Utilisation of plantation eucalypts in engineered wood products
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Executive Summary
This document reviews and summarises available information on the utilisation of plantation eucalypts in engineered wood products (EWPs). The primary focus of the review was on *Eucalyptus globulus* (southern blue gum) and *E. nitens* (shining gum), which comprise the majority of the Australian hardwood (eucalypt) plantation estate, but other plantation eucalypt species were also considered where information was available.

The EWPs covered in the review included laminated veneer lumber (LVL) and plywood, glulam, flake/strand-based products, fibreboard and particleboard.

Key findings
- 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.
- It is evident that significantly more research has been conducted overseas, particularly in South America and South-western Europe. Furthermore, it is apparent that wood processing industries in these regions have been utilising plantation eucalypt resources for some time for a variety of EWPs.
- Fast-grown, lower 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 believed that much of the current Australian plantation eucalypt resource (i.e. that originally planted for wood chip and pulp), and in particular *E. globulus*, *E. nitens* and *E. grandis*, would be suitable for use as a feedstock for LVL, selected strand/flake-based EWPs and medium density fibreboard.
- Further research efforts should primarily be directed towards tree breeding and improved silvicultural practices e.g. breeding for optimum density (500 to 550 kg/m$^3$) and pruning to reduce the incidence of defects. This would potentially open up opportunities for utilisation of the plantation eucalypt resource for plywood and glulam, as well as further increasing opportunities for utilisation in other EWP markets.
Introduction
The purpose of this document is to review and summarise available information on the utilisation of plantation eucalypts for engineered wood products (EWPs), with emphasis on gluing systems, the properties and performance of EWPs and any inherent limitations on the uses of particular eucalypt species. An assessment of current global industry practices with respect to the utilisation of plantation eucalypts is also included.

In undertaking the review, the primary eucalypt species of interest were *Eucalyptus globulus* (southern blue gum) and *E. nitens* (shining gum), since these together comprise around 75 percent of the hardwood plantation (eucalypt) estate in Australia. However, other species which comprise the majority of the remaining hardwood plantation (eucalypt) estate were also considered where information was available; these included *E. pilularis* (blackbutt), *E. grandis* (flooded gum), *E. regnans* (mountain ash), *E. cloeziana* (Gympie messmate), *E. dunnii* (Dunns white gum) and *Corymbia* spp. (spotted gums).

Literature Review
EWPs comprise a wide range of product types. Those considered in this review included:

- **Veneer-based.** Primary examples of this EWP type include plywood and laminated veneer lumber (LVL). Veneers are produced by rotary peeling of logs on lathes. After drying the veneers in ovens, adhesive is applied to the veneer surfaces, and they are laid together and hot-pressed to form the finished panel. In plywood the grain angle of adjacent veneers is at right angles; in LVL the grain angle of all veneers is parallel.

- **Glued laminated lumber (glulam).** Glulam is produced by clamping and gluing together lengths of seasoned, dressed lumber. The adhesives used typically cure at ambient temperature, though in some operations radio frequency heating is utilised to increase the rate of adhesive cure.

- **Strand/flake-based.** Examples include oriented strand board (OSB), oriented strand lumber (OSL), parallel strand lumber (PSL) and engineered strand lumber (ESL). These products are comprised of thin strands or flakes, bonded together by adhesive. In OSB the strands in the core layers are oriented at right angles to those in the surface layers. In lumber-based products the strands are parallel.

- **Fibreboard.** Examples include medium density fibreboard (MDF), high density fibreboard (HDF) and hardboard (Masonite). MDF and HDF are made from wood fibre produced by pressurised refining of wood chips. Adhesive may be applied either before or after drying of the fibre. Hardboard is produced from wood fibre that may be produced either by pressurised refining or steam explosion of wood chips. A mixture of fibre and water is applied to a moving wire to form a mattress, which is then hot pressed to form the final panel. No adhesive is used in the process.

- **Particleboard.** Particles are generated from wood chips and sawdust in ring flakers and hammermills. After drying and blending with adhesive the particles are formed into mattresses prior to hot pressing. Typically the coarser particles are in the core of the panel and the finer particles on the surfaces.
Veneer-based EWPs

Until relatively recently little or no work on the suitability of Australian-grown plantation eucalypts for veneer-based products had been published. The knowledge base has, however, been significantly improved with the publication of two Forest and Wood Products Australia (FWPA) reports in the last four years (Hopewell, Atyeo & McGavin, 2008; Farrell et al, 2011).

The studies conducted by Farrell et al (2011) were focused on assessing the suitability of the two main plantation species of interest in this work, E. nitens and E. globulus, for their potential to produce veneer and plywood. The material studied was grown in Tasmania, and was comprised of two ages of E. nitens (16 and 26 years old (YO)) and 33 YO E. globulus. The key findings from the work were as follows:

- The stiffness of the E. globulus and 26 YO E. nitens veneer was relatively high, indicating they had the potential to produce structural peeled products (plywood and LVL). The lower density of the E. nitens 26 YO resource could be advantageous in terms of stiffness per unit mass.
- The visual grade recovery of veneers was no better than Grade D for all resources, though the E. globulus veneers were typically of better quality; around 50 percent of the E. nitens veneer failed even to make visual Grade D. A predominant cause of the low grade of the veneers was the high incidence of knots, including dead knots.
- All plywood made from the E. globulus and 26 YO E. nitens veneer using phenolic adhesive achieved Type A bond quality. However, results for plywood made from the 16 YO E. nitens veneer were variable. One batch achieved a 73 percent pass result, whilst a second only achieved a 13 percent pass result; the poor performance of the latter was attributed to high veneer moisture content during processing.
- Based on estimated characteristic modulus of elasticity (MoE) values, plywood panels with F-ratings of F34, F27 and F11 (parallel to the face grain) were produced from E. globulus, E. nitens 26 YO and E. nitens 16 YO respectively; the F-rating dropped to F17 for E. nitens 26 YO when the estimated characteristic modulus of rupture (MoR) values were taken into account. However, when estimated characteristic shear strength values were taken into account, plywood panels with F-ratings of F8, F7 and <F7 (parallel to the face grain) were produced from the three resources. The authors stated that unless the poor shear performance could be addressed, the potential utilisation of unpruned material in structural veneer-based products would be limited. Log-steaming and veneer drying were identified as potential areas for future research.

The work of Hopewell, Atyeo & McGavin (2008) was aimed at evaluating tropical post-mid rotation plantation E. cloeziana and E. pellita (red mahogany) for their potential to produce veneer and

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1 Visual grading of veneer quality based on the incidence of defects, with A being the highest quality and D the lowest.
2 A measure of stiffness.
3 A measure of the deflection resistance under load. High F-ratings are commonly associated with hardwoods, whereas those for products made with softwoods are typically significantly lower.
4 A measure of strength.
plywood. The *E. cloeziana* material was 19 years old, whilst the *E. pellita* was 15 years old. The key findings from the work were as follows:

- *E. pellita* billets were prone to end splitting and also contained pockets of white rot; these factors significantly reduced the veneer recovery rate. In contrast the veneer recovery rate of the *E. cloeziana* was twice that of the *E. pellita*, comparing favourably with that typically achieved in industry for commercial regrowth species such as *E. pilularis* and mature-forest *Corymbia* spp. The *E. cloeziana* veneer was generally of a higher quality.

- The *E. pellita* plywood panels achieved stress grades in the range F11 to F14, which is typical for structural softwood plywood. In contrast, the *E. cloeziana* plywood panels achieved stress grades in the range F22 to F27, which is equivalent to those typically found at the higher end for domestic hardwood plywood from native forest.

- However, *E. pellita* performed better in the glue bond quality tests. For Type A\(^5\) bonds, commercially produced panels achieved a 100 percent pass rate, whilst laboratory made panels achieved a 90 percent pass rate; for *E. cloeziana* the respective pass rates were 80 percent and 42 percent. It was postulated that the poorer results achieved for *E. cloeziana* might be attributable to its higher density.

- Both species failed to produce panels with satisfactory Type B\(^6\) bonds. This was difficult to explain, given the results obtained for Type A bond testing.

The low grade recovery observed by Farrell et al. (2011) in veneer derived from unpruned *E. nitens* is in agreement with observations made by researchers who investigated the suitability of 15 YO unpruned *E. nitens* grown in New Zealand for making LVL (Gaunt, Penellum & McKenzie, 2003; McKenzie, Gea, & Gaunt, 2006). In this work, 93 percent of the veneers produced failed to achieve the minimum plywood grade because of knots. Veneer peeled from unpruned logs was segregated into three stiffness classes using an acoustic test, and LVL was manufactured with phenolic adhesive from sheets of each stiffness class. Subsequent strength tests showed that the sheets were successfully segregated by the acoustic stiffness test, and that the *E. nitens* LVL had strength and stiffness properties which were higher than those of LVL made from New Zealand-grown *Pinus radiata* veneer.

Lisperguer and Rozas (2005) also investigated the suitability of Chilean-grown 11 YO juvenile *E. nitens* wood for manufacturing exterior grade plywood panels. Laboratory panels made from *E. nitens* veneers met the British Standard Institution\(^7\) requirements for exterior use.

A number of researchers from South America and South-western Europe (Iberia) have investigated the suitability of *E. globulus* and *E. grandis* for veneer-based products. Much of the research appears to have been focused on using modified phenolic adhesives, with the aim of reducing both cost and environmental footprint. Vázquez and various co-workers have conducted a number of such studies (Vázquez et al 1992; Vázquez et al 1997; Vázquez, González & Antorrena 2000; Vázquez et al 2003).

\(^5\)Permanent structural bond that will not deteriorate under wet conditions, heat or cold.

\(^6\)Structural bond that will eventually deteriorate under wet conditions, heat or cold.

\(^7\)The specifications in national standards are broadly similar around the globe. As such, where it is demonstrated that products meet the specifications in a given national standard, it is highly likely that they will also meet the specifications given in Australian standards.
Vázquez et al (1992) investigated resins made from resoles and *Pinus pinaster* (maritime pine) bark tannins by copolymerization at room temperature. The moisture content of the tannins was reduced to below 60 percent to increase their stability. Various formulations were tested, with 50 percent of the phenols substituted by the tannins. The resins were used to manufacture 5-ply *E. globulus* panels which all met British Standard 1455: 1963 quality requirements.

Vázquez et al (1997) investigated the use of lignin-phenol-formaldehyde resins as binders for *E. globulus* and pine plywood. Lignin obtained from eucalyptus wood by acetic acid pulping was methyloleated or phenolated and used to prepare lignin-phenol-formaldehyde resins. Pine and eucalyptus plywood panels manufactured using the resins complied with European Standard EN 314-1:1993, and gave knife test results similar to those of panels manufactured with a commercial phenol-formaldehyde resin.

Vázquez, González, & Antorrena (2000) re-examined the use of tannins extracted from *Pinus pinaster* bark as partial replacements for phenol in adhesives for exterior-grade *E. globulus* plywood. They stated that such adhesives present advantages compared with commercial phenol-formaldehyde (PF) adhesives, since they are more tolerant of higher veneer moisture contents, allow the use of higher pressing temperatures, and improve adhesive spreading and wettability. Similar results were obtained by Vázquez et al (2003) when studying the influence of rotary peeling on the behaviour of tight and loose sides of *E. globulus* veneers.

Stefani et al (2008) also investigated the use of PF resoles containing *Acacia mearnsii* (black wattle) tannin extract to produce plywood panels from *E. globulus* veneers. The effect of processing conditions and tannin content on the gelation time of the adhesive in the glue line was evaluated by dynamic-mechanical analysis. The results were related to shear strength and wood failure of the glue line in the panels. It was shown that phenol could be partially substituted with tannin without compromising panel properties.

Dias & Lahr (2004) investigated the suitability of a castor oil-based polyurethane adhesive, developed at the São Carlos Institute of Chemistry, University of São Paulo, Brazil for bonding *E. grandis* veneers. The properties of the resulting plywood were determined in accordance with Brazilian standards; the test results exceeded minimum requirements and were better than those typically reported in the literature.

Saviana, Sosa Zitto & Piter (2009) investigated the properties of LVL manufactured from Argentinean *E. grandis*. The characteristic strength value was 74 percent and 118 percent higher, respectively, than those adopted by Argentinean standards for the best strength class of sawn timber and glulam of the same species. It was similar to that reported for LVL of *Picea abies* (Norway spruce), but lower than that published for LVL made from Uruguayan-grown *E. grandis*. However, the product had a higher stiffness than that published for Norway spruce and Uruguayan-grown *E. grandis* LVL.

It is worth noting that over 15 years ago CSIRO did investigate the potential for using eucalypts for the manufacture of LVL (McCombe et al 1997). However, the work was conducted on mixed species (*E. regnans*, *E. delegatensis* (alpine ash), *E. sieberi* (silvertop ash), *E. globoidea* (white stringybark), *E. fastigata* (cuttail), *E. obliqua* (messmate) and *E. cypellocarpa* (mountain grey gum)) residue logs from sawlog harvesting operations in natural forests in the Central Highlands and East Gippsland regions of Victoria. Whilst the LVL produced from the studies had high F-ratings (in the range F22 to F27),
there were significant issues with the recovery rates from the resource. Overall recoveries from log to finished LVL product were in the range 33 to 35 percent; the authors noted that recovery rates of 50 to 55 percent would typically be expected from peeler grade *Pinus* species logs.

*E. pilularis* (from natural forest) was for many years viewed as a potential resource for use in EWPs; one particular identified application was as plywood flooring in cargo containers, where there is a requirement for high strength and stiffness. However, the species has long been known to be difficult to glue with PF adhesives, in part because of its high density, but primarily due to the composition and quantity of extractives present in the wood (Yazaki, Collins & Iwashina 1993; Yazaki, Collins & McCombe 1994). CSIRO conducted a number of investigations (unpublished) in the period 1995 to 2005, aimed at trying to identify ways of achieving acceptable PF-bond quality in *E. pilularis* plywood and LVL. Approaches examined included incorporation of resorcinol or tannins in the PF adhesive, using a variety of additives and using the PF adhesive in emulsified form. Whilst some encouraging results were obtained, the adhesives industry showed little interest in the technology; the high density of the timber, and likely consequent small market demand for any resulting EWPs, was cited as the primary issue.

**Glulam**

No references to published work in Australia on the use of plantation eucalypts for glulam are evident in the literature. However, a number of South American researchers have published papers in recent years. Azambuja & Dias (2006) investigated the use of castor oil-based polyurethane adhesives for the production of glulam made from Brazilian-grown *E. grandis* and *Pinus caribea* (Caribbean pine). The performance of the adhesive was compared with that of a standard industry PF adhesive. The *E. grandis* glulam performed well with both adhesive types.

Lisperguer & Rozas (2005) evaluated bond quality in the solid wood of 11 YO Chilean-grown *E. nitens*. Edge-glued panels were manufactured and bonded with a non-structural PVA adhesive. The mechanical properties of the panels were determined and compared with those of 25 YO *Pinus radiata* panels. Shear strength values in *E. nitens* panels were found to be 35 percent higher than in *P. radiata* panels.

Neto (2010) investigated the properties of Brazilian-grown *E. grandis* and *E. urograndis* (*E. grandis* x *E. urophylla* (Timor white gum)) glulam bonded with a two component polyurethane adhesive. He also investigated the influence of preservative treatments (copper chrome arsenic (CCA) and copper chrome boron (CCB)) on bond quality. The mode of bond failure for both treated and untreated beams was variable, with a mixture of both wood and glueline failure (this is quite typical for polyurethane adhesives, and is one of the key reasons for objections to their adoption as structural adhesives alongside PF, phenol resorcinol formaldehyde (PRF) and resorcinol formaldehyde (RF) adhesives). Nevertheless, Neto (2010) concluded that the preservative treatments had no significant impact on bond strengths, and that the latter met minimum strength requirements.

Santos et al (2010) studied the deflection properties of PF-bonded *E. urograndis* glulam cross-arm beams for application in the Brazilian electricity industry. The properties of the three member beams were compared with those made with *Pinus taeda* (loblolly pine) lumber. When subjected to standard loads, the eucalypt beams easily met the requirements of the Brazilian standard in terms of maximum allowable deflection, and also outperformed the pine beams.

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At the last two Forest Products Society (FPS) International Conventions (2011 and 2012) in the USA Uruguayan researchers have presented data on the properties of glulam made from fast grown Uruguayan plantation eucalypts. However, no further details are available on the content of their presentations; the FPS does not publish proceedings from its conventions, and the authors of the presentations failed to respond to requests for further information.

**Strand/flake-based EWPs**

Research in Australia on strand/flake-based EWPs has primarily been conducted by CSIRO. The latter investigated the suitability of plantation *E. globulus* and *E. nitens* for OSB over a decade ago (Freischmidt *et al* 2001; Freischmidt 2001; Freischmidt, Hague & Warden 2001). The test material was 17 YO from the ACT region. OSB panels were fabricated with a commercially available PF resin and tested for flexural properties, internal bond strength and thickness swelling. Strength properties were satisfactory when compared to the Canadian Standard, but dimensional stability, particularly when exposed to cyclic environmental conditions, was relatively poor. This was likely linked in part to the relatively high density of the two materials, but also to the need to optimise adhesive and processing parameters.

More recently an Australian company, Lignor, has developed technology to utilise plantation *E. globulus* in an engineered strand lumber (ESL) product. It is believed that much of the research was conducted in Europe by potential equipment suppliers for a full scale production plant. The adhesive used was a polyurethane (polymeric methylene diphenyl diisocyanate (pMDI)); it is believed that this was chosen primarily to avoid the use of formaldehyde-based adhesives, rather than of necessity i.e. there were no inherent adhesion issues with the wood substrate.

According to Freischmidt & Blakemore (2009) a number of trials were undertaken with young aged eucalypt ‘thinnings’ during the development of the CSIRO invented ‘Scrimber’ product. Plantation thinnings of *E. globulus* and *E. pilularis* were used in early trials (1980 and 1981) using a variety of different resins (e.g. urea formaldehyde (UF), tannin formaldehyde and polyurethanes). The wood was reported to have ‘scrimmed’ well and was successfully bonded, but no mechanical performance data were presented. A 1990 trial investigated *E. sieberi* thinnings as a resource; the resultant beams were reported to have excellent stiffness, although there were issues with bond starvation during resin application. Another series of trials was carried out in the mid 1990s by the US-based Georgia Pacific at the now closed Mount Gambier production plant, in which young plantation *E. grandis* was processed. No data are available from the trial, but it is known that Scrimber beams were successfully produced.

Vintorg is a composite material that was developed in the Cooperative Research Centre (CRC) for Wood Innovations in the last decade. It is produced by impregnating Torvin (microwave treated timber) with thermosetting adhesives (MUF, pMDI etc.) and hot pressing. The resultant product shows modest improvements in stiffness and creep resistance compared with the original substrate. An undated CRC fact sheet sighted by the author refers to research conducted on ‘softwoods as well as Australia’s unique hardwood timbers’. It also states that the ‘research focus emphasises utilisation of young, fast growing plantation timbers’. However, no other supporting information could be found in the literature.
A number of studies have been undertaken overseas to investigate the suitability of plantation eucalypts for OSB. The work has primarily been undertaken by South American researchers. Gouveia, Santana & Souza (2000) investigated *E. grandis* and *E. urophylla* as feedstocks in non-oriented and oriented panels; they concluded that *E. grandis* was the superior feedstock. Gouveia, Vital & Santana (2003) also investigated blends of *E. grandis* and *Pinus elliottii* (slash pine) feedstocks for OSB; optimum results were obtained with blends comprising between 50 percent and 75 percent *E. grandis*. Iwakiri, Mendes & Saldanha (2003) investigated *E. grandis* as a feedstock for OSB, with varying resin and wax levels, and face to core weight proportions. Higher resin loadings (from 3 to 6 percent) improved mechanical and physical properties and a 60 percent by weight core layer improved panel flexural properties. Iwakiri *et al* (2004) investigated a broader range of potential feedstocks for OSB, including: *E. grandis*, *E. dunnii*, *E. tereticornis* (forest red gum), *E. saligna* (Sydney blue gum), *C. citriodora* and *C. maculata*. Test panels were manufactured to a target density of 700 kg/m$^3$ using 6 percent PF adhesive. *E. grandis* and *E. saligna* appeared to be the most promising feedstocks, with the former giving similar or higher average panel properties in comparison with *Pinus taeda*, the main species used for OSB production in Brazil.

**Fibreboard**

Available information on Australian studies looking at plantation eucalypts for fibreboard is scarce. Freischmidt & Blakemore (2009) cite a study conducted by CSIRO in 1998 (Coutts *et al*) in which both mature and younger age *E. obliqua*, *E. sieberi* and *E. globoidea* were investigated as feedstocks for MDF. UF, PF and polyurethane adhesives were trialled, with refined and dried furnish being dry blended before hot pressing into panels. The results were mixed, with high adhesive loadings and high panel densities required in order to achieve acceptable properties. Intriguingly, Freischmidt & Blakemore (2009) state that the study also included ‘some preliminary trials on plantation grown *E. grandis* and *E. globulus* to determine processing conditions for fibre production’. However, it appears that the resulting furnish was not evaluated for its suitability for panel manufacture.

Freischmidt & Blakemore (2009) also cite a second study (Olsen *et al* 2004) in which CSIRO investigated two eucalypt species, *E. loxophleba* (York gum) and *E. rudis* (WA flooded gum) as feedstocks for MDF. UF-bonded panels had promising properties at more realistic panel densities than those in the above study. This was likely in part attributable to the improved pilot scale production facilities available to the researchers.

Published overseas research on the use of plantation eucalypts for fibreboard is also limited. Krzysik *et al* (2001) conducted research to determine the suitability of plantation grown *E. saligna* from Brazil as a feedstock for MDF. Test panels of varying thickness (6, 13, and 19 mm) were made with 10 percent UF resin and 1.5 percent wax. Mechanical, water resistance, and dimensional stability properties were tested according to ASTM (American Society for Testing and Materials) standards. The results showed that nearly all the mechanical properties of the panels at all thickness levels were above the minimum specified requirements for MDF in the ANSI (American National Standards Institute) and European MDF standards.

**Particleboard**

There is no published work on the use of Australian-grown plantation eucalypts for particleboard production. Published data from overseas are again dominated by South American researchers.
Haselein et al. (1989) investigated combining Brazilian-grown *E. grandis* with a *Cecropia* species; a 50:50 (by weight) mixture produced the best results. The same authors (Haselein et al 2003) also investigated blends of *E. grandis* with *A. mearnsii* and *P. elliottii* and found similar results.

Niekerk & Pizzi (1994) presented data from studies conducted at a South African particleboard plant which utilised *E. grandis* as the feedstock and a tannin-based adhesive to produce a moisture resistant product. They highlighted two key problems that the plant had had to overcome in order to be viable: a) the low pH of the eucalypt furnish, particularly in the high steam environment developed in the mattress during hot pressing, which inhibited cure of the tannin adhesive, and b) the resistance of the eucalypt wood particles to crushing (and irreversible fracture) during the hot pressing process, which in turn resulted in poor dimensional stability of the finished panel. The adhesive curing problem was solved by raising the pH of the tannin adhesive prior to blending with the wood particles. The dimensional stability issue was addressed by using a smaller mean particle size in the wood furnish than is typically used with lower density feed-stocks.

More recently Cabral et al (2007) investigated the properties of particleboards made with particles generated from planer shavings and flakes of Brazilian-grown *E. grandis, E. urophylla* and *E. cloeziana; P. elliottii* particles were mixed with eucalypt particles, where necessary, in order to achieve target board densities of 700 kg/m$^3$. Samples of each of the eucalypt species were obtained from two different sites, with the *E. grandis* typically having the lowest density (approx. 550 kg/m$^3$) and the *E. cloeziana* the highest (approx. 700 kg/m$^3$); the density of the *P. elliottii* was 450 kg/m$^3$. The prepared particles were mixed with UF adhesive prior to hot pressing into boards. Generally boards made with the highest proportions of eucalypt particles had the highest water adsorption and thickness swelling. Boards made with particles generated from flakes tended to exhibit the highest internal bond strength, modulus of rupture and modulus of elasticity.

Pan et al (2007) investigated the properties of thin particleboard made from 8 YO Californian-grown *E. cinerea* (Mealy stringybark), a eucalypt species with potential to be used as a biomass crop in salinity prone agricultural regions. The properties of boards were compared with those made from *E. camaldulensis* (river red gum) of a similar age, grown under non-saline conditions. The densities of the two substrates were 770 and 760 kg/m$^3$ respectively. A range of variables were investigated, including particle size, bark content, resin type and addition level (pMDI (4 percent) and UF (7, 10, 13 & 16 percent)) and hot water pre-treatment. The results were largely as might be expected: increasing the UF adhesive content improved board properties; boards bonded with 4 percent pMDI generally had better properties than those bonded with 7 percent UF; increasing the bark content of the wood furnish reduced board properties; pre-treating particles in hot water significantly improved board properties. Boards made with *E. cinerea* particles had markedly better properties than those made with *E. camaldulensis*. Pan et al (2007) postulated that the improvements in board properties from hot water pre-treatment could have been due to changes in the chemical composition of particles (in particular a reduction in the level of alkaline extractives which are more prevalent in timber grown in saline conditions) and/or changes to the physical characteristics of the particles at the cellular level.

Colak et al (2007) studied the influence of log pre-steaming on the properties of particleboard made with 12 YO Turkish-grown *E. camaldulensis* bonded with UF and MUF adhesives. The results were
not clear cut, but there was some suggestion that pre-steaming improved the dimensional stability of the finished panel, but reduced the internal bond strength.

**Current Industry Practice**

**Veneer-based EWPs**

No wood processing companies in Australia are currently utilising any significant quantities of plantation-grown eucalypts to produce either veneer or veneer-based EWPs. According to S Dorries (2012, pers. comm., 17 Aug.), General Manager of Engineered Wood Products Association of Australasia (EWPAA), Ta Ann Tasmania may process small quantities of plantation eucalypt on occasion, but it predominantly peels a mixture of regrowth eucalypt species, primarily *E. obliqua*, *E. regnans* and *E. delegatensis* and exports the resulting veneer, mainly to Malaysia, for the manufacture of LVL, plywood and flooring (Freischmidt & Blakemore, 2009). Forestry Tasmania has recently launched and showcased a range of LVL-based products (framing, flooring, furniture etc.) made using veneer generated from small diameter and low grade logs of the same species as those processed by Ta Ann. Big River Timbers (NSW) also produces hardwood plywood from *E. pilularis*, *E. grandis*, *Corymbia* spp and a range of other species sourced from natural forest.

The situation in Australia contrasts strongly with that in South America and Iberia, where significant quantities of veneer-based EWPs are being produced from plantation eucalypts. Species being processed include *E. grandis*, *E. globulus* and *E. urograndis*. Weyerhaeuser in the USA has made significant investments in South America, in particular Uruguay, where its eucalypt plywood (Lumin™) is produced; the latter is rapidly gaining acceptance as a product of choice in the USA for a variety of applications, including construction, furniture, cabinetry, flooring, doors, transportation and toys. However, some of the plywood produced in South America is stated to be of relatively poor quality, with bond quality being a major issue (S Dorries 2012, pers. comm., 17 Aug.).

Plywood is also produced from plantation eucalypts in China. According to Turnbull (2007), species being utilised include *E. dunnii*, *E. saligna* and *E. urophylla*.

**Glulam**

No wood processing companies in Australia are currently utilising plantation-grown eucalypts to produce glulam.

Small quantities of various regrowth and natural forest eucalypts are utilised by a number of Australian manufacturers to produce glulam for largely niche applications (Freischmidt & Blakemore, 2009). For example, Hyne & Son Pty Ltd (QLD) produces approximately 250 m³ annually of glulam from spotted gum; the product is used in limited applications where there is a desire to see exposed timber beams and there are constraints on the cross-sectional dimensions that can be used (G Stringer, 2011, pers. comm., 2 Nov.).

After consultation with the EWPAA (S Dorries 2012, pers. comm., 17 Aug.), it is believed that no glulam is currently being manufactured from plantation eucalypts overseas. Saviana, Sosa Zitto & Piter (2009) make reference to an Argentinean standard for glulam made from eucalypts, so it may be presumed that if it is not already happening, plantation eucalypt glulam will eventuate in time in South America at least. S Dorries (2012, pers. comm., 17 Aug.) is of the view that plantation
eucalypts would potentially lend themselves well to glulam manufacture. Furthermore, the author is aware that CSIRO provided consulting advice to a Uruguayan company some 15 years ago on the gluing of *E. grandis* laminates; a variety of adhesive types were investigated, and the material showed excellent promise as a substrate for glulam manufacture. However, reference to the company’s website suggests that it is not currently offering eucalypt glulam amongst its product range.

**Strand Flake-based EWPs**

Australia has never had a successful full scale commercial production facility producing a strand flake-based EWP. The Scrimber plant at Mount Gambier closed in the 1990s without ever being commissioned. Whilst the company Lignor is still seeking to raise finance to construct a plant to produce ESL based on *E. globulus* in WA, this is unlikely to happen anytime in the short to medium term given the prevailing economic conditions; to be successful, such a venture would need a thriving and receptive domestic and commercial construction market, as well as favourable foreign exchange rates for the likely significant quantities of product that would need to be exported.

According to M Botting (2012, pers. comm., 15 Aug.), editor of Wood-based Panels International magazine, to date no plantation eucalypts have been utilised anywhere in the world for the commercial production of strand flake-based EWPs.

**Fibreboard**

No Australian MDF manufacturer is currently using eucalyptus as all or part of its raw material feedstock. However, the former Starwood / Carter Holt Harvey MDF mill at Bell Bay in Tasmania did successfully utilise plantation *E. nitens* for some of its product lines until its closure in 2006 after a major fire destroyed the continuous hot press (S Jeffery (former Technical Manager at the Starwood MDF mill) 2012, pers. comm., 16 Aug.).

Weathertex (NSW) 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. A number of other Australian hardboard plants which utilised a variety of eucalypt resources as feedstocks have closed over the last few decades. The last plant to close its doors was Australian Hardboards in Ipswich, QLD in 2010, with the company citing the unfavourable foreign exchange rate and cheap imports as the main cause of its demise after more than 52 years of operation.

For many years a number of MDF and hardboard production plants in both South America and South-western Europe have been utilising a variety of plantation eucalypts as feedstocks. The author is aware that the Brazilian company Duratex was exporting both MDF and hardboard made from plantation eucalypts to Europe over 15 years ago; the latter product attracted a significant premium in the market place because of its extremely smooth surface, which allowed door manufacturers to reduce paint consumption. Turnbull (2007) states that MDF is manufactured in China from a range of plantation eucalypt species, including *E. dunnii*, *E. globulus*, *E. grandis*, *E. maidenii* (Maiden’s gum), *E. saligna*, *E. smithii* (gully gum), *E. urophylla* and *E. urograndis*. 


Particleboard
The raw material of choice for particleboard manufacture in Australia is softwood. Generally particleboard manufacturers worldwide will allow around 10 percent of ‘other’ material to enter the feedstock, and it is feasible that some of this in Australia could comprise plantation eucalypt. However, inclusion of higher levels of non-preferred feedstock can lead to a drop off in panel properties if there aren’t significant adjustments made to the processing parameters, which in turn can increase overall production costs.

In Europe high levels of recycled timber are utilised in particleboard production. The feedstock can thus be comprised of a variety of wood species, both softwood and hardwood. In South Africa, particleboard has been produced from plantation eucalypts for decades using specially adapted processing parameters (Niekerk & Pizzi 1994).

Conclusions
The available information on the suitability of Australian-grown plantation eucalypts for EWPs based on the literature review is scarce. Furthermore, that which does exist is typically based on limited replication within given studies.

Nevertheless, when considering the research conducted overseas and the current industry practices in South America and South-western Europe in particular, some general observations can be made about the suitability of the current Australian plantation eucalypt resource for EWPs, and key areas for further research:

- It is believed that much of the current Australian plantation eucalypt resource (i.e. that originally planted for wood chip and pulp), and in particular *E. globulus*, *E. nitens* and *E. grandis*, would be suitable for use as a feedstock for LVL, selected strandflake-based EWPs and MDF.
- Fast grown, lower 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$^3$.
- Further research efforts should primarily be directed towards tree breeding and improved silvicultural practices e.g. breeding for optimum density (500 to 550 kg/m$^3$) and pruning to reduce the incidence of defects. This would potentially open up opportunities for utilisation of the plantation eucalypt resource for plywood and glulam, as well as further increasing opportunities for utilisation in other EWP markets.
References


Farrell, R., Blum, S., Williams, D. & Blackburn, D. (2011). The potential to recover higher value veneer products from fibre managed plantation eucalypts and broaden market opportunities for this resource: Part A. Forest and Wood Products Australia Ltd Project No.: PNB139-0809.


