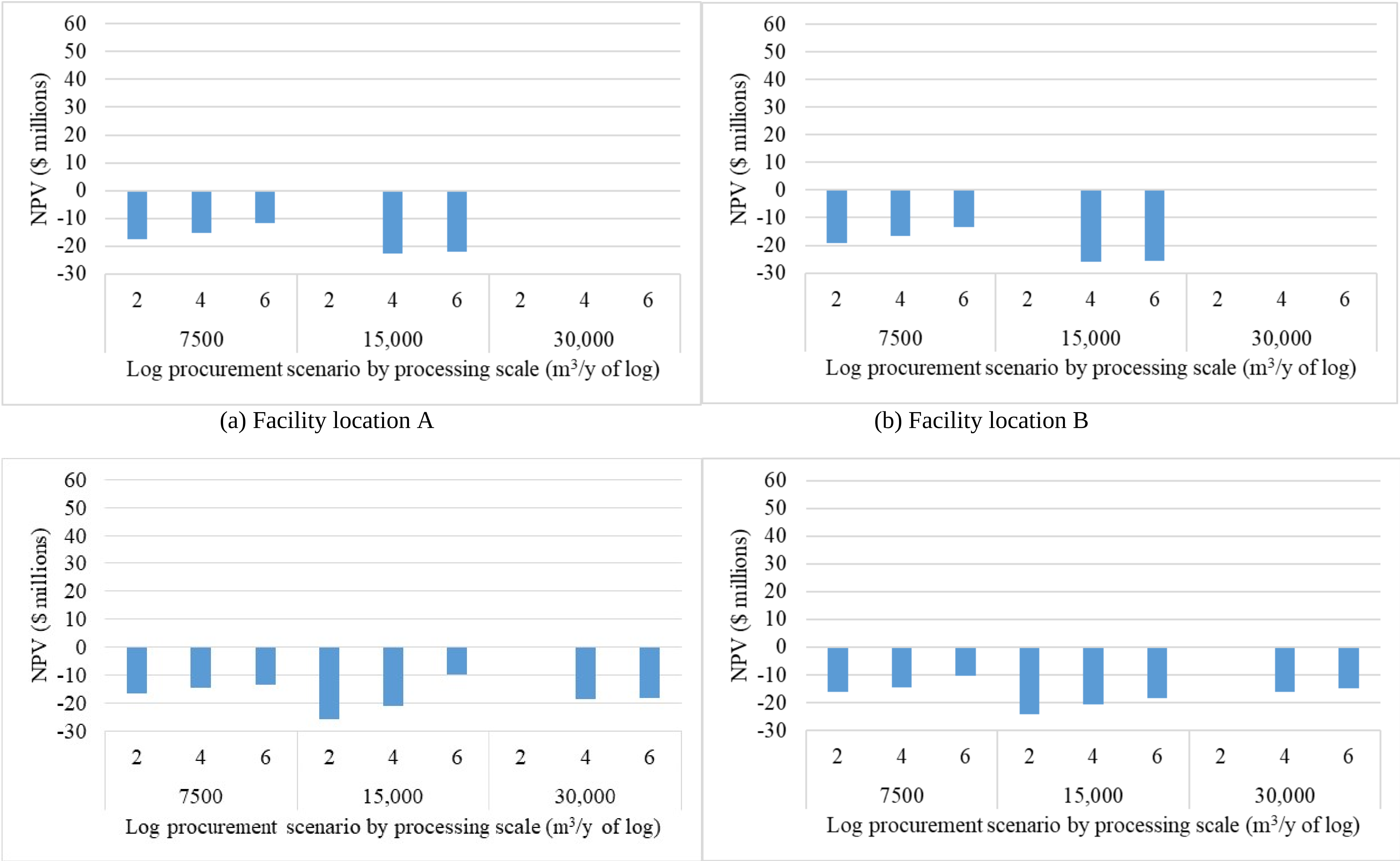
(a) Facility location A

(b) Facility location B

(c) Facility location C

(d) Facility location D

Figure 19.1. NPV of the manufacture and sale of green veneer



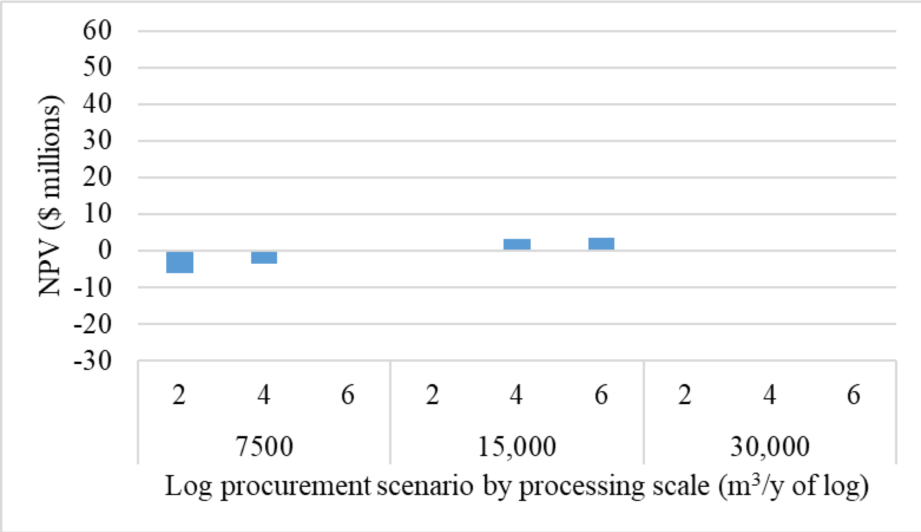
(a) Facility location A

(b) Facility location B

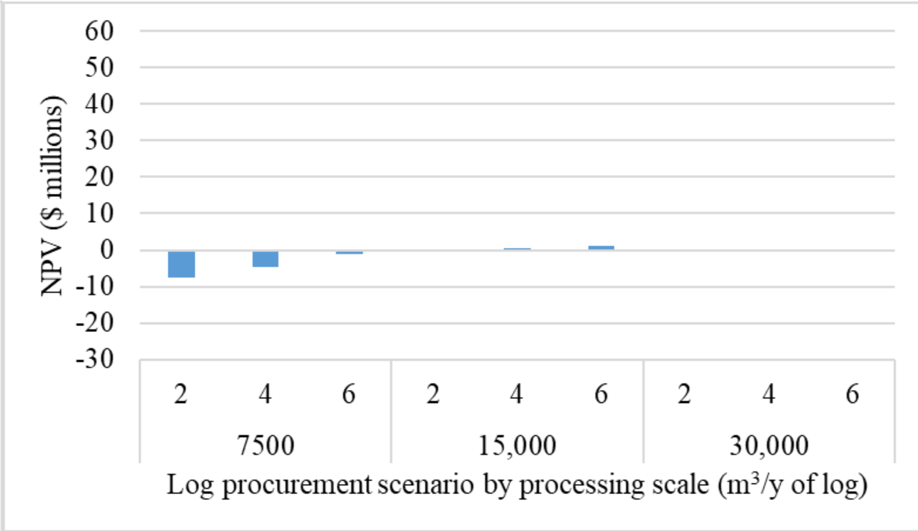
(c) Facility location C

(d) Facility location D

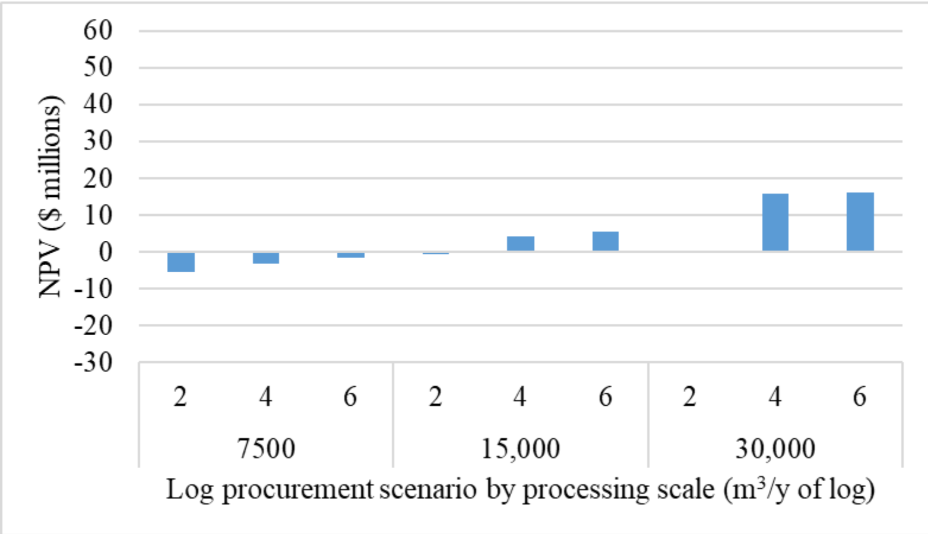
Figure 19.2. NPV of the manufacture and sale of dry veneer



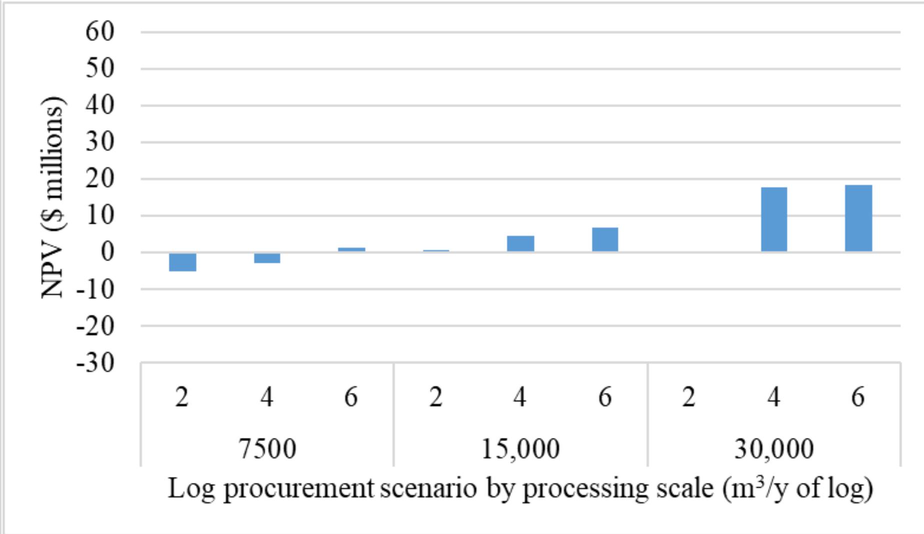
(a) Facility location A



(b) Facility location B

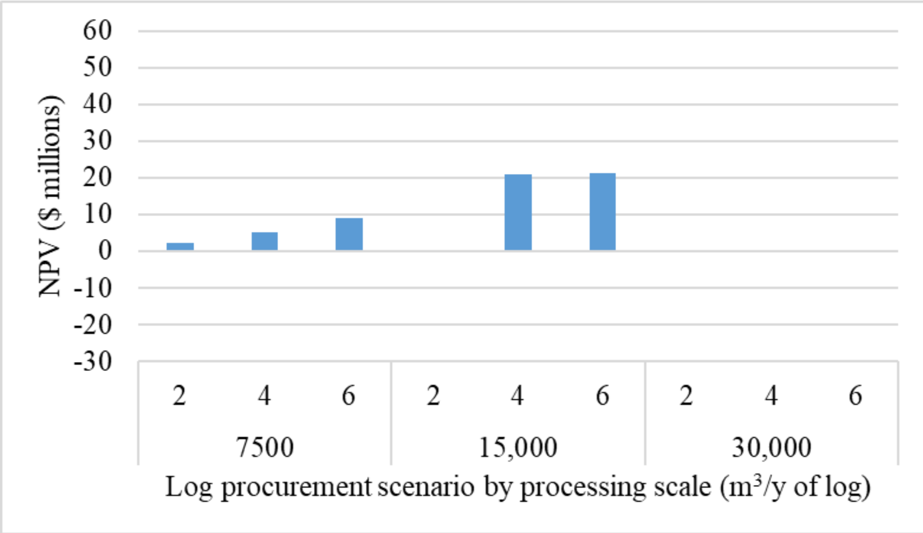


(c) Facility location C

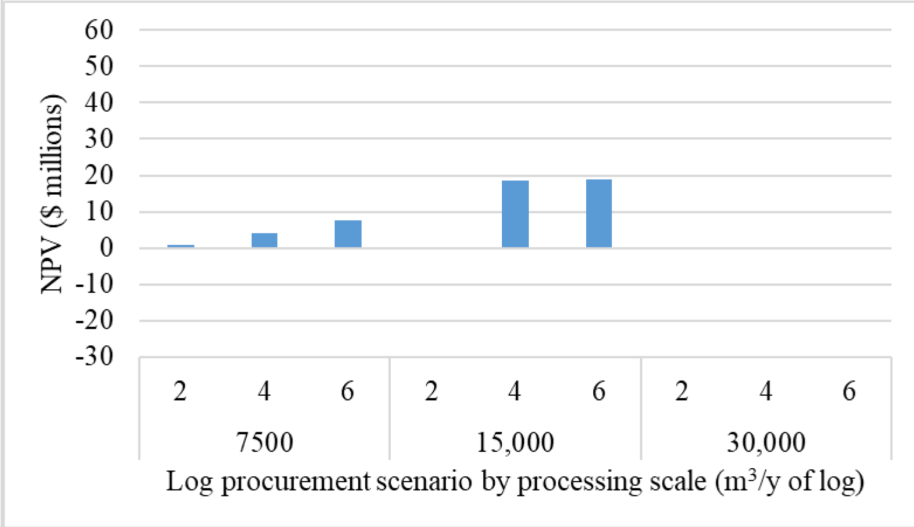


(d) Facility location D

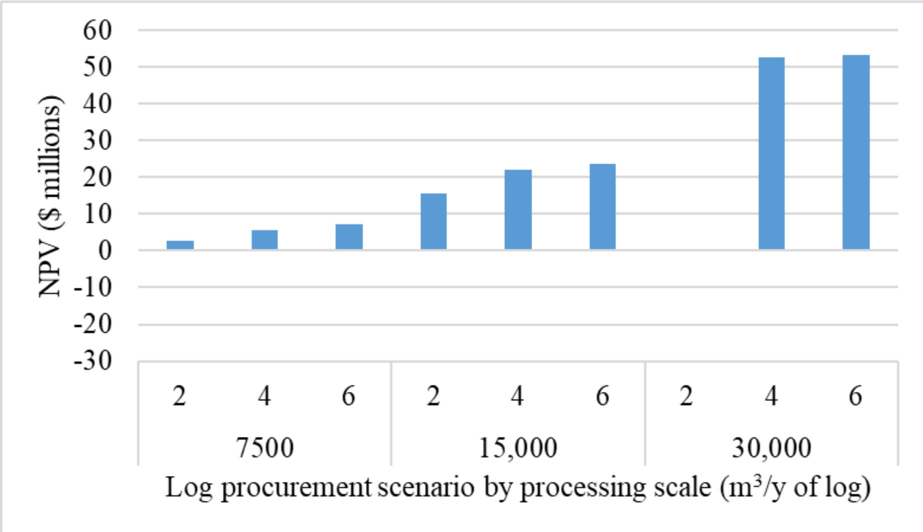
Figure 19.3. NPV of the manufacture and sale of one-stage LVL



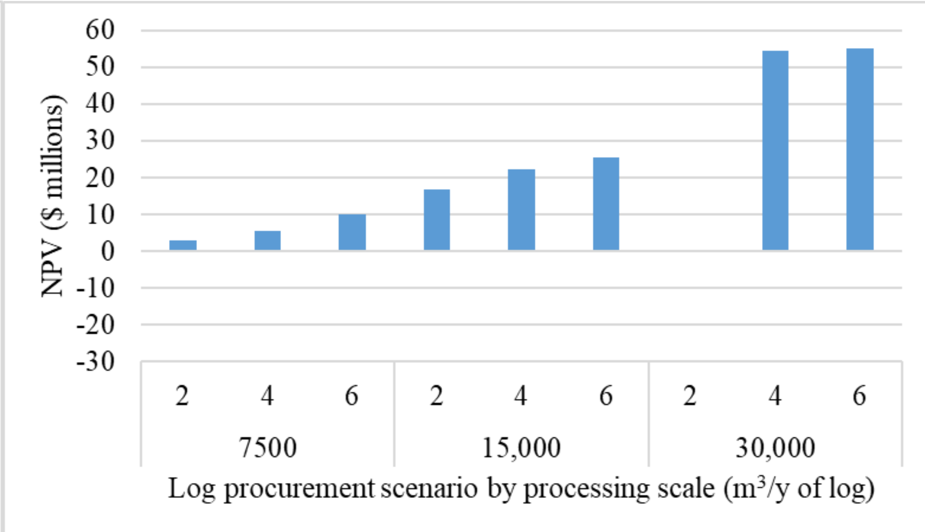
(a) Facility location A



(b) Facility location B



(c) Facility location C



(d) Facility location D

Figure 19.4. NPV of the manufacture and sale of two-stage LVL

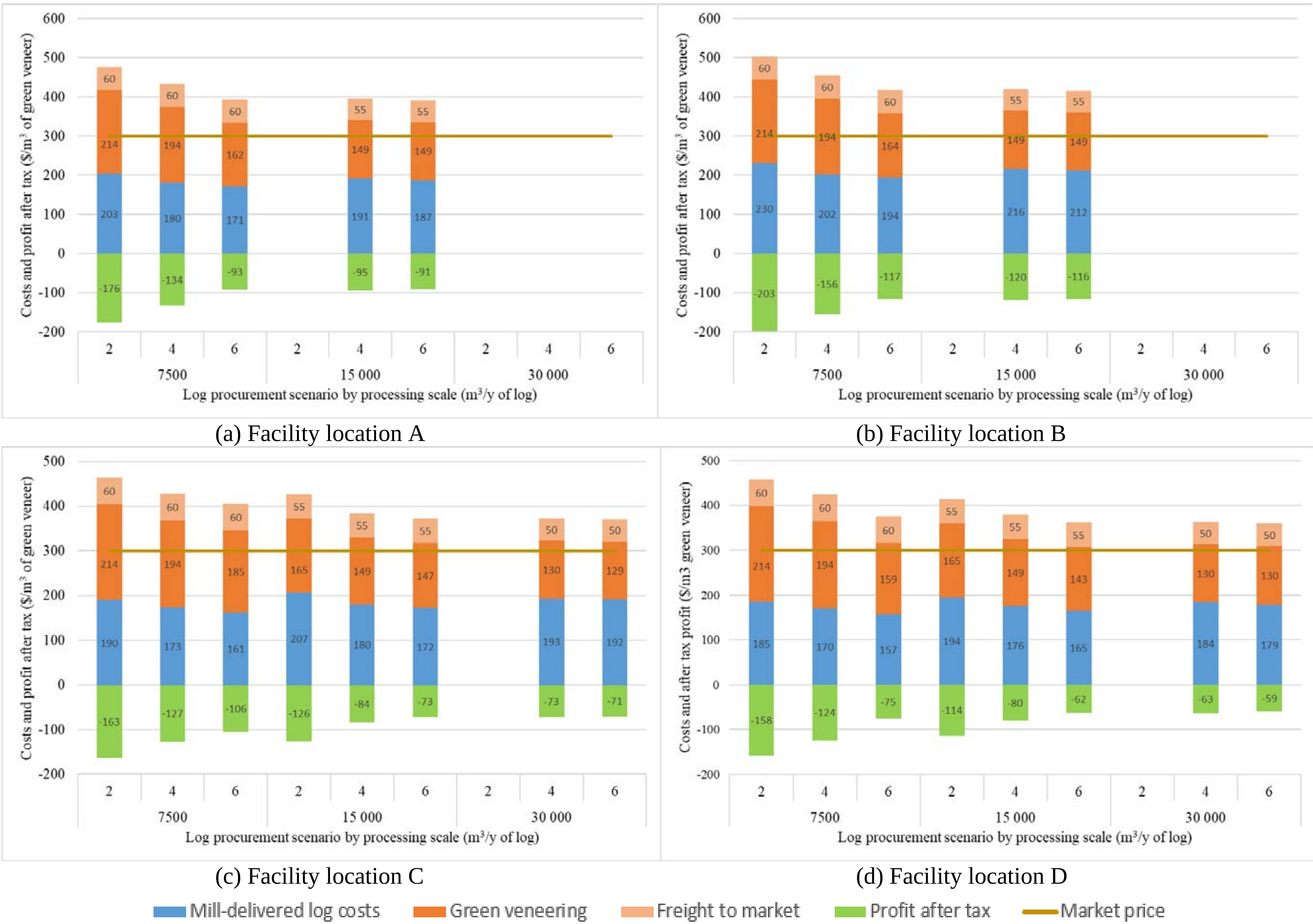
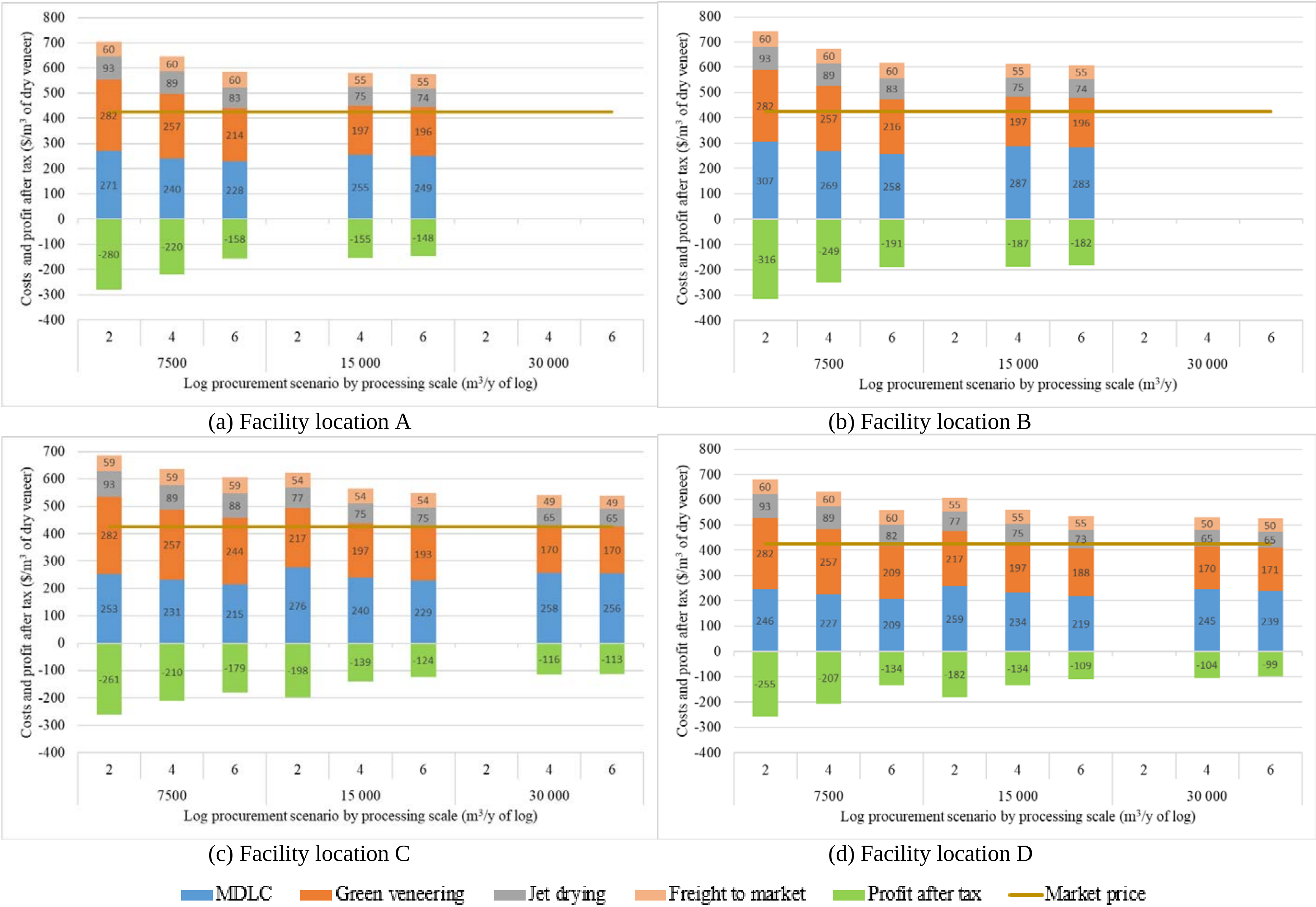


Figure 19.5. Average costs of production and profit after tax for the manufacture and sale of green veneer



(a) Facility location A

(b) Facility location B

(c) Facility location C

(d) Facility location D

Figure 19.6. Average costs of production and profit after tax for the manufacture and sale of dry veneer

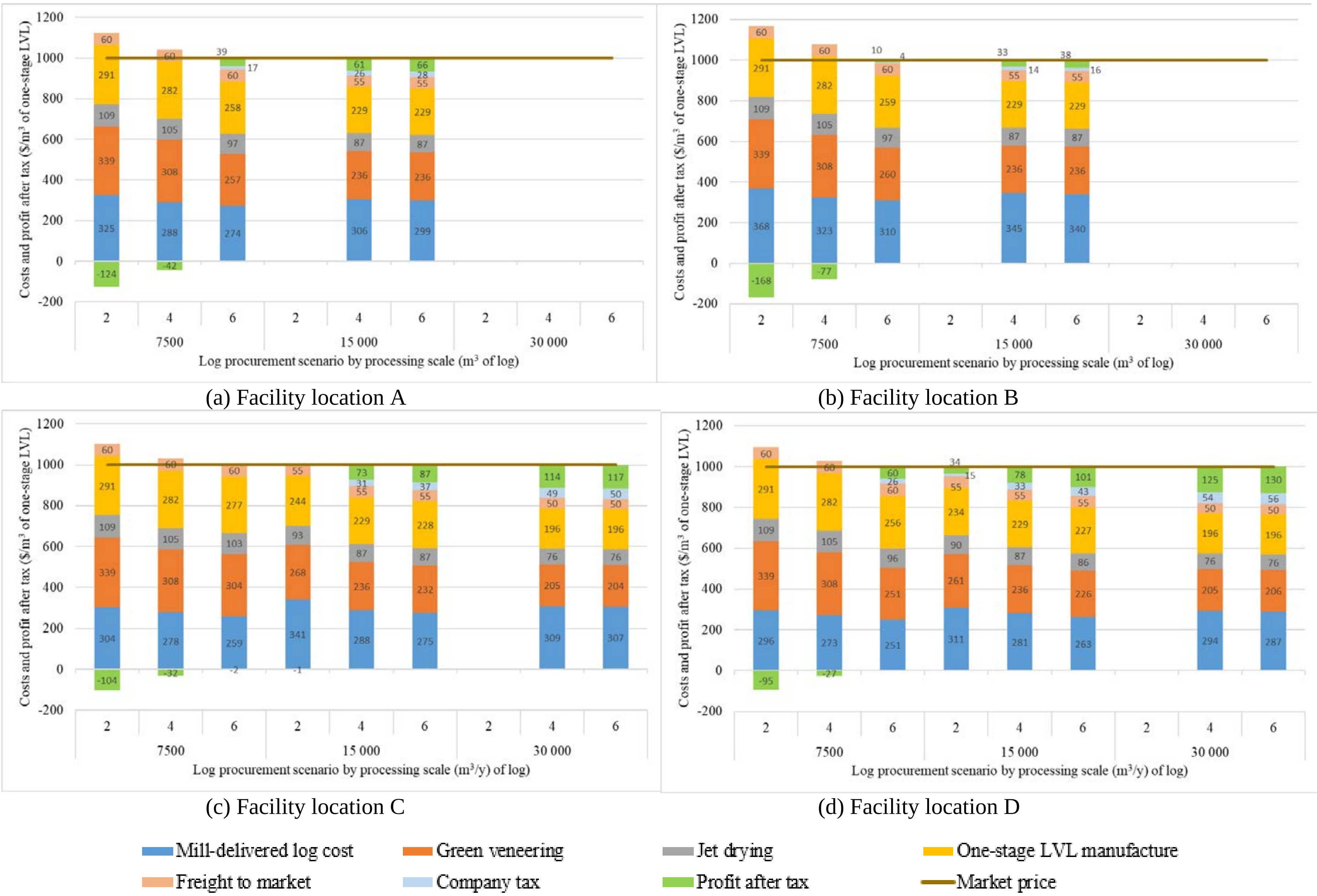


Figure 19.7. Average costs of production and profit after tax for the manufacture and sale of one-stage LVL

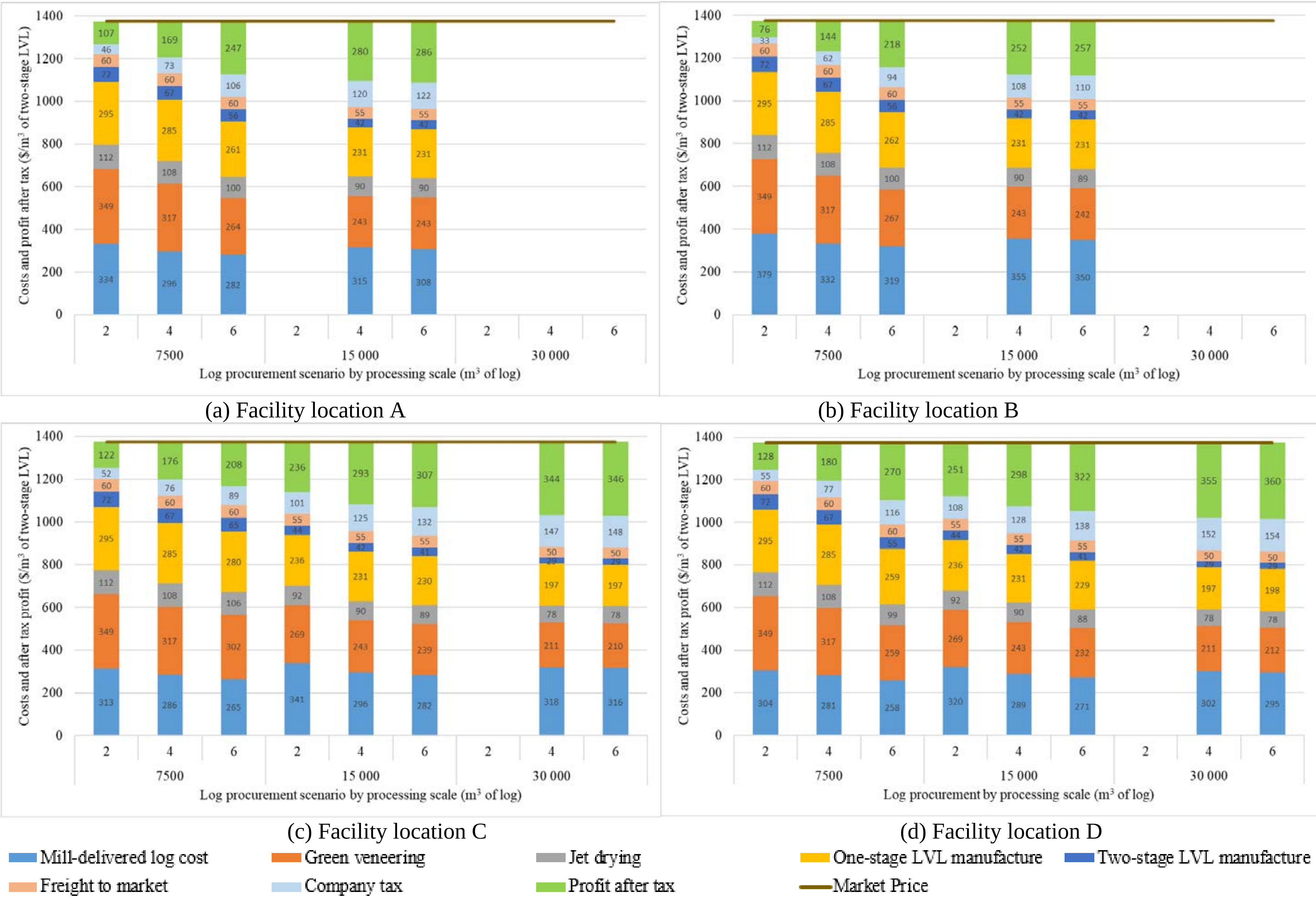


Figure 19.8. Average costs of production and profit after tax for the manufacture and sale of two-stage LVL

Sensitivity analyses have been performed for six parameters that NPV is most sensitive to. Alternative discount rates of 4% and 10% have been assessed. Base case parameter levels have been increased and decreased by 20% for mill-delivered log costs (the sum of stumpage, cut, snig, load and haul costs), equipment utilisation rates (rates for all processing stages assessed together), capital costs throughout the life of the investment, labour costs and market prices. The results of sensitivity analyses are presented in Appendix 19.1.

The negative financial performances of green and dry veneer manufacture for all facility locations, processing scales and log procurement scenarios were found to be robust against changes in all model parameters. That is, improvements in parameter levels of greater than 20% or a discount rate under 4% would be necessary for the manufacture of green or dry veneer to be financially viable.

The financial performance of one-stage LVL production is highly sensitive to the market price; a 20% increase in price results in all one-stage LVL scenarios being profitable, irrespective of facility location and processing scale, while a 20% decrease in market price results in none of these scenarios being profitable. The 7500 m^3/y scale for one-stage LVL at facility locations A or B is only financially viable with a higher market price. At the 15,000 m^3/y scale, pessimistic levels for any one model parameter make one-stage LVL manufacture unprofitable at facility locations A and B. The 30,000 m^3/y scale is not technically feasible at facility locations A and B. At facility locations C and D, for log procurement scenario 6 only, one-stage LVL manufacture at the 7500 m^3/y scale is financially viable with optimistic parameter levels for mill-delivered log costs and capital costs. The profitability of one-stage LVL manufacture for log procurement scenarios 4 and 6 at processing scales of at least 15,000 m^3/y is robust against changes in all parameters, except market price and the discount rate.

The profitability of most two-stage LVL manufacturing scenarios are highly robust against changes in parameter levels. There are only three cases where negative returns have been projected. First, at the 7500 m^3/y processing scale, profitability of two-stage LVL is sensitive to market price for all facility location scenarios. Second, at facility location B, negative returns have also been projected for the 7500 m^3/y processing scale for pessimistic levels of any single parameter. Third, at facility location B with processing at the 15,000 m^3/y scale, positive financial performance of two-stage LVL manufacture is sensitive to a high level of the discount rate. On balance, two-stage LVL manufacture at processing scales of at least 15,000 m^3/y has been revealed as the superior investment option.

Financial performance of distributed processing facilities

Figure 19.9 illustrates the results of the assessment of distributed production, with the four panels displaying the results by facility location scenario for the veneering part of the operation (facility location C or D), and by final product manufactured (one-stage or two-stage LVL). The x-axis has the three distributed production scenarios considered; one veneering facility processing 15,000 m^3/of log; one veneering facility processing 30,000 m^3/y of log; and two separate veneering facilities processing 15,000 m^3/y of log each. The box plots represent the distribution of after tax profits for distributed production, ranging from low shipping and handling costs (top of the box; \$20/m^3 of dry veneer) to high shipping and handling costs (bottom of the box; \$40/m^3 of dry veneer). There is no box plot for one 30,000 m^3/y of log veneering facility operating under log procurement scenario 2, because of insufficient log volume.

The line rising from the top of each box ends at the profit level estimated for one integrated LVL facility producing 15,000 m^3/y or 30,000 m^3/y under the specific log procurement scenario, as reported in Figures 19.7 and 19.8. Not surprisingly, for any particular processing scale and log procurement scenario, if production can be performed at a single facility, this will be more profitable than incurring additional shipping and handling costs for an intermediate product. More nuanced interpretation of the box plots to support investment decisions, including the box in each panel without a line extending from the top, are provided below.

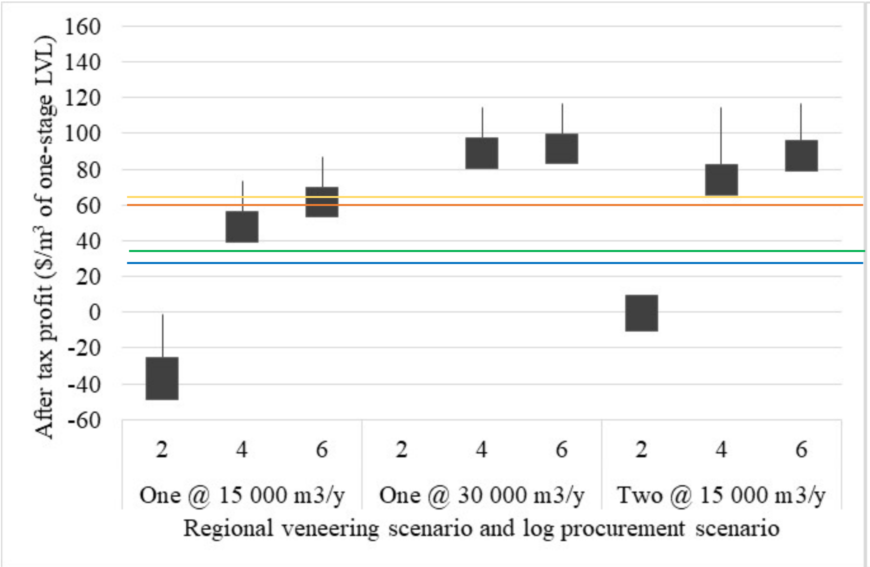
For comparative purposes, the coloured horizontal lines in each panel represent the profitability of LVL processing under facility location scenarios A and B for log procurement scenarios 4 and 6 at the 15,000 m^3/y scale (taken from Figures 19.7 and 19.8). Recall that for these facility location scenarios, log procurement scenario 2 was not feasible at the 15,000 m^3/y scale, and no scenario was technically feasible at the 30,000 m^3/y scale (insufficient log volume).

The distributed production analysis revealed five notable findings. First, all distributed production scenarios, except one-stage LVL at the 15,000 m^3/y scale for log procurement scenario 2 at facility location C, are expected to be profitable.

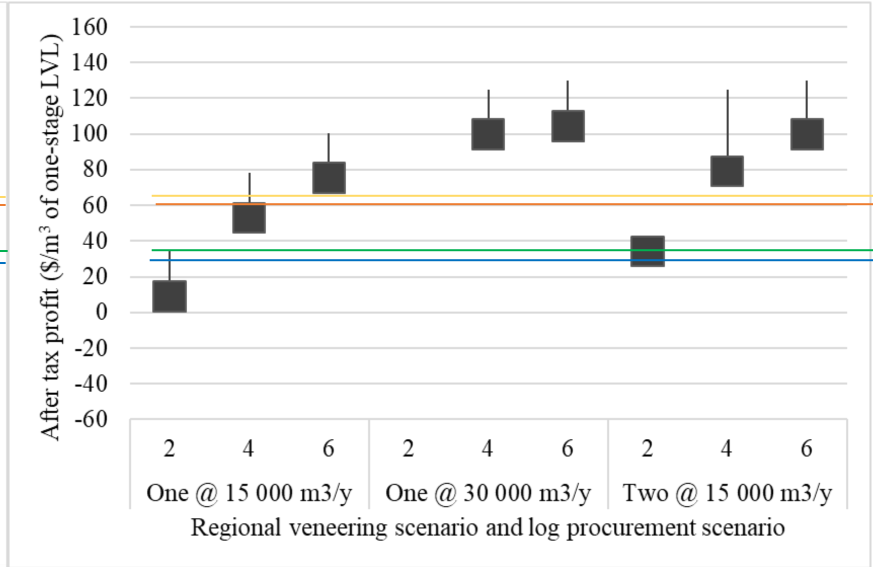
Second, distributed production with two 15,000 m^3/y veneering facilities makes log procurement scenario 2 technically feasible and profitable at the 30,000 m^3/y processing scale for one-stage and two-stage LVL with the veneering occurring at either facility location C or D. These results have no line at rising from the top of the box, because 30,000 m^3/y was not technically feasible with log procurement scenario 2 in Figure 19.9.

Third, strong economies of scale with veneering and LVL production highlighted elsewhere in this report are present in the distributed production scenarios. Despite lower mill-delivered log costs when two 15,000 m^3/y veneering facilities supply one LVL facility with dry veneer in a distributed production framework, the economies of scale gained by operating one 30,000 m^3/y veneering facility in distributed production always generates higher profits for either one-stage or two-stage LVL production, *ceteris paribus*. Furthermore, the profitability two 15,000 m^3/y veneering facilities supplying one 30,000 m^3/y LVL facility is always greater than one 15,000 m^3/y veneering facility supplying one 15,000 m^3/y LVL facility, *ceteris paribus.*

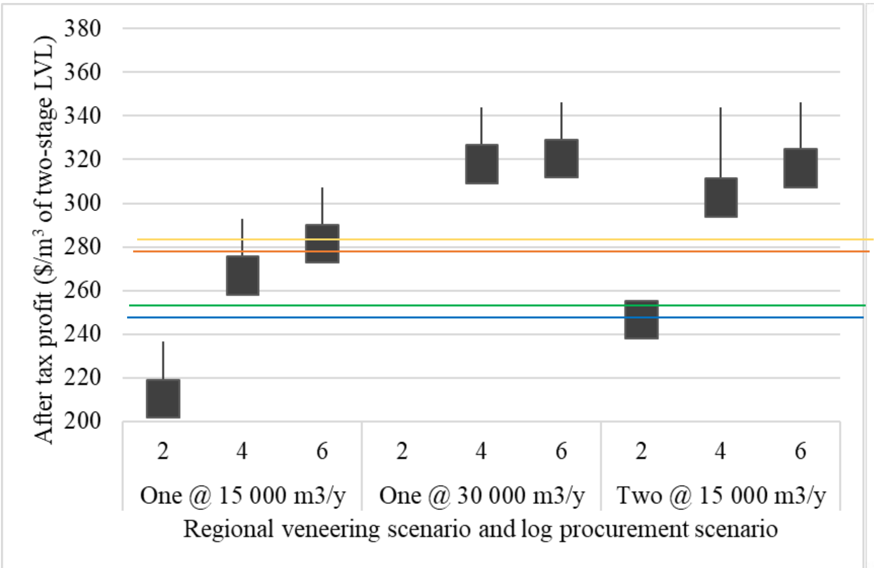
Fourth, distributed production for one or two-stage LVL from one 15,000 m^3/y processing scale veneering facility at location C or D will generate higher returns than an integrated facility at location B (green and blue lines in Figure 19.9). Fifth, distributed production for one or two-stage LVL from one 15,000 m^3/y veneering facility at location D for log procurement scenario 6 will generate higher returns than an integrated facility at location A (yellow and orange lines in Figure 19.9).



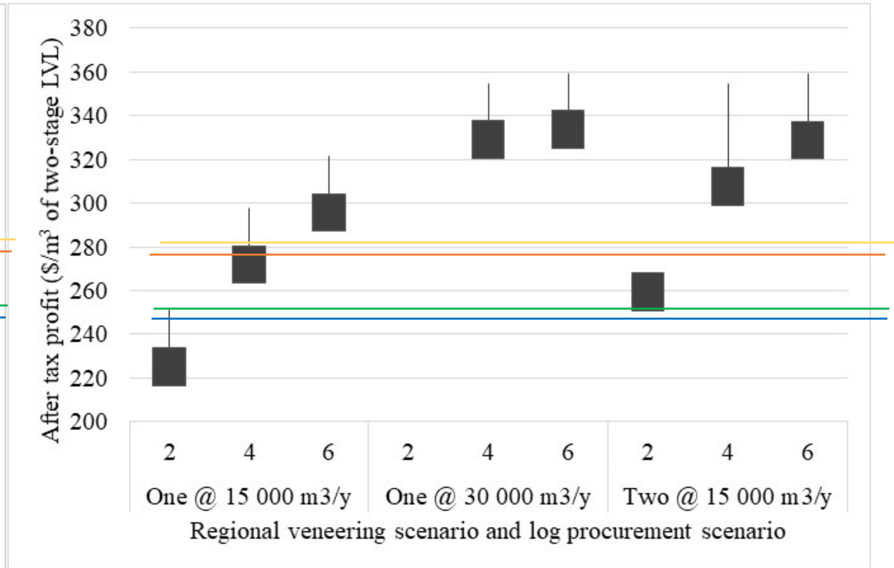
(a) One-stage LVL, veneering facility location C



(b) One-stage LVL, veneering facility location D



(c) Two-stage LVL, veneering facility location C



(d) Two-stage LVL, veneering facility location D

Processing scale 15,000 m^3/y, facility location A, log procurement scenario 4 A, 6 B, 4 B, 6

Figure 19.9. Profitability of distributed veneer, and one and two stage-LVL manufacture

Discussion

The decision-making environment of a particular wood processing firm may not be represented by any of the scenarios reported in this chapter. However, meetings with EWP and sawmilling industry representatives during 2018 and 2019 indicated that the model generates estimates of costs and returns that are within a range they expected. A high degree of satisfaction was expressed about the ease with which parameter levels can be changed and sensitivity analyses performed to support investment decision-making.

An extensive international literature review did not reveal estimates of NPV, costs of production and processing coefficients for spindleless rotary veneering and LVL manufacture against which the findings from this study could be compared. The levels of recovery of veneer from log volume adopted in this study are consistent with international estimates from several studies that have considered small and large diameter hardwood and softwood logs (Kewilaa 2007, Wang and Dai 2008, Belleville *et al.* 2018).

A comparison of the potential level of impact of strategic and tactical decisions on NPV will always be somewhat subjective, depending on the range in levels for the parameters evaluated. However, for this analysis, the importance of strategic and tactical decisions associated with veneer and LVL manufacture in decreasing order of their impact on NPV were found to be the:

1. product manufactured (level of value-adding);
2. processing scale;
3. log procurement strategy (log types processed); and
4. facility location (proximity to forest).

The level of value adding had the greatest impact on NPV, with returns increasing substantially with increasing value-adding. This is consistent with industry experience in Sweden and Finland (Roos *et al*. 2001; Lahtinen and Toppinen 2008;Brege *et al.* 2010). The strong financial returns to two-stage LVL and, to a lesser extent one-stage LVL manufacturing, suggests Australian processors could learn from the experience of Nordic European counties. Singer and Donoso (2007) found that large-scale production of relatively low-value products was the comparative advantage of wood processors located within the extensive and fast-growing plantation forest estates of Chile, where log costs are comparatively low. The subtropical native hardwood forests of eastern Australia are shrinking in terms of the area managed for timber production, and are not fast-growing. The financial analysis indicated investment in the production and sale of hardwood veneer from native forests in subtropical eastern Australia cannot be justified at prices competitive with softwood and commodity hardwood veneer in domestic and international markets. If markets develop that value the superior mechanical properties, natural durability and aesthetics of subtropical Australian hardwood veneers, then higher prices could be achieved. The possible development of markets for EWPs, such as the LVL products examined in this study, may stimulate such a premium.

Decisions about processing scale had the second greatest impact on NPV, with strong economies of scale in production, particularly with one and two-stage LVL. However, findings in this study about limited profitability at small-scales need to be interpreted with caution, as the 7500 m^3/y processing scale was deliberately examined as a part-time operation with the hourly processing capacity of a 15,000 m^3/y operation. The financial performance of a full-time operation at 7500 m^3/y has not been investigated and it is challenging to hypothesise whether such an operation (presumably utilising lower cost, but also lower processing capacity equipment) would be viable.

The third most important decision was the tactical one of which log types to procure and process. The financial model has highlighted that a simple focus of log procurement officers on either log size or mill-delivered log cost, is insufficient to maximise profitability. This conclusion was also reached by Dobner Jr. *et al.* (2013) for veneer production from *Pinus taeda* logs in Brazil. Log procurement scenario 6 maximised profitability by preferentially utilising B-grade sawlogs, then small peelers and top logs, and finally, A-grade sawlogs. B-grade sawlogs were targetted for harvest in log procurement scenario 6 because of their moderate mill-delivered log cost relative to A-grade sawlogs, and their high veneer recovery from log volume and high rate of log processing, relative to small peeler logs and top logs. Log procurement scenario 2 performed comparatively poorly, because it only utilised small peeler and top logs. Log procurement scenario 4 performed poorly in comparison to scenario 6 because it utilised relatively large volumes of A-grade sawlogs, and small peeler and top logs.

The interest in utilising small peeler and top logs in the study area, particularly to encourage and offset the costs of silvicultural treatment, warrants further comment. Figures 19.1 to 19.9 revealed log procurement scenario 2 was always the least profitable, and only generated positive returns with two-stage LVL manufacture. It can be deduced from Figures 19.5 to 19.8 by how much log costs would have to fall in log procurement scenario 2, so that profitability would be comparable with scenarios 4 and 6. For example, at the 15,000 m^3/y processing scale at facility location C, the difference in financial performance of two-stage LVL manufacture under log procurement scenarios 4 and 6, relative to scenario 2, has a value equivalent to \$27/m^3 of log and \$33/m^3 of log, respectively[34]. Therefore, reducing the stumpage price paid to landholders for small peeler logs and top logs from the base case level of \$40/m^3 to between \$7/m^3 and \$13/m^3 would make log procurement scenario 2 as profitable as scenarios 4 and 6.

Although the returns to log procurement scenario 2 are relatively low, the opportunity costs associated with using small peeler and top logs are also low, because they are not presently in high demand in the study area. In contrast, A-grade and B-grade sawlogs are actively procured by sawmills. A-grade and B-grade sawlogs may generate higher returns when processed into particular roundwood or sawnwood products, rather than veneer and LVL[35]. Therefore, investment in veneering small peeler logs may be a more appealing prospect than this analysis indicates. Furthermore, the log procurement scenario 6 does maximise profitability by utilising substantial volumes of small peeler and top logs at larger processing scales (42.6% at the 30,000 m^3/y scale; Table 19.6). While this case study does not justify the adoption of log procurement scenario 2 by processing facilities, utilising small peeler and top logs within a mix of log types is optimal. Therefore, establishment of hardwood LVL manufacturing facilities in subtropical eastern Australia does have the potential to develop new markets for small logs.

Access to and utilisation of small peeler logs will be impacted by potential changes to forest policy, codes of practice for native forest silviculture and harvesting on private land, tree marking and sales practices on state-owned lands, and the diversion of logs from traditional sawlog markets to veneering (Leggate *et al.* 2019). Therefore, findings reported about scenarios utilising large volumes of small peeler and top logs should be applied with caution. Existing forest policy for a large proportion of state-owned land in the study area requires that

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[34] For example, the increased profitability of two-stage LVL manufacture at the 15,000 m^3/y processing scale under log procurement scenario 4, relative to scenario 2 is \$57/m^3 of LVL. Subtracting this difference from mill-delivered log costs for Scenario 2 (\$341-\$57) indicates profitability of these two scenarios would be identical if mill-delivered log costs in scenario 2 were \$284/m^3 of LVL. Given 42% product recovery from log volume (Table 19.4), that is equivalent to a mill-delivered log cost of \$119/m^3 of log, which is \$27/m^3 lower than reported in Table 19.7.

[35] No estimates of gross margins or profitability of sawn hardwood production have been made in this study or published elsewhere for subtropical eastern Australian hardwoods.

only traditional log types can be harvested, preventing development of new log types, such as small peeler and top logs, as the timber industry evolves (McAlpine *et al.* 2005; McAlpine *et al.* 2007; Burgess and Catchpoole 2016). At the time of publication, the code of practice on private land was under review, and some proposed changes may affect permissible silvicultural practices and harvestable volumes. The major policy implication arising from this study is that opportunities for processors in the region to profitably adopt LVL processing technologies will be enhanced by state government forest policy and codes of practice for private land that permit utilisation of small logs, particularly from suppressed trees that will never attain the specifications of traditional log types. A market for small logs will also help facilitate the silvicultural treatments necessary to increase the productivity of private native forests in sub-tropical eastern Australia.

The fourth most important strategic or tactical decisions was facility location. This was being driven by mill-delivered log costs, with facilities proximate to forests being more profitable (facility locations C and D). However, the distributed production analysis revealed that, if for technical or logistical reasons, an integrated LVL production facility had to be located at facility location A or B, an investor should look carefully at distributed production opportunities where veneering could be performed at facility locations C or D. If veneering can be performed at either facility locations C or D with log procurement scenarios 4 or 6, and the LVL manufactured at facility location B, this would be more profitable than having a single integrated operation at location B. If veneering can be performed at facility location D with log procurement scenarios 4 or 6, and the LVL manufactured at facility location A, this is more profitable than having a single integrated operation at location A. In both cases, the lower mill-delivered log costs of distributed production more than made up for the handling and shipping costs of the intermediate product.

If an LVL facility has challenges procuring sawlogs, or managers choose not to produce veneer from sawlogs, such that only small peeler and top logs (log procurement scenario 2) are utilised, an integrated facility at the 30,000 m^3/ scale would not be technically feasible given the parameter levels adopted. However, the assessment of distributed production revealed that it is technically feasible and profitable to have distributed production with two 15,000 m^3/y veneering facilities utilising small peeler and top logs at facility locations C or D, and supplying one 30,000 m^3/y two-stage LVL manufacturing facility[36]. For two-stage LVL manufacture under this scenario, profits are expected to be greater than \$240/m^3 of LVL. Although this is low relative to other log procurement scenarios, it does still represent a strong return.

There are five assumptions embedded within the design of scenarios that should be considered when interpreting results. First, log procurement scenario 6 assumes alternative log types can be optimally procured from the landscape surrounding the processing facility. This may be difficult to achieve in practice, as described in Chapter 17. In contrast, log procurement scenarios 2 and 4 can be regarded as ‘near feasible’, because the contractual arrangements necessary to achieve them are no more burdensome for contracted parties than existing operations.

Second, the manufacturing facility is assumed to use a biomass boiler that is largely (although not entirely) supplied by on-site waste to generate the heat necessary for log steaming and veneer drying. If electricity or natural gas had to be used to generate all of this heat instead, this would add substantially to annual energy costs, although there would be potential capital savings in not requiring a biomass boiler.

Third, the scenarios examined assume an expansion of activity at an existing processing facility (e.g. a sawmill). Consequently, the analysis did not consider land acquisition costs and

[36] One-stage LVL production would be only marginally profitable (Figure 19.9).

non-labour costs of administration (e.g. office space, stationery, telecommunications). Fourth, the model assumes market acceptance of new hardwood LVL products commencing in year one, but there are likely to be challenges promoting adoption in some markets (Evison et al. 2018). Fifth, while the analysis did consider the impact of company tax on financial performance, it did not account for tax benefits arising from asset depreciation. This suggests the financial performance of LVL manufacturing scenarios that generated a positive return have been slightly underestimated.

Conclusions

Given the market prices adopted for analysis, producing green or dry veneer for sale from native forest hardwood logs in subtropical eastern Australia was found to not be financially viable. In contrast, the manufacture of two-stage LVL products was generally projected to be highly profitable. Many one-stage LVL scenarios evaluated were estimated to be marginally to moderately profitable.

This chapter revealed that, in decreasing order of impact on profitability of a veneering or LVL manufacturing operation, the strategic and tactical decisions in subtropical eastern Australia are the product manufactured (level of value-adding), processing scale, log procurement strategy (log types processed), and facility location (proximity to forest). A single integrated facility processing logs into veneer and then LVL was found to be most profitable. However, if technical or logistical constraints prevented a single integrated facility being located close to the log resource, then the financial analysis highlighted opportunities for profitable distributed production of LVL, with veneer produced close to the log resource, before being shipped to an LVL manufacturing facility.

Strong economies of scale appear to exist with LVL manufacture. The analysis also revealed that the log procurement strategy can substantially affect profitability. Although B-grade sawlogs were revealed to be the most profitable log type to process into veneer and LVL, maximising NPV at the 30,000 m^3/y processing scale required 42.6% of logs to be small, non-traditional log types (small peeler and top logs). Therefore, if LVL manufacture with native forest logs becomes more common in subtropical eastern Australia, the demand for small logs is likely to rise. This would be a ‘win-win’ opportunity for landholders and processors (and associated regional communities), because increased utilisation of small logs is likely to facilitate and offset the costs of silvicultural treatment in degraded forests, increasing forest productivity, and future harvestable volume and value. Forest policy that permits the utilisation of small, suppressed trees is necessary for the timber industry in subtropical eastern Australia to take full advantage of the short and long-term opportunities with hardwood veneer and LVL manufacture.

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Appendix 19.1: Sensitivity of net present value of product manufacture to changes in levels of several important model parameters

Table A.19.1.1. Facility location A, sensitivity of NPV of green veneer manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-8.98	-7.14	-6.43		-8.67	-8.18			
	Base	-11.55	-9.62	-8.85		-13.93	-13.34			
	+20%	-14.13	-12.09	-11.27		-19.19	-18.50			
Utilisation rate	-20%	-12.13	-10.14	-9.36		-14.98	-14.40			
	Base	-11.55	-9.62	-8.85		-13.93	-13.34			
	+20%	-11.17	-9.27	-8.50		-13.23	-12.64			
Capital cost	-20%	-9.68	-7.74	-6.97		-12.06	-11.47			
	Base	-11.55	-9.62	-8.85		-13.93	-13.34			
	+20%	-13.43	-11.49	-10.72		-15.80	-15.22			
Labour cost	-20%	-10.90	-9.00	-8.24		-12.06	-11.46			
	Base	-11.55	-9.62	-8.85		-13.93	-13.34			
	+20%	-12.21	-10.23	-9.46		-15.80	-15.22			
Market price	-20%	-15.27	-13.65	-12.99		-21.99	-21.43			
	Base	-11.55	-9.62	-8.85		-13.93	-13.34			
	+20%	-7.84	-5.62	-4.85		-5.88	-5.33			
Discount rate	4%	-15.26	-12.54	-11.46		-18.61	-17.78			
	Base	-11.55	-9.62	-8.85		-13.93	-13.34			
	10%	-9.23	-7.77	-7.19		-11.01	-10.57			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.2. Facility location A, sensitivity of NPV of dry veneer manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-14.77	-12.75	-11.98		-17.37	-16.87			
	Base	-17.35	-15.23	-14.40		-22.63	-22.03			
	+20%	-19.92	-17.71	-16.82		-27.89	-27.19			
Utilisation rate	-20%	-18.45	-16.28	-15.44		-26.50	-25.90			
	Base	-17.35	-15.23	-14.40		-22.63	-22.03			
	+20%	-16.14	-14.06	-13.23		-20.47	-19.87			
Capital cost	-20%	-14.60	-12.48	-11.65		-20.45	-19.85			
	Base	-17.35	-15.23	-14.40		-22.63	-22.03			
	+20%	-19.53	-17.41	-16.58		-24.81	-24.21			
Labour cost	-20%	-15.71	-13.62	-12.80		-19.01	-18.40			
	Base	-17.35	-15.23	-14.40		-22.63	-22.03			
	+20%	-18.99	-16.84	-16.00		-26.26	-25.66			
Market price	-20%	-21.30	-19.52	-18.81		-31.22	-30.64			
	Base	-17.35	-15.23	-14.40		-22.63	-22.03			
	+20%	-13.39	-10.90	-9.24		-14.05	-13.36			
Discount rate	4%	-23.26	-20.28	-19.11		-30.66	-29.81			
	Base	-17.35	-15.23	-14.40		-22.63	-22.03			
	10%	-13.67	-12.08	-11.46		-17.66	-17.21			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.3. Facility location A, sensitivity of NPV of one-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-3.83	-1.38	-0.56		6.85	7.26			
	Base	-6.11	-3.42	-2.44		3.06	3.55			
	+20%	-8.40	-5.61	-4.54		-0.87	-0.28			
Utilisation rate	-20%	-8.03	-5.41	-4.43		-0.00	0.54			
	Base	-6.11	-3.42	-2.44		3.06	3.55			
	+20%	-4.83	-2.15	-1.24		5.22	5.72			
Capital cost	-20%	-3.17	-0.68	0.19		5.71	6.22			
	Base	-6.11	-3.42	-2.44		3.06	3.55			
	+20%	-9.05	-6.35	-5.34		0.54	1.04			
Labour cost	-20%	-4.40	-1.75	-0.86		6.40	6.89			
	Base	-6.11	-3.42	-2.44		3.06	3.55			
	+20%	-7.82	-5.18	-4.20		-0.32	0.12			
Market price	-20%	-13.45	-11.07	-10.15		-11.04	-10.42			
	Base	-6.11	-3.42	-2.44		3.06	3.55			
	+20%	0.30	3.04	4.03		14.99	15.51			
Discount rate	4%	-7.09	-3.40	-2.06		5.62	6.32			
	Base	-6.11	-3.42	-2.44		3.06	3.55			
	10%	-5.41	-3.34	-2.59		1.56	1.93			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.4. Facility location A, sensitivity of NPV of two-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	4.04	6.96	8.00		24.53	25.00			
	Base	2.13	5.17	6.27		20.81	21.35			
	+20%	0.18	3.35	4.51		17.10	17.70			
Utilisation rate	-20%	0.41	3.43	4.52		17.74	18.30			
	Base	2.13	5.17	6.27		20.81	21.35			
	+20%	3.26	6.31	7.42		23.04	23.59			
Capital cost	-20%	4.98	7.91	8.98		23.72	24.28			
	Base	2.13	5.17	6.27		20.81	21.35			
	+20%	-0.82	2.31	3.44		18.13	18.66			
Labour cost	-20%	3.62	6.68	7.79		24.22	24.76			
	Base	2.13	5.17	6.27		20.81	21.35			
	+20%	0.61	3.64	4.73		17.47	17.95			
Market price	-20%	-6.19	-3.33	-2.34		4.90	5.40			
	Base	2.13	5.17	6.27		20.81	21.35			
	+20%	9.62	13.15	14.43		36.65	37.23			
Discount rate	4%	4.51	8.78	10.32		30.83	31.59			
	Base	2.13	5.17	6.27		20.81	21.35			
	10%	0.77	3.06	3.88		14.79	15.19			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.5. Facility location B, sensitivity of NPV of green veneer manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-10.35	-8.34	-7.78		-11.36	-10.97			
	Base	-13.27	-11.11	-10.49		-17.30	-16.83			
	+20%	-16.19	-13.89	-13.21		-23.23	-22.70			
Utilisation rate	-20%	-13.85	-11.64	-11.01		-18.35	-17.89			
	Base	-13.27	-11.11	-10.49		-17.30	-16.83			
	+20%	-12.89	-10.76	-10.15		-16.60	-16.13			
Capital cost	-20%	-11.40	-9.24	-8.62		-15.42	-14.96			
	Base	-13.27	-11.11	-10.49		-17.30	-16.83			
	+20%	-15.15	-12.99	-12.37		-19.17	-18.71			
Labour cost	-20%	-12.62	-10.50	-9.88		-15.42	-14.96			
	Base	-13.27	-11.11	-10.49		-17.30	-16.83			
	+20%	-13.93	-11.73	-11.11		-19.17	-18.71			
Market price	-20%	-16.99	-15.14	-14.60		-25.36	-24.93			
	Base	-13.27	-11.11	-10.49		-17.30	-16.83			
	+20%	-9.56	-7.08	-6.39		-9.24	-8.74			
Discount rate	4%	-17.68	-14.64	-13.77		-23.35	-22.70			
	Base	-13.27	-11.11	-10.49		-17.30	-16.83			
	10%	-10.52	-8.89	-8.43		-13.54	-13.19			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.6. Facility location B, sensitivity of NPV of dry veneer manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-16.15	-13.95	-13.35		-20.06	-19.65			
	Base	-19.07	-16.73	-16.07		-26.00	-25.52			
	+20%	-21.99	-19.50	-18.78		-31.94	-31.39			
Utilisation rate	-20%	-20.16	-17.78	-17.11		-29.87	-29.39			
	Base	-19.07	-16.73	-16.07		-26.00	-25.52			
	+20%	-17.86	-15.55	-14.89		-23.84	-23.36			
Capital cost	-20%	-16.32	-13.97	-13.31		-23.82	-23.34			
	Base	-19.07	-16.73	-16.07		-26.00	-25.52			
	+20%	-21.25	-18.91	-18.25		-28.18	-27.70			
Labour cost	-20%	-17.43	-15.12	-14.46		-22.38	-21.89			
	Base	-19.07	-16.73	-16.07		-26.00	-25.52			
	+20%	-20.71	-18.33	-17.67		-29.62	-29.14			
Market price	-20%	-23.02	-21.02	-20.44		-34.58	-34.14			
	Base	-19.07	-16.73	-16.07		-26.00	-25.52			
	+20%	-15.11	-12.43	-11.70		-17.41	-16.90			
Discount rate	4%	-25.68	-22.38	-21.45		-35.40	-34.72			
	Base	-19.07	-16.73	-16.07		-26.00	-25.52			
	10%	-14.96	-13.20	-12.71		-20.19	-19.83			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.7. Facility location B, sensitivity of NPV of one-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-5.04	-2.32	-1.68		4.91	5.27			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-10.36	-7.20	-6.37		-4.20	-3.63			
Utilisation rate	-20%	-9.62	-6.73	-5.99		-2.61	-2.12			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-6.35	-3.41	-2.64		2.79	3.21			
Capital cost	-20%	-4.69	-1.84	-1.15		3.30	3.73			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-10.61	-7.68	-6.91		-2.02	-1.58			
Labour cost	-20%	-5.92	-2.97	-2.23		3.98	4.40			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-9.40	-6.51	-5.76		-2.97	-2.54			
Market price	-20%	-15.17	-12.56	-11.84		-14.41	-13.90			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-1.01	1.94	2.69		12.61	13.06			
Discount rate	4%	-9.18	-5.22	-4.16		2.13	2.73			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	10%	-6.58	-4.36	-3.77		-0.32	0.00			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.8. Facility location B, sensitivity of NPV of two-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	3.02	6.10	6.86	0.00	22.63	23.06			
	Base	0.83	4.08	4.89	0.00	18.43	18.91			
	+20%	-1.38	2.02	2.90	0.00	14.24	14.76			
Utilisation rate	-20%	-0.89	2.33	3.13	0.00	15.36	15.86			
	Base	0.83	4.08	4.89	0.00	18.43	18.91			
	+20%	1.98	5.23	6.05	0.00	20.67	21.15			
Capital cost	-20%	3.73	6.85	7.64	0.00	21.34	21.84			
	Base	0.83	4.08	4.89	0.00	18.43	18.91			
	+20%	-2.12	1.18	2.02	0.00	15.75	16.23			
Labour cost	-20%	2.35	5.61	6.42	0.00	21.84	22.33			
	Base	0.83	4.08	4.89	0.00	18.43	18.91			
	+20%	-0.69	2.53	3.34	0.00	15.09	15.52			
Market price	-20%	-7.71	-4.64	-3.83	0.00	2.42	2.85			
	Base	0.83	4.08	4.89	0.00	18.43	18.91			
	+20%	8.40	12.09	13.02	0.00	34.29	34.82			
Discount rate	4%	2.69	7.25	8.39	0.00	27.48	28.15			
	Base	0.83	4.08	4.89	0.00	18.43	18.91			
	10%	-0.22	2.23	2.85	0.00	13.01	13.37			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.9. Facility location C, sensitivity of NPV of green veneer manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-8.31	-6.78	-5.73	-11.55	-7.44	-6.22		-11.16	-10.74
	Base	-10.72	-9.17	-8.02	-16.80	-12.39	-11.03		-21.76	-21.29
	+20%	-13.13	-11.56	-10.34	-22.05	-17.34	-15.83		-32.37	-31.83
Utilisation rate	-20%	-11.29	-9.69	-8.53	-17.95	-13.44	-12.07		-23.69	-23.21
	Base	-10.72	-9.17	-8.02	-16.80	-12.39	-11.03		-21.76	-21.29
	+20%	-10.34	-8.82	-7.69	-16.04	-11.69	-10.33		-20.48	-20.00
Capital cost	-20%	-8.85	-7.29	-6.15	-14.93	-10.52	-9.15		-18.29	-17.82
	Base	-10.72	-9.17	-8.02	-16.80	-12.39	-11.03		-21.76	-21.29
	+20%	-12.59	-11.04	-9.90	-18.68	-14.26	-12.90		-25.23	-24.75
Labour cost	-20%	-10.07	-8.55	-7.42	-14.85	-10.52	-9.16		-18.80	-18.33
	Base	-10.72	-9.17	-8.02	-16.80	-12.39	-11.03		-21.76	-21.29
	+20%	-11.37	-9.78	-8.63	-18.75	-14.26	-12.89		-24.72	-24.25
Market price	-20%	-14.43	-13.20	-12.23	-24.23	-20.45	-19.23		-37.83	-37.40
	Base	-10.72	-9.17	-8.02	-16.80	-12.39	-11.03		-21.76	-21.29
	+20%	-7.01	-5.23	-4.06	-9.37	-4.51	-3.18		-6.24	-5.78
Discount rate	4%	-14.09	-11.91	-10.30	-22.65	-16.44	-14.52		-28.58	-27.91
	Base	-10.72	-9.17	-8.02	-16.80	-12.39	-11.03		-21.76	-21.29
	10%	-8.60	-7.43	-6.57	-13.17	-9.85	-8.83		-17.41	-17.05

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.10. Facility location C, sensitivity of NPV of dry veneer manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-14.11	-12.39	-11.18	-20.60	-16.14	-14.85		-8.16	-7.72
	Base	-16.52	-14.78	-13.54	-25.85	-21.09	-19.65		-18.77	-18.27
	+20%	-18.92	-17.17	-15.85	-31.10	-26.05	-24.45		-29.37	-28.82
Utilisation rate	-20%	-17.61	-15.83	-14.57	-29.81	-24.96	-23.50		-22.15	-21.65
	Base	-16.52	-14.78	-13.54	-25.85	-21.09	-19.65		-18.77	-18.27
	+20%	-15.31	-13.61	-12.37	-23.63	-18.93	-17.50		-17.04	-16.54
Capital cost	-20%	-13.76	-12.03	-10.79	-23.67	-18.91	-17.47		-14.84	-14.34
	Base	-16.52	-14.78	-13.54	-25.85	-21.09	-19.65		-18.77	-18.27
	+20%	-18.70	-16.96	-15.72	-28.03	-23.27	-21.83		-22.69	-22.19
Labour cost	-20%	-14.87	-13.18	-11.95	-22.15	-17.47	-16.03		-15.27	-14.78
	Base	-16.52	-14.78	-13.54	-25.85	-21.09	-19.65		-18.77	-18.27
	+20%	-18.16	-16.39	-15.13	-29.55	-24.72	-23.27		-22.26	-21.76
Market price	-20%	-20.47	-19.07	-18.02	-33.76	-29.68	-28.38		-35.88	-35.43
	Base	-16.52	-14.78	-13.54	-25.85	-21.09	-19.65		-18.77	-18.27
	+20%	-12.56	-10.46	-7.96	-17.94	-11.21	-8.98		-4.87	-4.39
Discount rate	4%	-22.09	-19.64	-17.89	-35.20	-28.49	-26.46		-24.08	-23.38
	Base	-16.52	-14.78	-13.54	-25.85	-21.09	-19.65		-18.77	-18.27
	10%	-13.04	-11.74	-10.81	-20.08	-16.51	-15.42		-15.33	-14.96

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.11. Facility location C, sensitivity of NPV of one-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-3.24	-1.11	0.18	3.20	7.72	8.92		23.34	23.75
	Base	-5.37	-3.02	-1.58	-0.71	4.17	5.50		15.82	16.27
	+20%	-7.50	-5.13	-3.50	-5.08	0.53	2.02		8.23	8.73
Utilisation rate	-20%	-7.28	-5.01	-3.50	-4.27	1.16	2.59		9.10	9.55
	Base	-5.37	-3.02	-1.58	-0.71	4.17	5.50		15.82	16.27
	+20%	-4.09	-1.79	-0.41	1.46	6.33	7.67		19.58	20.03
Capital cost	-20%	-2.43	-0.34	1.00	1.84	6.80	8.19		19.71	20.16
	Base	-5.37	-3.02	-1.58	-0.71	4.17	5.50		15.82	16.27
	+20%	-8.31	-5.96	-4.39	-3.38	1.69	3.05		11.87	12.33
Labour cost	-20%	-3.66	-1.41	-0.03	2.65	7.50	8.83		21.33	21.79
	Base	-5.37	-3.02	-1.58	-0.71	4.17	5.50		15.82	16.27
	+20%	-7.07	-4.79	-3.26	-4.42	0.84	2.12		10.27	10.72
Market price	-20%	-12.62	-10.62	-9.27	-14.78	-9.53	-8.09		-9.73	-9.25
	Base	-5.37	-3.02	-1.58	-0.71	4.17	5.50		15.82	16.27
	+20%	0.92	3.37	4.91	10.49	16.08	17.59		39.54	40.06
Discount rate	4%	-6.08	-2.86	-0.87	0.34	7.19	9.06		24.72	25.36
	Base	-5.37	-3.02	-1.58	-0.71	4.17	5.50		15.82	16.27
	10%	-4.84	-3.04	-1.94	-1.29	2.40	3.40		10.59	10.93

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.12. Facility location C, sensitivity of NPV of two-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	4.54	7.22	8.86	19.43	25.40	26.94		60.21	60.72
	Base	2.76	5.50	7.21	15.73	21.90	23.55		52.69	53.25
	+20%	0.95	3.75	5.55	12.02	18.40	20.15		45.17	45.77
Utilisation rate	-20%	1.05	3.77	5.46	12.52	18.83	20.53		45.81	46.36
	Base	2.76	5.50	7.21	15.73	21.90	23.55		52.69	53.25
	+20%	3.88	6.64	8.37	17.86	24.13	25.80		56.59	57.16
Capital cost	-20%	5.57	8.23	9.91	18.41	24.81	26.53		56.95	57.50
	Base	2.76	5.50	7.21	15.73	21.90	23.55		52.69	53.25
	+20%	-0.18	2.65	4.41	13.04	19.22	20.86		48.37	48.93
Labour cost	-20%	4.24	7.00	8.73	19.02	25.31	26.98		58.38	58.95
	Base	2.76	5.50	7.21	15.73	21.90	23.55		52.69	53.25
	+20%	1.25	3.97	5.67	12.43	18.56	20.11		47.00	47.55
Market price	-20%	-5.44	-2.96	-1.48	0.85	6.02	7.41		20.98	21.45
	Base	2.76	5.50	7.21	15.73	21.90	23.55		52.69	53.25
	+20%	10.21	13.47	15.50	30.34	37.72	39.63		84.20	84.84
Discount rate	4%	5.39	9.24	11.65	23.65	32.37	34.69		77.01	77.80
	Base	2.76	5.50	7.21	15.73	21.90	23.55		52.69	53.25
	10%	1.24	3.30	4.59	10.98	15.61	16.84		38.09	38.51

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.13. Facility location D, sensitivity of NPV of green veneer manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-8.05	-6.62	-5.50	-10.26	-6.96	-5.12		-9.24	-8.43
	Base	-10.40	-8.96	-7.70	-15.19	-11.80	-9.73		-19.16	-17.96
	+20%	-12.74	-11.31	-9.96	-20.11	-16.64	-14.44		-29.24	-27.77
Utilisation rate	-20%	-10.97	-9.49	-8.20	-16.33	-12.85	-10.75		-21.08	-19.91
	Base	-10.40	-8.96	-7.70	-15.19	-11.80	-9.73		-19.16	-17.96
	+20%	-10.02	-8.61	-7.36	-14.42	-11.10	-9.05		-17.87	-16.67
Capital cost	-20%	-8.52	-7.09	-5.82	-13.31	-9.92	-7.86		-15.69	-14.50
	Base	-10.40	-8.96	-7.70	-15.19	-11.80	-9.73		-19.16	-17.96
	+20%	-12.27	-10.84	-9.57	-17.06	-13.67	-11.61		-22.62	-21.43
Labour cost	-20%	-9.74	-8.35	-7.10	-13.24	-9.92	-7.88		-16.20	-14.99
	Base	-10.40	-8.96	-7.70	-15.19	-11.80	-9.73		-19.16	-17.96
	+20%	-11.05	-9.58	-8.30	-17.14	-13.67	-11.58		-22.12	-20.94
Market price	-20%	-14.11	-12.99	-12.51	-22.62	-19.86	-18.11		-35.22	-34.00
	Base	-10.40	-8.96	-7.70	-15.19	-11.80	-9.73		-19.16	-17.96
	+20%	-6.68	-5.05	-4.29	-7.76	-3.99	-1.89		-3.94	-2.92
Discount rate	4%	-13.64	-11.62	-10.68	-20.38	-15.61	-12.70		-24.92	-23.25
	Base	-10.40	-8.96	-7.70	-15.19	-11.80	-9.73		-19.16	-17.96
	10%	-8.36	-7.28	-6.78	-11.96	-9.41	-7.86		-15.45	-14.55

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.14. Facility location D, sensitivity of NPV of dry veneer manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-13.85	-12.23	-10.92	-19.31	-15.66	-13.49		-6.08	-5.18
	Base	-16.19	-14.58	-13.21	-24.24	-20.50	-18.26		-16.16	-14.99
	+20%	-18.54	-16.92	-15.46	-29.17	-25.34	-22.97		-26.24	-24.79
Utilisation rate	-20%	-17.29	-15.63	-14.24	-28.20	-24.37	-22.09		-19.54	-18.38
	Base	-16.19	-14.58	-13.21	-24.24	-20.50	-18.26		-16.16	-14.99
	+20%	-14.99	-13.40	-12.05	-22.02	-18.34	-16.12		-14.43	-13.25
Capital cost	-20%	-13.44	-11.83	-10.46	-22.06	-18.32	-16.08		-12.24	-11.06
	Base	-16.19	-14.58	-13.21	-24.24	-20.50	-18.26		-16.16	-14.99
	+20%	-18.37	-16.76	-15.39	-26.42	-22.68	-20.44		-20.09	-18.91
Labour cost	-20%	-14.55	-12.97	-11.62	-20.54	-16.88	-14.66		-12.67	-11.48
	Base	-16.19	-14.58	-13.21	-24.24	-20.50	-18.26		-16.16	-14.99
	+20%	-17.84	-16.18	-14.80	-27.94	-24.12	-21.85		-19.65	-18.49
Market price	-20%	-20.15	-18.87	-19.29	-32.15	-29.09	-27.18		-33.27	-32.07
	Base	-16.19	-14.58	-13.21	-24.24	-20.50	-18.26		-16.16	-14.99
	+20%	-12.24	-9.50	-9.46	-16.33	-10.66	-7.53		-2.67	-1.66
Discount rate	4%	-21.63	-19.35	-18.70	-32.93	-27.66	-24.49		-20.41	-18.77
	Base	-16.19	-14.58	-13.21	-24.24	-20.50	-18.26		-16.16	-14.99
	10%	-12.80	-11.59	-11.75	-18.87	-16.06	-14.38		-13.37	-12.49

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.15. Facility location D, sensitivity of NPV of one-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	-3.01	-0.99	0.39	4.13	8.05	10.21		24.81	25.38
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	-7.16	-4.91	-3.15	-3.37	1.06	3.49		10.49	11.46
Utilisation rate	-20%	-7.00	-4.83	-3.19	-2.85	1.60	4.03		10.98	11.75
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	-3.81	-1.63	-0.15	2.65	6.75	9.05		21.42	22.19
Capital cost	-20%	-2.16	-0.18	1.25	3.02	7.22	9.61		21.56	22.32
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	-8.02	-5.78	-4.09	-2.08	2.13	4.45		13.75	14.53
Labour cost	-20%	-3.38	-1.25	0.23	3.82	7.91	10.21		23.18	23.94
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	-6.79	-4.60	-2.96	-2.99	1.28	3.49		12.15	12.91
Market price	-20%	-12.29	-10.42	-10.94	-13.17	-8.97	-6.72		-7.42	-6.41
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	1.16	3.52	3.70	11.63	16.50	19.21		41.39	42.10
Discount rate	4%	-5.69	-2.62	-2.78	2.05	7.79	10.99		27.33	28.40
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	10%	-4.62	-2.90	-2.99	-0.36	2.72	4.44		11.97	12.54

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Table A.19.1.16. Facility location D, sensitivity of NPV of two-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV ($ millions) by processing scale (m^3/y of log) and log procurement scenario								
		7500			15,000			30,000		
		2	4	6	2	4	6	2	4	6
Average mill-delivered log cost	-20%	4.72	7.34	9.07	20.34	25.74	28.66		61.68	62.17
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	1.23	3.93	5.85	13.38	18.90	22.00		47.39	48.27
Utilisation rate	-20%	1.29	3.92	5.72	13.65	19.25	22.36		47.66	48.34
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	4.11	6.78	8.62	19.00	24.55	27.61		58.44	59.12
Capital cost	-20%	5.81	8.37	10.16	19.54	25.22	28.37		58.78	59.45
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	0.06	2.80	4.68	14.17	19.63	22.65		50.22	50.90
Labour cost	-20%	4.47	7.15	8.99	20.15	25.73	28.80		60.23	60.91
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	1.48	4.12	5.93	13.56	18.98	21.86		48.85	49.53
Market price	-20%	-5.17	-2.79	-2.89	2.07	6.44	8.84		22.83	23.57
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	10.43	13.61	14.25	31.47	38.14	41.75		86.03	86.64
Discount rate	4%	5.72	9.45	9.85	25.25	32.96	37.21		79.62	80.58
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	10%	1.41	3.42	3.63	11.83	15.92	18.18		39.48	39.99

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30 year duration.

Chapter 20: Summary and recommendations

Summary of key findings

Australia's forest resource availability and suitability for spindleless lathe processing

Field and desktop studies showed that Australia's forest resources contain substantial volumes of logs potentially suitable for rotary veneer processing using spindleless lathe technologies. Case studies undertaken in crown and private native hardwood forests in Queensland revealed that significant volumes of small peeler logs were potentially available -on average 14 m^3/ha and 10.5 m^3/ha in private and crown forests respectively. However, access to and utilization of these logs will depend on many factors including: accommodating Government policies and log supply agreements; potential alterations in the code of practice for native forest harvesting, silviculture, tree marking and sales practices; diversion of logs from other uses; and development of appropriate log specifications. The resource assessment study also identified that the creation of a new market for currently underutilised small diameter logs may assist in supporting improved silvicultural management in both native forests and plantations.

Comparison of processing methods for small-diameter native forest logs

This study demonstrated that processing small-diameter logs from native forests into rotary veneer using spindleless lathe technology can yield higher recoveries compared to using traditional solid wood processing techniques. This processing method also produced a more consistent recovery result across the range of log sizes included in the study. For spotted gum, processing small-diameter logs into dried and graded rotary veneer recovered twice the volume of saleable product compared to the same log quality sawn into flooring type products (43-46% versus 15-22%). The recovery benefits were not as great for white cypress pine as the larger dimension sawn boards aided in achieving a higher recovery compared to the spotted gum and product grading was limited. Comparable dried and finished product grading was not undertaken as part of the study for white cypress pine, however, this would be expected to further improve the comparative performance of veneer processing.

For both species, the graded veneer recovery was dominated by D-grade veneer. While D-grade is the lowest visual grade quality for structural veneer, the veneers are suitable for face veneers on non-appearance structural panels as well as the core veneers for the vast majority of appearance and non-appearance structural panels. The low recovery of higher grade veneers (C-grade and better) may make the commercial production of structural panel products challenging (because of insufficient quantities of face veneer) if a processor were relying solely on this grade of resource. However, the blending of veneers from small-diameter logs with higher appearance grade veneer, potentially from larger diameter logs from the same forest type, may produce a suitable mix for a range of end-products. In addition, white cypress pine veneer has no commercial history and therefore the willingness for the market to accept the range of defects present with this species is untested. The presence of some defects may indeed provide a marketing advantage for this species.

There was a relatively narrow variation of veneer properties within species. This is an advantage for industry as sorting and segregation systems can be simplified compared to the management of more variable resources. The spotted gum produced veneer with very high stiffness properties. Eight-five percent of the sampled veneer contained a modulus of elasticity above 19,000 MPa and 25% above 25,000 MPa. Stiffness properties in this range could be a key asset for this resource and would support its use in high performance structural products. The white cypress pine veneer had inferior mechanical properties compared with the spotted gum; however, the properties are suitable for structural applications.

The marketability of engineered wood products using low-grade or residual feedstock

Laminated veneer lumber and veneer-based mass panels were example products identified that could effectively utilise low-grade or residual feedstock and have sufficient marketing potential. Specifically, opportunities may exist for these products within the emerging mid-rise construction sector for structural and appearance purposes.

LVL cross-arms were also investigated as a possible product manufactured from sub-optimal log resources. Current estimates have suggested there are more than five million timber cross-arms in Australia, with between 80,000 and 100,000 requiring replacement each year. This potential market opportunity is estimated to generate $5M each year.

A review of the positive attributes of Australian native species revealed a key market advantage in structural performance and natural durability compared to most commodity timbers available internationally. Historically, the native timber industry have capitalised on these attractive properties and developed successful markets with minimal competition by suppling large dimension, high structural capacity and naturally durable, sawn timber products. With the general decline in available log quality, these markets are becoming increasingly difficult to supply and as a result, many markets are forced to move towards other materials such as concrete and steel to achieve the necessary performances. Retention of these markets may be possible through high performance EWPs manufactured from native species. Substituting high performance EWPs made from native species into traditional markets used to accepting the same or similar wood type may offer advantages in accelerating new product commercialisation.

Mechanical properties of laminated veneer lumber

The study has revealed that LVL products are able to be manufactured from the three included species (spotted gum, hoop pine and white cypress) using a variety of different construction strategies. The included species represented a high density native hardwood, mid-density native softwood and a plantation softwood. The spotted gum and the blended spotted gum and hoop pine LVL products were shown to be superior in structural properties, compared to many currently commercially available LVL products in the market. It should be noted that the adopted construction strategies used veneers with MOEs close to the population mean for each species. This therefore suggests that opportunities exist to manufacture LVL products targeting specific performances while optimising the use of the variable veneer qualities generated from log processing. With accurate product performance criteria, construction strategies that minimise manufacturing cost, and product weight, as well as maximising the utilisation of variable feedstocks could be achieved, while still manufacturing fit-for-purpose products. The exploration of construction strategy modelling would provide guidance for developing the most efficient construction strategies taking into account the various constraints and objectives, and the targeted product performance.

Case studies showed limited correlation between visual grading and dynamic MOE-based grading, suggesting that visual grading may not be the most appropriate method to guide the manufacture of veneer-based products of targeted MOE from the native forest spotted gum veneers.

Mixed-species cross-banded LVL (LVL-C) manufactured from native forest spotted gum and plantation hoop pine veneers showed mechanical properties superior to commercially available LVL-C and could represent a marketable product worthy of further investigation.

Termite durability of plywood and laminated veneer lumber products

A blended species 7-ply plywood block comprised of naturally durable white cypress pine face and back veneers, and non-durable hoop pine core veneers was shown to have some resistance to attack by the subterranean termite *C. acinaciformis*, if the core veneer thickness was limited to 1.0 mm.

A blended species 7-ply plywood block comprised of white cypress pine face, back and long band veneers, and hoop pine cross band veneers was shown to have some resistance to termite attack if the hoop pine cross band veneers were no greater than 1.5 mm thick. The improved termite resistance that was observed in the thicker hoop pine veneers used in the plywood configurations that alternated white cypress pine long bands and hoop pine cross bands compared to all hoop pine core veneers (long bands and cross bands) indicates that the increased protection is a result of the neighbouring white cypress pine.

An LVL construction type comprising either 100% white cypress pine or 100% spotted gum were found to be resistant to subterranean termite attack.

Fire performance of laminated veneer lumber products

Six different LVL lay-up types manufactured from spotted gum (representing a high density native hardwood), white cypress pine (representing a mid-density native softwood) and hoop pine (representing a plantation softwood), including various blended combinations of these species where tested to provide an indication of fire performance. The analysis indicated that there were different fire performances between the different species and LVL layup types, however, this difference wasn't reflected in the assigned Material Group classification in accordance with Australian standard AS5637.1, with all lay-up types achieving Group 3 classification. Further investigations are necessary to understand how the observed fire performance benefits of different species and layup types can be realised.

Economic feasibility of veneer and laminated veneer lumber production using sub-optimum quality log resources

The economic assessment of veneer and LVL production from hardwood logs in the subtropics of eastern Australia revealed that, in decreasing order of impact on profitability, the strategic and tactical investment decisions are: (1) the product manufactured (level of value-adding); (2) processing scale; (3) log procurement strategy (log types processed); and (4) facility location (proximity to the forest).

There are strong returns to value-adding. The manufacture of two-stage LVL products was generally projected to be highly profitable, generating after tax profits of up to $360/m^3 of LVL, and a net present value (NPV) of about $50 million at the 30,000 m^3/y processing scale. Many one-stage LVL scenarios were estimated to be marginally to moderately profitable. In contrast, the production of green and dry veneer for market was not financially viable, assuming market prices achieved by commodity exotic pine veneer in Australia. The analysis revealed that market prices would have to be higher (or costs lower) by at least $71/m^3 of green veneer and $119/m^3 of dry veneer for the best-case veneer manufacturing scenarios to provide a 7% return on invested capital over 30 years. Therefore, market prices would need to be in the order of $371/m^3 and $545/m^3 for green and dry veneer, respectively. This may be achieved if veneer markets develop that value the positive attributes of these resources, such as the superior mechanical properties and natural durability of subtropical Australian hardwoods.

Analyses revealed there are economies of scale in LVL manufacture. That is, larger scale manufacturing is substantially more profitable, even though this increases mean mill-delivered log costs and up-front plant and equipment costs.

Log geometry was found to substantially affect recovery of marketable veneer from log volume and the financial performance of rotary veneer and LVL manufacture. In decreasing order of impact on financial performance, the log geometry characteristics were found to be log length, sweep, small-end diameter under bark (SEDUB), taper and ovality. Efficiencies in veneering larger diameter logs, in terms of marketable veneer produced per hour of operation, were also quantified.

Because of their relatively low stumpage price and relatively large log diameter, optional (B-grade) sawlogs (35 cm SEDUB) were identified as the optimal log type for veneer and LVL production in the subtropical eastern Australia study area. Financial analyses revealed that LVL products can be profitably manufactured from small peeler and top logs (25 cm SEDUB). Indeed, maximising the NPV of an investment in LVL manufacturing that utilises subtropical eastern Australian native forest hardwood logs was found to require large proportions of log volume in small, non-traditional log types. For example, profitability was maximised at facility location C for a processing scale of 30,000 m^3/y by having small peeler and top logs comprise 42.6% of the processed volume. Therefore, establishment of hardwood LVL manufacturing facilities in subtropical eastern Australia does represent an opportunity to develop new markets for small logs, and could help facilitate the silvicultural treatments necessary to increase the productivity of private native forests in region. Notably, compulsory (A-grade) sawlogs (45 cm SEDUB) were identified as the least desirable log type for veneer and LVL manufacture because the increase in marketable product recovery from log volume was insufficient to overcome the higher stumpage prices.

Consistent with expectations, mill-delivered log costs per cubic metre were found to rise with increasing processing scale and distance of the resource from the processing plant. Mean mill-delivered log costs in south east Queensland and north east New South Wales would likely vary between \$125/m^3 of log and \$175/m^3 of log. However, if the veneering facility was located at least 50 km from any log resource, mean mill-delivered log costs can be up to about \$30/m^3 of log higher than for a facility located proximate to the resource. A single integrated facility processing logs into veneer and then LVL was found to be most profitable, with much stronger returns being earned when the facility is located closer to the log resource. However, if technical or logistical constraints prevented a single integrated facility being located close to the log resource, then the financial analysis highlighted opportunities for profitable distributed production of LVL, with veneer produced close to the forest and then manufactured into LVL at an alternative location.

Recommendations

This research has demonstrated that rotary veneer peeling can provide an efficient method to process small diameter logs and other sub-optimal log resources into engineered wood products, such as LVL. Further research is required to more accurately assess the availability of log resources in Queensland, explore additional products to develop, provide additional performance testing and further the economic and market assessment associated with spindleless lathe peeling and veneer-based EWP manufacture.

Future research

This project has identified key specific areas where additional research would be beneficial:

- *Further inventory work and resource assessments will increase confidence in estimates of the current and future availability of small peeler logs and other sub-*

optimal log resources. This will support the decision making processes of industry stakeholders and help encourage the adoption of rotary veneer peeling in Australia.

This report discusses the results of a preliminary resource assessment based on limited case studies. Further inventory work and analysis is recommended to determine how transferrable the findings are to the wider Crown and private native forest estate in Queensland and elsewhere in Australia. Further processing, product and market research could result in a new set of log specifications being developed that could positively change the resource availability estimates.

Ideally, state and private forestry authorities should ensure that data collected during routine resource assessments are collected in such a way that enables extrapolation of possible peeler log volumes for spindleless lathe processing. The method needs to be flexible to allow refinement of peeler log specifications which are likely to be influenced by processing, market and economic factors.

- *The exploration of construction strategy modelling would provide guidance for developing the most efficient construction strategies taking into account various constraints and objectives, and the targeted product performance.*

While the study has demonstrated that LVL products can be manufactured from the three included species (high density native hardwood, mid density native softwood and plantation softwood) and that blending species (or qualities) within a construction strategy can provide key advantages, more efficient construction strategies would be possible with direction being provided from knowledge of the market demanded performance requirements. With accurate product target performance criteria, construction strategies that minimise manufacturing cost, minimise product weight, and maximise utilisation of variable feedstocks could be achieved, while targeting fit-for-purpose products. These strategies could ensure that the utilisation of lower quality veneers (e.g. low mechanical properties), which have a lower value, are maximised and positioned within the product construction where their impacts are minimised, while higher quality (and more valuable) veneers are used sparingly and strategically positioned to maximise their contribution to the product's performance. The exploration of construction strategy modelling would provide guidance with developing the most efficient construction strategies taking into account the various constraints, objectives, and market demands.

- *More comprehensive economic modelling would allow for more accurate estimates of the economic feasibility of processing sub-optimal log resources into high-end EWPs that can be provided to industry stakeholders. This would promote investment in the forest products industry and improve the productivity of native forests.*

Further research is necessary to ascertain small peeler log stumpage, cut, snig and load costs acceptable to industry (and landholders) to provide more accurate estimates of the mill-delivered log costs outlined in this report.

The analyses undertaken demonstrated difficulties achieving a profitable green or dry veneer production scenario of. However, the analyses adopted a benchmark market price set by commodity veneer species (e.g. radiata pine). Further analyses with prices that may be achievable from markets that value the unique properties of native species veneers are necessary.

Furthermore, the economic decision support tool developed in this project assumed an expansion at an existing wood processing operation. To promote industry expansion and investment in the forest products industry, the model could be extended to include all costs, variables and parameters associated with the construction, installation and establishment of a new, ‘green field’ log processing and product manufacturing facility.

Veneer and EWP manufacture is sensitive to harvestable volumes per hectare and forest resource distribution. It would be useful to update estimates of financial performance as findings from future forest inventory research become available. The profitability of veneer and EWP manufacture has been estimated independently for the utilisation of 25 cm, 35 cm and 45 cm SEDUB logs. This was done to determine the effect of log size on financial performance. Some log procurement scenarios (combinations of log types) have also been evaluated, which are closer to the reality that a veneering facility is likely to process a range of log sizes, influenced by the available log resource, the cost of getting that resource to the mill, and the competition from alternative utilisation options (e.g. sawmilling and roundwood products). Although this analysis revealed 35 cm logs generate the highest returns from veneer and EWP manufacture, and that 45 cm logs are also profitable, the reality may be that the opportunity cost of using 35 cm and 45 cm logs for veneering outweigh the benefits. It would be useful for future research to compare the financial performance of manufacturing veneer and EWP products against roundwood and sawnwood products to determine optimal log allocation at a processing facility.

The analysis did consider the impact of company tax on financial performance, but did not account for tax benefits arising from asset depreciation. This would suggest the financial performance of LVL manufacturing scenarios that generated a positive return have been slightly underestimated. To better support industry investment decisions, it would be useful to refine the financial model to accommodate asset depreciation.

- *Further product and market development is required to fully capitalise on the outputs from this project*

Additional collaborative effort between industry and researchers is required to advance the definition of target markets, allowing further product development focus that optimizes species selection, lay-up strategies, manufacturing protocols and final product performance criteria. This close collaborative partnership would have the best chances of commercial adoption, demonstrated by product commercialization, by involvement of industry who are ready to adopt and develop the necessary practices required to manufacture the new product(s). Specialist marketing expertise would add significant value to further efforts to better enable genuine ‘new’ markets (markets not currently occupied by a wood product) to be identified and developed as well as ‘substitute’ markets (markets historically or currently occupied by wood products of some description) to be targeted.

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- DAF Forest Products and Forest Industries staff – Mr Peter Clark, Mr Bill Gordon, Ms Jane Siebuhr, Mr Chris Oppermann, Mr Neil Reinke, Mr Nathaniel Lindsay, Mr Trevor Beetson, Mr Stuart Olive, Mr John Ludlow, Dr Kerrie Catchpoole and Mr Jim Burgess.
- EWPAA – Mr Andy McNaught, Mr Dave Gover, Mr Harrison Brooke and laboratory staff.
- Forestry Corporation of NSW – Mr Justin Crowe and Mr Tony Johnston
- Forest Product Commission WA – Ms Jane Charles and Mr Chaz Newman
- FWPA – Dr Chris Lafferty and Mr Jim Houghton

- Gersekowski & Son Pty Ltd – Mr Victor Gersekowski
- Griffith University – Associate Professor Benoit Gilbert, Dr Ian Underhill and laboratory staff
- Hurford Wholesale – Mr Bob Engwirda, Mr Peter Clarke and sawmill staff at the Chinchilla facility.
- Landscapes Sciences, DSITI – Mr Phil Norman, Ms Kelly Bryant
- Parkside Group – Mr John McNamara, Mr Neville Smith and other field and mill staff
- Private Forestry Services Queensland – Mr Sean Ryan
- Private property owner of Esk – Mr Don Gordon
- Private property owner of Ironpot – Mr Greg Northcote
- Queensland Herbarium, Ecological Sciences – Dr Michael Ngugi
- Super Forest Plantations – Mr James Wright, Mr Mark Wright and Mr Andrew Simpson
- Sustainable Timber Tasmania – Dr Dean Williams
- University of Southern Cross – Mr Simon Boivin-Dompierre
- VicForests – Mr Bruce McTavish

Researcher’s Disclaimer

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