Resource circular economy: Opportunities to reduce waste disposal across the supply chain

Timber

Research Report 5

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1 EXECUTIVE SUMMARY

Due to its flexibility, durability, and appealing visual attraction timber has multiple applications in the construction industry. The amount of wood waste generated from C&D is influenced by the life span of the building materials. In Australia, timber waste is classified into three major categories: untreated timber (Type A), engineered timber products (Type B), and treated timber (Type C). Australia generated 2,369,680 tonnes of timber waste in 2016-17. The share of the C&D sector as the second-largest timber waste generator was almost 612 kt (25.8%), preceding C&I with almost 1,524 kt (64.3 %). Among the jurisdictions, NSW, Vic and Qld had the largest amount of timber waste in total and in the C&D waste stream in 2016-2017. This report identifies the opportunities for reducing waste throughout the timber products lifecycle. Furthermore, these opportunities are eventually conceptualised through a model called Timber-LowMor. Lastly, the recommendations for reducing timber waste are provided as follows:

- To use non-disposable metal formwork instead of timber one in several construction projects
- To redefine and harmonise timber waste in national and jurisdictional regulations and policies
- To exclude timber waste recovered from construction activities from generic timber waste
- To improve the existing and employing new varieties of machinery instead of old and obsolete one help reducing the wood waste
- To fund the development of waste energy recovery infrastructure particularly those that are able to recover energy from chemically treated timber waste
- To consider precast timber frames in the designs

2 INTRODUCTION

Due to its flexibility, durability, and appealing visual attraction, timber has multiple applications in the construction industry. The main areas of applications include structural, exterior and interior. Timber is used extensively to construct single-unit housing and multi-unit apartments and renovation projects. Definition of timber (wood) waste in the Australian context presents challenges as it does not reflect the total timber waste and varies in different regulations and policies[1]. Timber waste from C&D activities is generated in large quantity all over the world. The main timber waste includes untreated timber, preservative-treated timber, engineered wood products, coated or painted timber, timber packaging, sawdust and offcuts.

2.1 Application of timber in the construction industry

Trees and their derivative products have been used by societies around the world for thousands of years for their versatility, strength and natural beauty. While there are limitless possible designs, and construction is based in both engineering and cultural practice, timber has a high strength to weight ratio and is used most efficiently in structures where it is carrying a lot of its own self-weight. Table 1 lists and describes timber applications in the construction and highly reverent industries.

Table 1. Various applications of timber in the construction (highly relevant) industry

Application	*Description*
Architectural Roof Trusses	A truss is a structure comprising one or more triangular units. Each triangle is constructed with straight and usually slender members of timber, connected at the ends by joints. The benefits of timber trusses are notable and numerous. Timber roof trusses are an ecologically sound choice compared to conventionally pitched roofs, they use smaller dimension timbers that span greater distances and this, in turn, reduces the total timber volume contained within. There are two forms of trusses within a building nail plated and architectural trusses: nail plated trusses are trusses hidden from view that use nail plates as connectors. Architectural trusses refer to those attractively detailed timber trusses, exposed to view. Architectural timber trusses are lightweight, enabling speedy and efficient construction and installation that results in a visual feature to be enjoyed for decades.
Cladding, External	No other cladding material can offer the design freedom, ease of handling, range and natural beauty of timber. Timber cladding can create a building to suit almost any environment, taste or style. Timber cladding has an inbuilt flexibility that provides natural advantages on sites subject to high winds, extreme climate, highly reactive soils, subsidence or earth tremors. And unlike masonry and other rigid materials, the natural resilience and high strength to weight ratio of timber enable it to withstand far greater stresses and movement. Modern finishes give a long-lasting and attractive appearance to timber cladding and can be used to change the colour and style of the building, making it a versatile material that will keep pace with changing tastes and fashions.
Decking	Timber decks are a practical and attractive addition to any outdoor landscape. Natural timber decks blend seamlessly with their surrounding environment and will serve as popular entertaining areas all year long. As an external structure, carrying large loads of traffic, timber decking has high structural performance requirements. In addition, decks are usually raised clear off the ground and fully exposed to the

[1] Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

	weather meaning an effective deck must be able to cope with wear and tear from repeated use and in addition discharge rainwater efficiently. Timber decking is available in both seasoned and unseasoned wood, in a wide range of species, sizes and grades.
Fencing	The inherent appeal and strength of timber make it the obvious choice for fencing. Timber fencing not only provides a natural look in keeping with the outdoor environment but it also enables the construction of a long-lasting, durable property boundary. Fences come in many forms including the traditional paling, picket, post and railing styles. Most rely on a structural frame of posts embedded into the ground and two or more rails spanning between the posts. The ultimate selection of a suitable fence type or style is determined by application and aesthetics. A fence can serve a variety of purposes, including the provision of security, privacy and safety in addition to defining property boundaries.
Flooring	Whether for structural or finished flooring applications, timber offers durability, versatility and adaptability. The warmth, strength and natural beauty of timber flooring have proved enduringly popular in a wide variety of interior settings. Timber flooring is a timeless product, offering warmth and natural beauty largely unmatched by other flooring options. Timber flooring is typically supplied as either solid timber or laminated wood products, made from layers of bonded timber There is a wide variety of species to select flooring from and the right species for a given application will be dependent on numerous factors.
Framing	Lightweight timber construction typically comprises framed and braced structures to which one or more types of cladding are applied. Framing configurations can range from the closely spaced light timbers commonly seen in stud frame construction to large, more widely spaced timbers. A timber-framed building can be placed on a concrete slab or on posts/poles or bearers resting on piers/stumps supported on pad footings. Used in houses or multi-residential dwellings, lightweight timber construction offers the flexibility of a wide range of cost-effective design options. When the timber comes from sustainable sources, this construction method can be environmentally advantageous as it combines timber's low embodied energy with its capacity to store carbon.
Packaging	From pallets to customised packing solutions, timber is a highly flexible, efficient packaging material that delivers value, performance and environmental benefits. As packaging usually uses lower grades of timber, it also optimises log utilisation. Wood consistently delivers value across the supply chain.
Pergolas	Timber pergolas offer an attractive and economical way to create functional living and entertainment areas in the outdoors. Pergolas designed with care can maximise both winter sunshine and summer shade, ensuring outdoor living is enjoyed all year round. With its natural look, durability and versatility there are few other materials that can match the advantages of timber in pergola construction. A protective finishing coat will preserve the life of the pergola and a variety of paints and stains are available on the market to facilitate this.
Rails and Balustrades, Exterior	The versatility, strength and natural beauty of timber make it the ideal material choice for external handrails and balustrades. Usually built from treated softwood and durable hardwoods these timbers can be turned to create a range of styles and designs, resulting in balusters that are unique as they are individual. Painting, staining and oil-based finishes broadly cover the wide range of finishing options available and with the appropriate care and attention a timber balustrade can last a lifetime.
Rails and Balustrades, Interior	When used internally balustrades and handrails are typically finished with a clear lacquer to showcase the natural beauty of the timber and with appropriate care and attention will last a lifetime.

Retaining Walls (Landscaping)	Timber is an excellent choice for retaining walls used in landscaping. Retaining wall systems include cantilevered round or sawn timber, mass wall and crib wall construction. Walls up to one metre in height follow a basic design and can usually be constructed using standard proprietary wall systems. An engineer will be required to plan and design walls greater than one metre, including the footings and drainage. Drainage of retaining walls is a critical factor in influencing the long term stability of the wall and should thus form a significant part of the design and planning process. Regular care and maintenance of retaining walls is essential in ensuring the long-term stability and safety of the structure.
Stairs, Exterior	All exterior stairs serve a functional purpose, but the choice of timber in the application will turn a functional building element into an aesthetically pleasing feature. While the construction of stairs is demanding, the investment of time will be returned, with a well-constructed timber staircase typically lasting decades. Exterior stairs are usually built from treated softwood and durable hardwoods and typically finished with paint. The construction procedure described here applies to most general type stairs of either conventional or contemporary construction. When it comes to stairs there is a multitude of variations available for application depending on the structural requirements of the building. This guide discusses the most commonly specified stair types.
Stairs, Interior	Interior staircase work is considered a specialised area of carpentry and joinery as its construction requires high levels of workmanship, detail and accuracy. Many interior stairs are built from quality joinery timber, cut and seasoned especially for staircases. Interior stairs differ considerably in design, from simple straight flights, commonly used in domestic work, to more elaborate stairs, constructed purposely as stand out features in public and commercial buildings.
Windows	With natural aesthetic appeal, versatility and sound structural performance, timber provides excellent window joinery design options. Whether stained to bring out natural tones or painted to compliment particular décors, timber windows can be tailored to suit a huge variety of styles and can be installed into any type of building.
Shingles and Shakes	A shingle, generated from a sawn piece of timber is characterised by its relatively smooth face and back, while in contrast a shake, essentially a split piece of timber, is dominated by a strongly textured surface. A shingle, generated from a sawn piece of timber is characterised by its relatively smooth face and back, while in contrast a shake, essentially a split piece of timber, is dominated by a strongly textured surface. Timber shingles and shakes are most commonly used on roofs as cladding. While they are typically applied in straight single courses, this can be varied to achieve other more decorative effects.
Doors	Whether manufactured from solid or engineered timber, there are many stylish and practical options that won't compromise on strength and structural performance. A distinctive timber door can also create visual impact, adding value to any commercial or domestic building. Timber makes an attractive choice for door design and construction, offering a strength, flexibility and versatility that other materials find hard to match. Protected from moisture, a timber door will perform satisfactorily for the life of any building. With regular maintenance, carefully designed and finished timber doors can perform in the toughest external environment and if required, can be refurbished or updated easily and effectively.
Panelling, Interior	Internal panelling, also known as appearance boards and linings, is not just a practical means of covering one or more walls and ceilings in a building, its inclusion in a room's interior design can generate looks that are both dramatic and stylish. Internal panelling comes as either solid natural timber panelling or as sheets of engineered wood products that provide a durable and hardwearing surface for areas subject to high impact. As they typically function as appearance products they

	generally have no structural requirements. This guide describes the variety of panelling products available and outlines the straightforward process of installing them.
Structural Insulated Panel Systems (SIPS)	SIPS are a modern alternative to traditional timber-framed construction and function as the structural element for walls, roofs, and suspended floors. They consist of two outer layers of Oriented Strand Board (OSB) sandwiched around an Expanded Polystyrene (EPS) core. In the fabrication of OSB 85-90% of the log can be used. Compared with conventional milling, where the recovery is typically 50-70%, the board makes use of timber that would be otherwise discarded.
Portal Frames	For buildings that require large spans and column-free interiors, timber portal frames provide one of the most aesthetically pleasing solutions. Utilising modern engineering technology, portal frame design transforms timber into a highly effective, efficient and economical structural product. Timber portal frames offer a strong, sound and superior structure. Structural action is achieved through rigid connections between column and rafter at the knees, and between the individual rafter members at the ridge. These rigid joints are generally constructed using nailed plywood gussets and on occasion, with steel gussets.
Shear walls	Lateral loads such as wind or earthquake on framed timber buildings - either post and beam or stud and joist - need to be resisted and shear walls and diaphragms offer an effective and economical solution. Framed timber buildings, of post and beam or stud and joist construction, resist lateral loads (wind, earthquake or impact) by using rigid frames (portals), braced frames (trusses and cross-bracing) or structural sheathing elements (diaphragms).
Structural Timber Poles	Timber poles are utilised in structural construction to provide support for gravity loads and resistance against lateral forces. Not only serving a structural function, but timber poles also provide many aesthetic benefits, with their use in construction often complementing architectural designs aimed at harmonisation with the natural environment.
Temporary Structures	Wood has an important role in providing temporary structural support during the building process. Common wooden temporary structures include formwork and scaffolding.

Source: www.woodsolutions.com.au

The following (Figure 1) shows 22 different applications of timber in the construction industry in Australia that are listed in Table 1.

Figure 1. Applications of timber in the construction industry

3 TIMBER INDUSTRY OVERVIEW

Generally, there are two major industries that operate in the field of timber production and supply. These include the commercial forestry industry and the timber wholesale industry. Also, there are other industries that directly contribute to supply, demand and wastage of timber products namely log sawmilling, hardware and building supplies retailing, construction and hardware wholesaling, wooden structural component manufacturing, wooden furniture and upholstered seat manufacturing, timber resawing and dressing, pallets and other wood product manufacturing. The following section provides some information on the current status of these two industries in Australia. The major sources from which this information was extracted are the Australian Bureau of Agricultural and Resource Economics and IBISWorld 2019.

3.1 Commercial forestry industry

The forestry industry is the main source of domestic production of timber material. The total log harvest in 2017–18 was 32.9 million cubic metres (Figure 2), a 1% decrease from the record high 2016–17 log harvest of 33.2 million cubic metres and 44 % higher compared with 2012–13. In 2017−18 the gross value of log production reached a record high of $2.7 billion (mill door prices); from 2016-17 this was a 4 % increase[2]. The majority of annual total log harvest stems from commercial plantations. The remainder is sourced from native production forests. In 2017–18, commercial plantations accounted for 87 % of Australia’s total log harvest by volume and native production forests contributed 13 %.

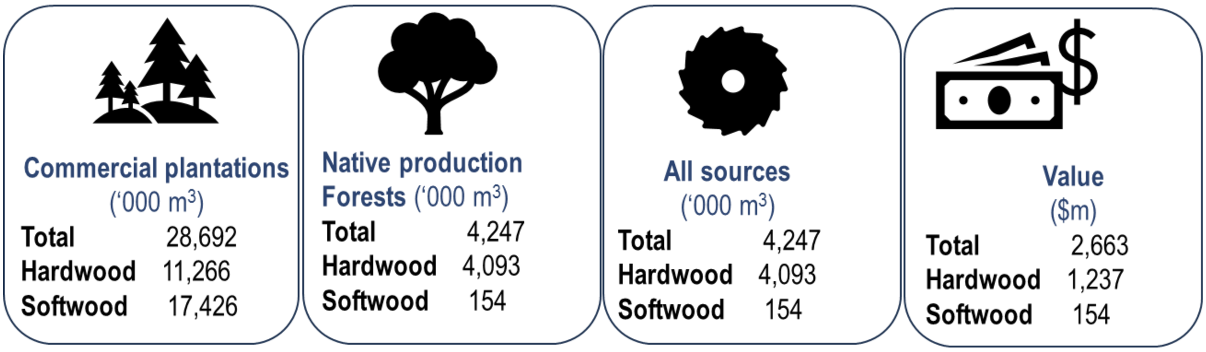


Figure 2. The indication of local timber production in Australia based on log harvested between 2017-18.
Source: Australian Bureau of Agricultural and Resource Economics, 2019.

In contrast with the modest growth in the native production forest hardwood log harvest since 2012–13, the hardwood plantation log harvest more than doubled over the past five years to 11.3 million cubic metres in 2017–18, down 1 % from the previous year (Figure 3). The pulp log harvest decreased to 10.5 million cubic metres (down 4 % from 2016−17) and the sawlog harvest increased to 810,000 cubic metres (up 69 % from 2016−17). In 2017–18, pulp logs harvested mainly for woodchip exports represented 93 % of all hardwood logs harvested from commercial plantations. Sawlogs, veneer logs and other log products made up the remaining 7 %. Plantation hardwood logs represented 73 % of

[2]Australian forest and wood products statistics: Industry performance.2018 Australian Bureau of Agricultural and Resource Economics, 2018. http://www.agriculture.gov.au/abares/research-topics/forests/forest-economics/forest-wood-products-statistics/industry-performance#hardwood-plantations

total hardwood logs harvested in Australia in 2017–18. In 2017–18 the total value of plantation hardwood logs increased to a record $851 million (mill door price), up 6 % from the previous year.

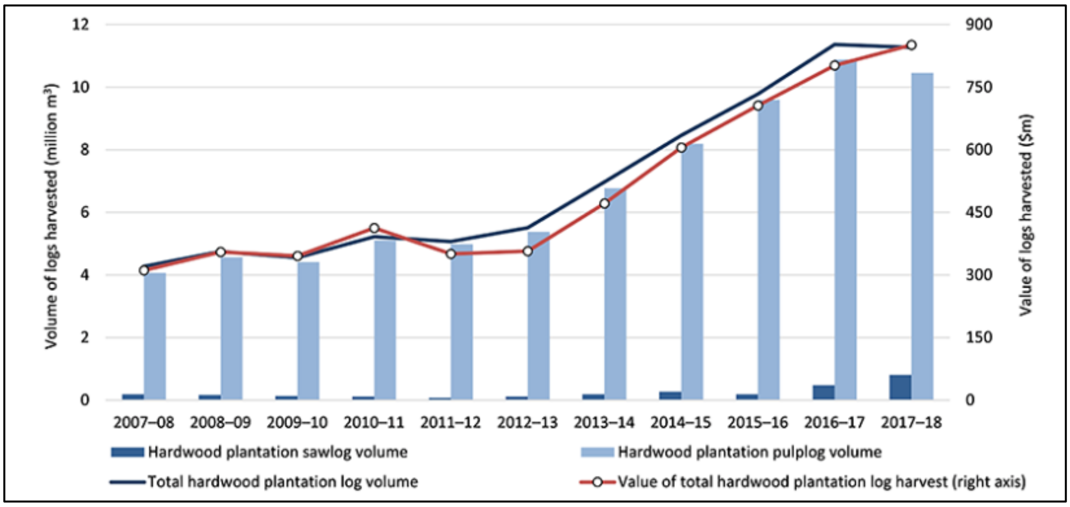


Figure 3. Volume and value of logs harvested from the commercial hardwood plantation
Source: Australian Bureau of Agricultural and Resource Economics, 2019.

The total volume of softwood plantation logs harvested annually in Australia—comprising sawlogs, pulp logs and other log products—has fluctuated over the past decade, largely in response to changes in housing construction. Since 2012–13 the annual harvest volume of softwood plantations has been increasing but at an average slower rate than the plantation hardwood log harvest (Figure 4). In 2017–18 the total volume of softwood plantation logs harvested was 17.4 million cubic metres, down 0.6% from the previous year. The softwood plantation sawlog harvest decreased in 2017−18 to 10.7 million cubic metres (down 0.1% from 2016−17) and the softwood plantation pulp log harvest decreased to 6.3 million cubic metres (down 3 % from 2016−17). The majority of softwood logs harvested from commercial plantations in 2017–18 were sawlogs and veneer logs (61%). Softwood plantation pulp logs—used for woodchip exports and domestic paper, paperboard and panel production—comprised 36 % of the total plantation softwood log harvest. Other log products, including round wood, posts and poles, made up the remainder. In 2017–18 the total value of plantation softwood logs increased to a record $1.4 billion (mill door price), up 4% from the previous year (Figure 4).

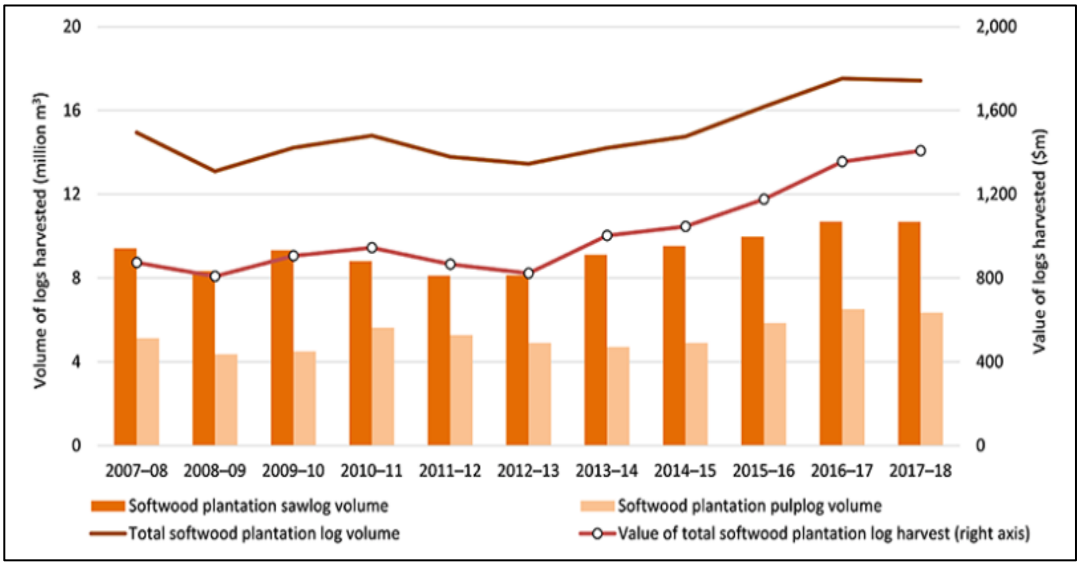


Figure 4. Volume and value of logs harvested from commercial softwood plantation
Source: Australian Bureau of Agricultural and Resource Economics, 2019.

The annual wood production in Australia yields 32, 940 m^3 of hardwood (native and plantation) and softwood logs. Vic (29.8%), NSW (20.5%) and Tas (19.2%) are the largest producers of wood log in Australia. The individual figures of the volume of the logs harvested for various Australian states are presented in Figure 5.

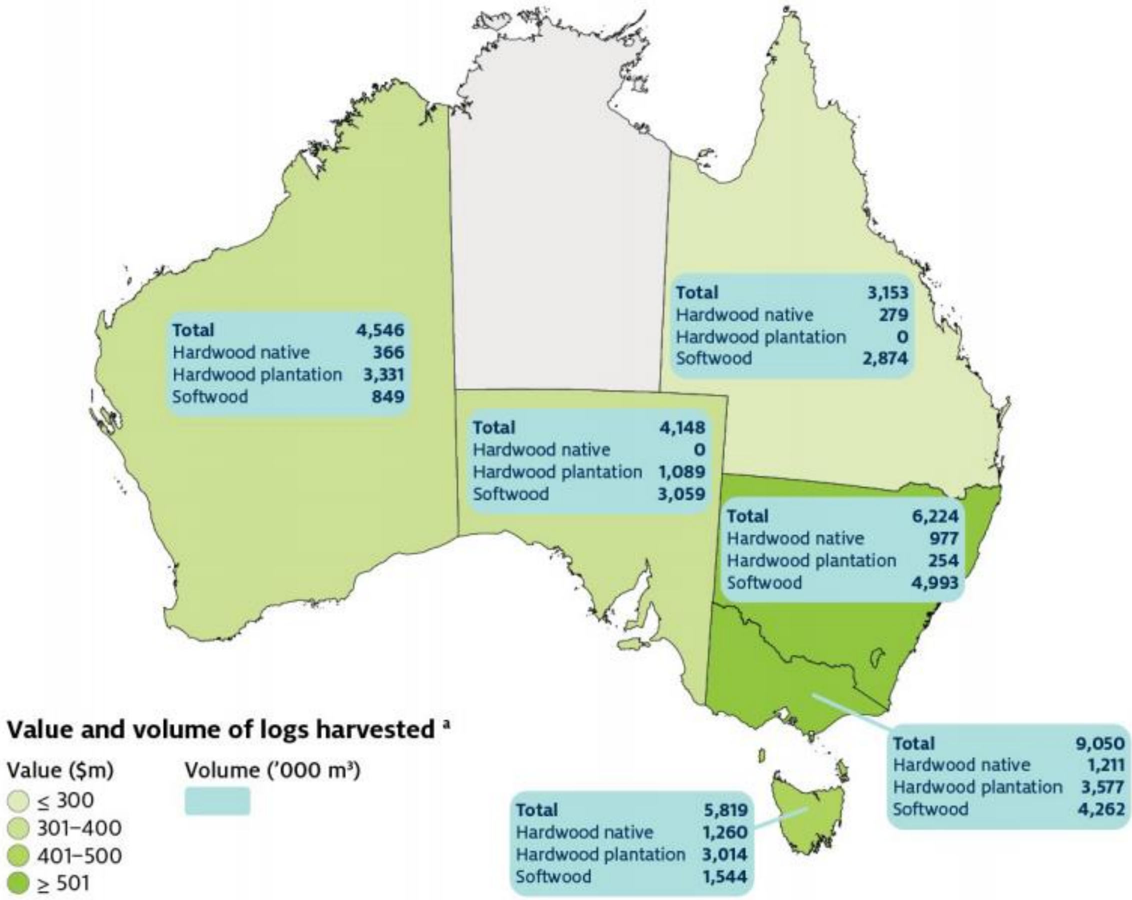


Figure 5. Logs harvested in Australia.
Source: Australian Bureau of Agricultural and Resource Economics, 2019

3.2 Timber wholesale industry

Industry operators wholesale sawn timber and other wood products to retailers such as hardware stores, commercial and residential construction companies, carpenters and furniture manufacturers. The industry revenue is $4.4bn with $178.8m profit[3]. Operators in the timber wholesaling industry (TWI) have experienced difficult trading conditions over the past five years. Timber wholesalers have lost market share to alternative building materials such as steel. However, the TWI is forecast to moderately grow over the next five years (2019-2024), supported by positive demand conditions from residential building construction and improved demand from wooden structural component manufacturers. The key drivers and major demand and supply industries for TWI are tabulated in Table 2.

[3] Youren, M. (IBISWorld) 2019. Far from the tree: Increasing wholesale bypass trends have contributed to revenue declines. IBISWorld Industry Report F3331: Timber Wholesaling in Australia. IBISWorld publications.

Table 2. Key drivers and the major industries dealing with timber wholesaling (demand & supply).

Key Economic Drivers	Demand Industries	Supply industries
Demand from residential building construction	Wooden Structural Component Manufacturing	Fabricated Wood Manufacturing
Demand from non-residential building construction	Wooden Furniture and Upholstered Seat Manufacturing	Log Sawmilling
Demand from wooden structural component manufacturing	Construction	Pallets and Other Wood Product Manufacturing
Demand from wooden furniture and upholstered seat manufacturing	Hardware and Building Supplies Retailing	Timber Resawing and Dressing
		Wooden Structural Component Manufacturing

Source: IBISWorld 2019

Timber products in Australia are divided into four main categories (Figure 6): carpentry and joinery timbers (46%), hardwood and particle board timbers (28%), plywood and veneer timbers (15%), and other timber products (11%). These categories are developed by the IBISWorld database and are presented in Figure 6.

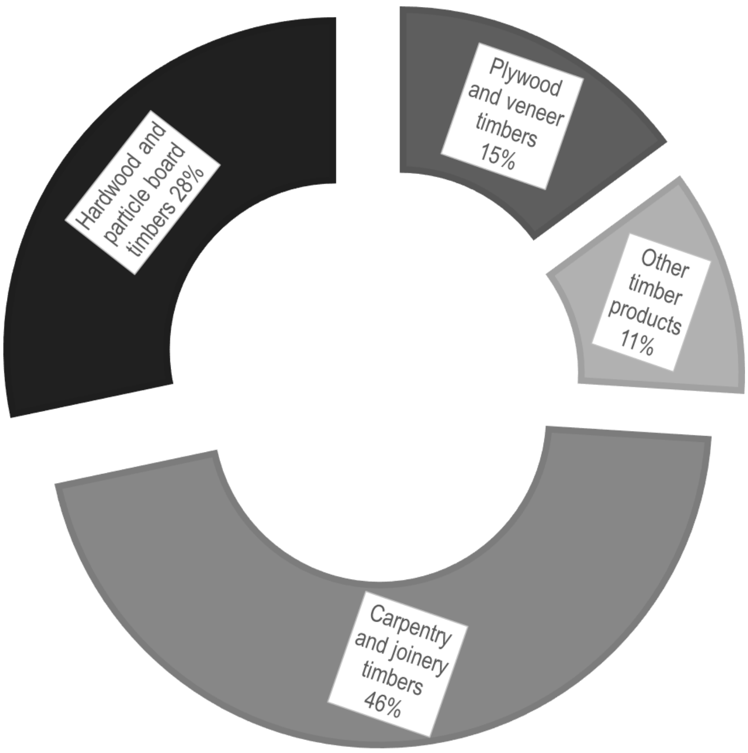


Figure 6. The major timber products in Australia in 2019.
Source: IBISWorld 2019

According to IBISWorld 2019, the annual Australian domestic price of timber is forecast to decrease by 0.3% in 2019-20, to 143.8 index points. Decreased demand from construction in previous years, in combination with greater timber stockpiles due to reduced construction activities, is likely to exert downward pressure on the price index. However, the price decline may be limited by greater demand from wooden structural component manufacturers. Figure 6 provides an insight into the fluctuations in and projections of the TWI's revenue from 2014 to 2021.

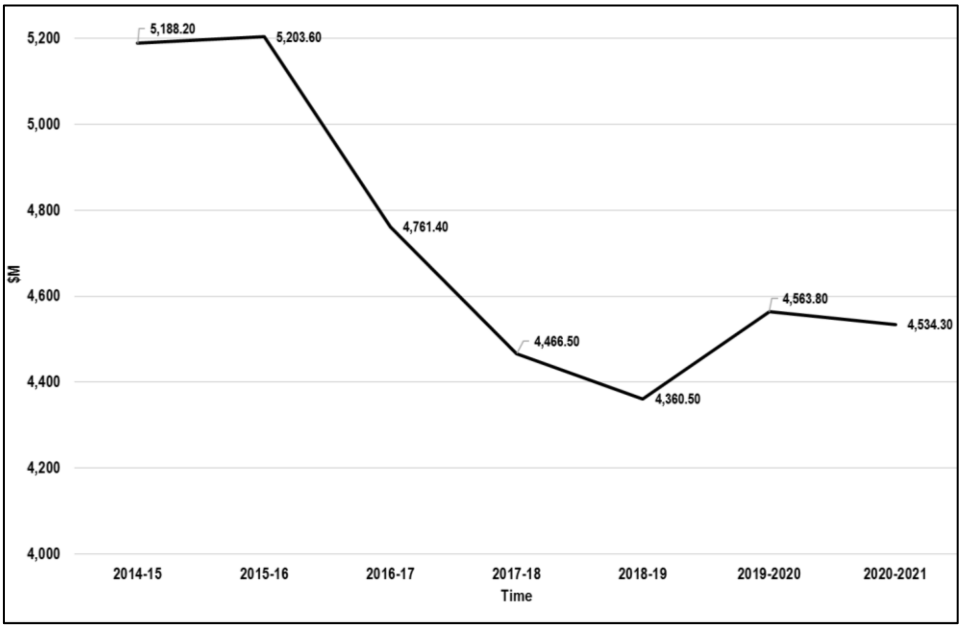


Figure 7. Statistics pertaining to the TWI (revenue) in Australia between 2014 and 2021.
Source: IBISWorld 2019

3.2.1 Major timber market shareholders in Australia

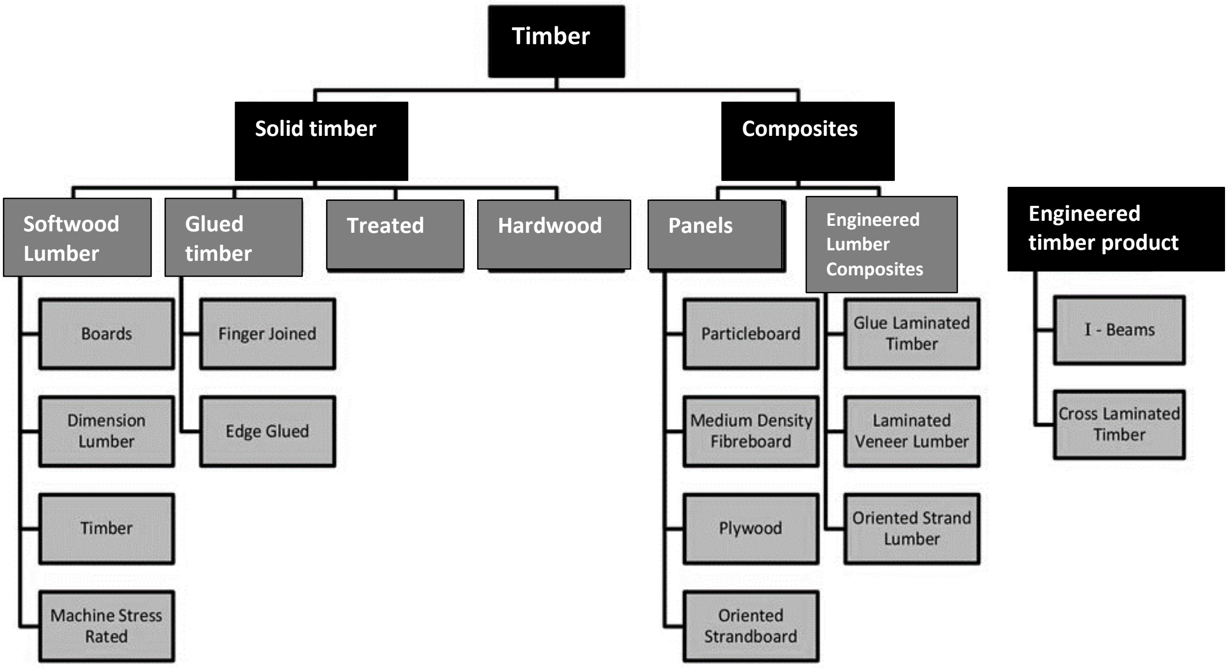
The TWI industry features a pretty scattered market with only two major shareholders that own only 22.1% of the market only. These major shareholders of timber wholesaling in Australia are Westfarmers Limited/Bunnings (13.6%) (https://www.wesfarmers.com.au/) and Metcash Limited/Home Timber & Hardware (8.5%) (https://www.metcash.com/). The remaining 77.9% market share belongs to many small- to medium-size industry operators that service narrow geographic markets. These operators work alongside a handful of medium- to large-scale multi-establishment firms that supply timber products to clients across state and regional markets.

3.2.2 Demand determinants

The demand for timber product is largely dependent on market conditions in the building construction sector. Typically, increased activities in the building construction industry will increase the demand for industry products, as greater amounts of products such as glue-laminated timber are needed to fulfil the demands by this sector. Also, the demand for timber from the Wooden Furniture and Upholstered Seat Manufacturing industry also determines industry demand.

3.3 Raw materials

In this section, the raw materials for timber productions that are used in the construction industry are reviewed. In broad timber terms, there are two different categories of woods: softwood and hardwood. Timber is cut from logs into different shapes and sizes. Softwood is mainly used for structural purposes in housing construction such as wall and floor framing, lining boards, and roof trusses and cladding. In Australia, it accounts for the majority of total sawn wood production (85 % in 2017–18)[4]. As a result, one of the key factors influencing sawn wood consumption is domestic dwelling commencements. Hardwood-based timbers are heavy, strong and stable. They are generally used for their durability or appearance in flooring, piers, decking and joinery applications. Primarily, they are sourced largely from native production forests. In 2017–18 Australia produced 4.6 million m^3 of sawn wood, a 2% decrease from 2016–17. Softwood sawn wood production in 2017–18 decreased to 3.9 million m^3 (down 1 % from the previous year) and hardwood sawn wood production decreased to 711,000 m^3 (down 6%)[4]. Following a set of preparatory and manufacturing work, the harvested timber from the forest is converted to marketable products. According to the timber product taxonomy timber products are divided into three major categories (Figure 8) namely solid timber, composites and engineered timber products (ETP).



The engineered timber products are called ETP (engineered timber product). ETPs are the products that bonded together with adhesives, typically manufactured from wood fibre, particles, strands, flaks, veneers, solid timber sections, or any combination of these. Figure 9 exhibits the most common ETPs produced and used in the construction industry.

[4] ABARES 2019, Australian forest and wood products statistics, September and December quarters 2018, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, June. CC BY 4.0. https://doi.org/10.25814/5cf8f713b3782.

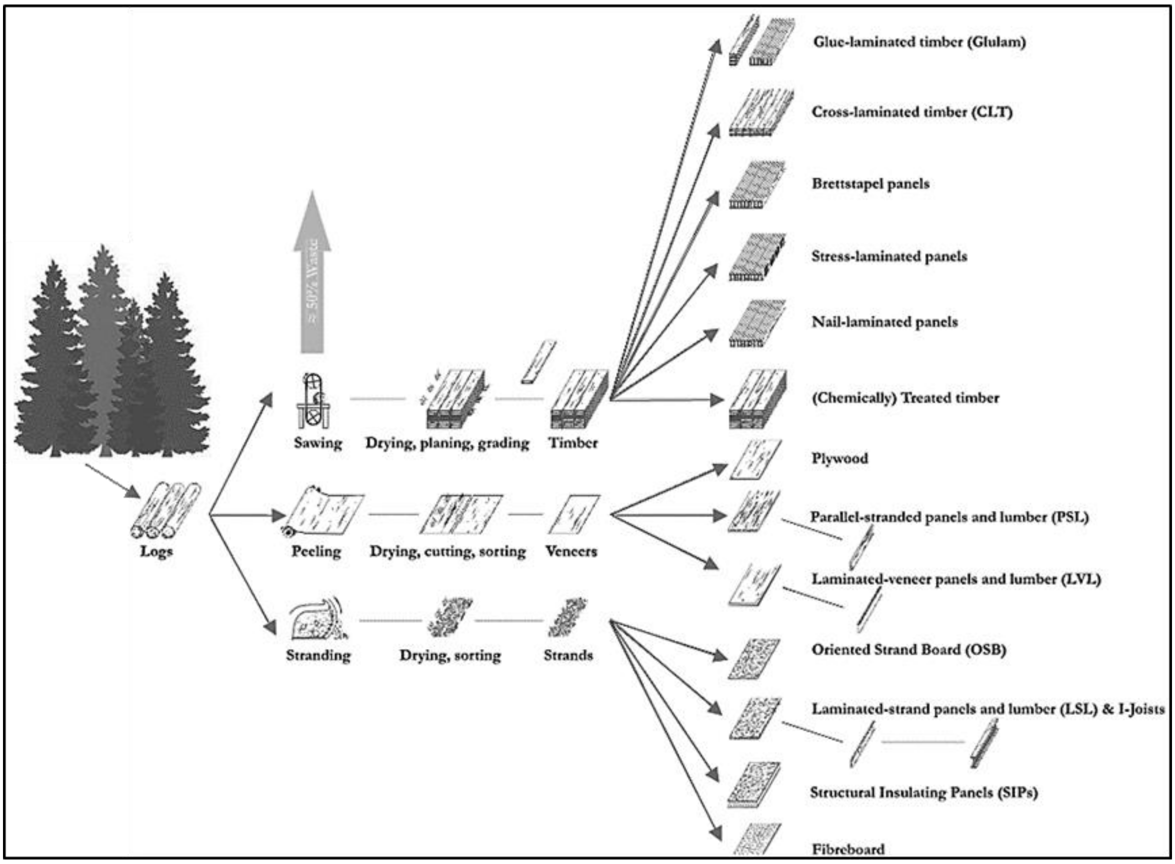


Figure 9. A schematic overview of ETPs.

Source: Ramage et al. (2017)

4 MANUFACTURING PROCESS

The typical timber manufacturing process involves five steps: log preparation, processing, log break down, green sawn and seasoning (Figure 10). The following is a brief description of timber manufacturing in the Australian context which is adapted from the guideline provided by WoodSolutions accessible through their official website at www.woodsolutions.com.au.

Figure 10. The five main phases of the timber manufacturing process.

4.1 Log preparation

The first step in the conversion of logs to wood is the preparation of the log. The branches and bark are removed from the tree trunks prior to any processing. Removing the bark leaves all the hardwood and most of the sapwood. This process now takes place in a matter of seconds on the forest floor with specialised machinery. Where the logs are to be used as poles or piles, some specifications may call for the removal of the sapwood. This can shape the log so that it is perfectly round, has sixteen or more faces, or is true to the original shape of the tree.

4.2 Processing

Logs classified as ‘saw logs' are sent to a sawmill to be processed. Logs are stockpiled under water sprays to prevent them from splitting as they rapidly dry out. The logs are then sawn into rectangular shapes in the ‘green mill'. Here the logs are fully saturated, and the saws leave a rough surface on the wood, as some of the fibres are torn out rather than cut. If timber is to be seasoned, or dried, then this will take place next with the removal of much of the moisture from inside the timber. Seasoned products are then machined to give smooth or shaped surfaces.

4.3 Log breakdown

Logs present handling difficulties due to their cylindrical shape, so the first steps in a normal saw mill operation involve cutting the logs to provide flat surfaces. There are many different cutting patterns used to produce timber – the most common cutting methods are splits and cants.

- Splits - the first saw cut is through the centre of the log to give two splits, each of which has a flat face for registering in further cutting operations.
- Cants - the first saw cuts go either side of the corewood in the very centre of the log. The pieces that are left on the outside are called wings, and the almost-rectangular piece from the centre is called a centre cant.

4.4 Green sawn

Once the breakdown saw has established some flat surfaces, the other saws in the green mill can cut the various pieces into marketable timber. Each mill establishes its own cutting patterns for different sized logs, in an attempt to maximise the number of pieces cut in the most popular sizes.

4.5 Timber seasoning

I. Kiln drying timber

The most common commercial process for seasoning of timber is kiln-drying. Kiln seasoning accelerates the process of seasoning by using external energy to drive the moisture out. The timber is stacked in much the same way as it is for air drying and is placed inside a chamber in which the conditions can be varied to give the best seasoning results. Air is circulated around the charge (stacked timber) and the temperature and humidity can be varied to give optimum drying. Each species has different cell characteristics and therefore requires different drying schedules. Typically, the timber may be in the kiln for a period of between two days to one week.

Generally, it is not feasible to kiln-dry structural timber in thicknesses greater than 45 mm, although there are limited amounts of 70 mm thick kiln-dried softwood members in the market place. All untreated structural pine and some commercial hardwoods are seasoned, mostly using kilns that are often heated by sawmill by-products or gas. Kiln-seasoning of softwoods such as pine can be done fairly quickly, however, seasoning of hardwoods tends to be a much longer process, due to the different cell structure of hardwoods.

II. Air drying

The traditional method of seasoning timber was to stack it in air and let the heat of the atmosphere and the natural air movement around the stacked timber remove the moisture. The process has undergone a number of refinements over the years that have made it more efficient and reduced the quantity of wood that was damaged by drying too quickly near the ends. The basic principle is to stack the timber so that plenty of air can circulate around each piece. The timber is stacked with wide spaces between each piece horizontally, and with strips of wood between each layer ensuring that there is a vertical separation too. Air can then circulate around and through the stack, to slowly remove moisture. In some cases, weights can be placed on top of the stacks to prevent warping of the timber as it dries.

Moisture loss from the side of the wood is at about the correct rate so as not to cause the collapse of the cells, but near the ends of the wood, the moisture loss can prove to be too fast. Often the ends are wrapped or painted to slow the moisture loss from the end grain. While little additional energy needs to be supplied for this type of seasoning, the stacks of timber require a lot of land, represent a potential fire hazard, and the product is not able to be sold for a considerable time. Air-drying of timber is really more controlled facilitation of what happens to unseasoned sawn timber, once it is placed into its ‘work' environment. The amount of drying that can occur is decided by the relative humidity of the drying environment and will often vary within individual boards as well as within the stack itself. The time taken for air-drying is a function of the thickness of the timber. Air-drying is a slow process, particularly for hardwoods, typically taking 6 to 9 months to reach a moisture content in the range 20% to 25%.

4.6 Sawing patterns

Each cutting pattern produces timber with a distinct appearance and character. Each type has its advantages and disadvantages. The following describes various types of sawing patterns.

I. Quartersawn timber

Also called quarter cutting, with quarter-sawn timber the growth rings are parallel to the short face. The long face of every board is close to a radial face. A large number of growth rings can be seen on this face. Quarter sawing timber is best for hardwood species that are prone to collapse during drying.

II. Back sawn timber

Also known as back cutting and tangential cutting, back sawing is the most common sawing method used in Australia. Back sawing helps to obtain high-grade timber from logs. Most structural timber and many appearance products are backsawn. With backsawn timber, the long face of each board is close to a tangential face, and the short face is close to a radial face. Growth rings are parallel to the long edge and the wide face does not intersect many growth rings. The growth rings on the wide face appear to be very wide apart, and some interesting patterns can be seen. This cut offers more flexibility in that quite large boards can be backsawn from the wings of logs. Here the maximum depth can be just less than the diameter of the log.

III. Radial sawn timber

This cut is not very common, and, if required, would need special negotiation with the mill. However, radial sawing has an efficiency that the other cuts cannot achieve and makes optimal use of a log. Because of the cutting pattern, each piece of radially sawn timber is a wedge shape. It has sapwood on the wider edge and pith or corewood at the point. As real logs are not perfectly round and not perfectly straight, each radially sawn board reflects the longitudinal shape of the log. These details can make for interesting architectural use of the timber. Apart from flooring, radial sawn timber is used mainly for external applications such as cladding, decking, poles, wedges and timber screens.

Sawn timber will either be available as unseasoned or seasoned:

- **Unseasoned timber** - is classified according to its moisture content. Any timber with a moisture content > 25% is said to be unseasoned or ‘green'. However, for practical reasons, most timber sold as unseasoned has a moisture content > 15% rather than the stricter definition of unseasoned timber (> 25%).

- **Seasoned timber** - producing seasoned timber is the process of drying timber to remove the bound moisture contained in walls of the wood cells. Seasoning can be achieved in a number of ways, but the aim is to remove water at a uniform rate through the piece to prevent damage to the wood during drying (seasoning degrade). Seasoned timber has a moisture content between 10 and 15%. Timber in this condition will be in equilibrium with internal environments in many parts of Australia.

Seasoned timber has a reduced weight, improved strength and the cross-sectional dimensions remain almost constant. It is more stable than unseasoned timber and is much less prone to warping and splitting. It also provides improved gluing and nail-holding properties and increased joint strength. In higher grades of timber, particularly hardwoods, the process of seasoning can enhance the basic characteristic properties of timber, increasing stiffness, bending strength and compression strength. Seasoned timber should be chosen for indoor use where it is particularly important not to have shrinkage associated with drying out in service.

5 REGULATIONS, POLICIES, AND GUIDELINES

There are several examples of the regulation of timber waste. For instance, EU has several directives that directly impact timber waste disposal and recycling, including the Directive on Packaging and Packaging[5] waste with the aim of 50-60% recovery of packaging waste and 24-45% recycling. The UK has developed its own version based on this European directive using two regulations: Producer Responsibility Obligations (packaging waste) Regulations 2007[6] and the Packaging (essential requirements) Regulations 1998[7]. The goal of these two regulations is 50% recovery and recycling of packaging waste.

Germany has the most specific national legislation on timber waste management: Ordinance on the Management of Waste Wood 2003[8]. This ordinance classifies timber waste and specifies technologies for timber waste recycling of combustion. In the US, the federal government is responsible for overriding environmental legislation and regulation. Each state has an independent authority to develop environmental protection policies. This has led to inconsistencies in the way that timber waste is dealt with in the various states.

In Australia, regulation of wood wastes is independently legislated in each state by an environmental protection authority or equivalent. It is embedded within the legislation that covers the management of general waste. Timbers treated with hazardous preservatives are classified based on the level of protection required to ensure structural integrity. These standards are monitored by the state EPA as chemicals used to preserve wood can have impacts on air, water and human health. The preservation industry is reviewed through EPA's compliance audit program, whereby the EPA ensures preservers comply with environmental laws. Protection ranges from H1 to H6 the lowest to the highest level of protection needed, respectively. H1 preservatives protect the timber from insects such as termites, and H6 protects the timber from Marine Borer attack and decay. Timbers treated with preservatives must also be stored in well-ventilated areas to prevent them from contaminating other products.

In the last decade, the timber industry has voluntarily formed a National Timber Product Stewardship Group (NTPSG) to address the environmental impacts arising from the disposal of timber products[9]. The NTPSG comprises timber companies and national associations from all parts of the timber supply chain together with importers, wholesalers and retailers of timber and wood products. The group has prepared a National Product Stewardship Strategy for post-consumer timber and wood products. The NSW’s Office of Environment and Heritage’s protocol for infrastructure timber waste recycling provides useful information about safe and productive recycling of timber waste.
Timber waste is one of the 16 materials that are in the scope of extended producer responsibility (EPR) that is NSW waste management policy.

[5] European Environmetn Agency. 2019. Directive 94/62/EC on packaging and packaging waste. https://www.eea.europa.eu/policy-documents/directive-94-62-ec-on

[6] UK Staturoy Instruments. The Producer Responsibility Obligations (Packaging Waste) Regulations 2007. http://www.legislation.gov.uk/uksi/2007/871/contents/made

[7] UK Statutory Instruments. 1998 No. 1165. The Packaging (Essential Requirements) Regulations 1998. http://www.legislation.gov.uk/uksi/1998/1165/contents/made

[8] Protection Federal Ministry of Justice and Consumer. Ordinance on the Management of Waste Wood 2003.

[9] NTPSG .2017. http://www.timberstewardship.org.au/

6 TIMBER WASTE

6.1 Types of timber waste

The amount of wood waste generated from C&D is influenced by the life span of the building materials. Solid hardwood can last up to 90 years, and softwood furniture and preservative-treated pine could last for 50 years, while plywood, particleboards and MDF for cabinetry only last for about 30 years[10]. Timber waste is defined in different ways by various national and jurisdictional policies and guidelines. In Europe, in the European Waste Catalogue (EWC) timber waste is classified under 170201 Code[11]. In Australia[12], timber waste is classified into three major categories: untreated timber (Type A), engineered timber products (Type B), and treated timber (Type C). The following describes these types of timber waste.

6.1.1 Untreated timber (Type A)

Untreated timber is a material that is not treated with a preservative, such as copper chrome arsenic (CCA). Common sources of untreated timber are furniture and framing for houses. This timber is generally of high quality. Timber log products are untreated timbers that are usually categorised as either "softwood" or "hardwood". The softwood is identified as timber that comes from coniferous (cone-bearing) trees (e.g. pines or firs). Hardwood comes from trees with broad leaves that produce seeds in an enclosed case (e.g. eucalypts, oak and walnut).

6.1.2 Engineered timber products (Type B)

Engineered wood products are manufactured in a variety of ways using wood (e.g. veneers, flakes, chips and fibres) and resins (adhesives), which bond the pieces together to form a variety of products, including structural applications. Common engineered wood products include plywood, laminated veneer lumber (LVL), glued laminated lumber, particleboard and medium-density fibreboard (MDF). Finger-jointed timber is also a common engineered wood product, manufactured by gluing and joining small pieces of timber end to end to form a longer piece of timber.

6.1.3 Treated timber (Type C)

Treated timber is timber with timber preservatives, or coated or painted to improve the timber products' resistance to attack by biological agents such as fungi, insects and animals. In Australia, treated timber consists primarily of softwood treated with preservatives such as Copper Chromium Arsenic (CCA) (also known as Chromated Copper Arsenate), synthetic pyrethroids as Light Organic Solvent Preservative (LOSP) or creosote. Small volumes of hardwood timber are also preservative treated for various uses including marine pilings and poles. Timber painted with lead-based paint, although phased out in Australia in 1970, still appears in the waste stream. A large quantity of Australian softwood framing is now H2F treated against termites. Common timber preservatives are tabulated below (Table 3):

[10] Jaakko Poyry Consulting 1999, Usage and life cycle of wood products / Jaakko Poyry Consulting (Asia-Pacific), National Carbon Accounting System Technical Report: no. 8.', Australian Greenhouse Office, Canberra

[11] European Waste Catalogue and Hazardous Waste List. 2002. Ireland's Environmental Protection Agency http://www.nwcpo.ie/forms/EWC_code_book.pdf

[12] Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

Table 3. The common preservatives applied to timber materials in Australia.

Type	Description
Copper Chromium Arsenic (CCA).	Compounds of copper, chromium and arsenic that are recognised by a characteristic green colour in the timber.
Other chemicals usually including creosote-in-oil, pigment-emulsified-creosote (PEC), double treatment (CCA followed by creosote), treatment with boron compounds and treatment with sodium fluoride.	Used only to produce timber for specific customer needs.
Other water-based treatments such as alkaline copper quaternary (ACQ) and copper azole.	None.
Supplementary treatments.	Applied on-site to improve the timber products' resistance to attack by biological agents such as fungi, insects and animals.
Light Organic Solvent Preservative (LOSP) .	Incorporating a synthetic pyrethroid is used to introduce pesticides into the timber, and usually associated with little or no colour change.

Source: Taylor and Warnken (2008).

6.2 How much timber waste is generated

The international reports indicate that timber waste comprises a significant portion of waste materials. However, the timber waste composition rate largely depends on the technology and style of construction. For instance, in Finland, timber waste composes 36% of C&D waste[13]. In Germany, 401 million tonnes of wastes were generated in 2015, of which waste wood accounts for 11.9 million tonnes[14,15]. These reports indicate that the C&D waste stream is accountable for 27% of timber waste generated per year. The results of a report by the US Environmental Protection Agency indicated that timber waste accounted for 16% and 42% of non-residential buildings and residential buildings, respectively[16]. A Malaysian study[17] found that timber waste contributed to the largest percentage of construction waste, ranging from 35% to 69.5% in three separate projects.

In Australia, traditionally, the challenge with reporting timber waste data is mostly concerned with the separation of the waste source. However, during recent years data reporting systems have improved, and as a result, more accurate data is available. In 2008, a report on timber waste showed that 1,781 kt of timber waste were generated annually[18]. In Vic, SV reported that between 2013-14 the quantity of waste timber collected from C&I (primarily from packaging- pallets) and C&D waste

[13] Meinander, M, U. Mroueh , J. Bacher, J. Laine-Ylijoki, M. Wahlström, J. Jermakka, N. Teirasvuo & H. Kuosa. 2012. Directions of future developments in waste recycling. VTT TECHNOLOGY 60. https://www.vtt.fi/inf/pdf/technology/2012/T60.pdf

[14] Sommerhuber PF, Welling J, Krause A .2015. Substitution potentials of recycled HDPE and wood particles from post-consumer packaging waste in wood-plastic composites. *Waste Management*. 46:76–85

[15] Garcia CA, Hora G .2017. State-of-the-art of waste wood supply chain in Germany and selected European countries. Waste Management 70:189–197.

[16] Ward, J., Mackes, K., Lynch, D., 2004. Wood Wastes and Residues Generated Along the Colorado Front Range as a Potential Fuel Source. Res. Pap. RMRS-RP-50. Fort Collins, Colorado. USDA Forest Service, Rocky Mountain Research Sta.

[17] Lau,H.H., Whyte, A., & Law, P.L. Composition and Characteristics of Construction Waste Generated by Residential Housing Project. International Journal of Environmental Research. 2(3): 261-268.

[18] Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

streams was 505kt[19], from which 165Kt was recovered and 340kt sent to landfill sites. The results of a survey[20] that was conducted by Zero Waste SA in 2007 showed that C&D timber waste accounts for 21.03% of the total timber waste received in seven landfills and transfer stations; the remaining part (79%) was contributed by C&I waste stream. The latest data for timber waste was reported in 2018[21], in a report prepared by the Blue Environment Pty Ltd and the Randel Environmental Consulting.

Table 4 summarises the waste data reports on the national and jurisdictional timber waste in various

Waste generation				Waste landfill				Waste recycling				E	
SW	C&I	C&D	total	MSW	C&I	C&D	total	MSW	C&I	C&D	total	MSW	C
672	15,246	32,558	73,236	4,486	14,640	31,264	50,390	-	-	-	20,760	186	6
310	546,443	181,994	762,747	25,309	359,776	76,725	461,810	8,099	173,844	102,534	284,477	902	12,
237	5,111	7,422	13,771	1,215	5,020	7,290	13,525	-	-	-	-	22	9
457	200,078	92,255	413,549	18,085	180,201	90,394	288,680	-	-	-	102,758	372	19,
197	273,193	58,411	342,801	10,437	6,101	17,963	34,501	500	210,000	40,000	250,500	260	57,
740	26,879	1,491	30,109	1,699	26,249	1,456	29,404	-	-	-	-	41	6
907	313,330	205,967	544,203	5,727	107,767	138,809	252,303	18,880	199,922	59,892	278,694	300	5,
879	144,512	31,873	189,264	10,646	94,407	20,776	125,829	2,029	48,296	10,699	61,024	204	1,
,399	**1,524,792**	**611,971**	**2,369,680**	**77,604**	**794,161**	**384,677**	**1,256,442**	**29,508**	**632,062**	**213,125**	**998,213**	**2,287**	**98,**

waste streams in 2016-17. As can be seen in the table, Australia generated 2,369,680 tonnes of timber waste in the year reported. The share of the C&D sector as the second-largest timber waste generator was almost 612 kt (25.8%), preceding C&I with almost 1,524 kt (64.3 %). Among the jurisdictions, NSW, Vic and Qld had the largest amount of timber waste in total and in the C&D waste stream in 2016-2017.

[19] Sustainability Victoria. 2015. Factsheet: Market summary – recycled timber. Netbalance.pp.1-5.
[20] Waste Audit and Consultancy Services (Aust) Pty. Ltd. (2007) Disposal Based Survey, Zero Waste SA, Oct. Nov. 2007. 133.
[21] Department of Environment and Energy. 2018. P863 National waste data and reporting cycle 2017-19. https://www.environment.gov.au/system/files/resources/7381c1de-31d0-429b-912c-91a6dbc83af7/files/national-waste-report-2018-data.xlsx

Table 4. Timber waste data in various jurisdictions

	Waste generation				Waste landfill				Waste recycling				Energy recovery			
State	MSW	C&I	C&D	total	MSW	C&I	C&D	total	MSW	C&I	C&D	total	MSW	C&I	C&D	Total
ACT	4,672	15,246	32,558	73,236	4,486	14,640	31,264	50,390	-	-	-	20,760	186	606	1,294	2,086
NSW	34,310	546,443	181,994	762,747	25,309	359,776	76,725	461,810	8,099	173,844	102,534	284,477	902	12,823	2,735	16,460
NT	1,237	5,111	7,422	13,771	1,215	5,020	7,290	13,525	-	-	-	-	22	91	132	246
QLD	18,457	200,078	92,255	413,549	18,085	180,201	90,394	288,680	-	-	-	102,758	372	19,877	1,861	22,111
SA	11,197	273,193	58,411	342,801	10,437	6,101	17,963	34,501	500	210,000	40,000	250,500	260	57,092	448	57,800
TAS	1,740	26,879	1,491	30,109	1,699	26,249	1,456	29,404	-	-	-	-	41	630	35	705
VIC	24,907	313,330	205,967	544,203	5,727	107,767	138,809	252,303	18,880	199,922	59,892	278,694	300	5,641	7,266	13,206
WA	12,879	144,512	31,873	189,264	10,646	94,407	20,776	125,829	2,029	48,296	10,699	61,024	204	1,809	398	2,411
Total	**109,399**	**1,524,792**	**611,971**	**2,369,680**	**77,604**	**794,161**	**384,677**	**1,256,442**	**29,508**	**632,062**	**213,125**	**998,213**	**2,287**	**98,569**	**14,169**	**115,025**

7 TIMBER WASTE MANAGEMENT

In Australia, the quantity of timber waste generated at the national level is significant and its recycling rate is low in comparison with other C&D wastes such as concrete and ferrous metal[22]. The following sections demonstrate the opportunities to minimise waste generation or reduction the waste volume going to landfill during various steps of timber lifecycle.

7.1 Waste during timber harvest

Generation of waste during timber the lifecycle begins with log harvest from commercial or natural forests. There is evidence proving that this waste can be significant in large quantities. For instance, Dionco-Adetayo (2001) found that out of 1 m^3 of tree removed from the forest, about 50% goes to waste in the form of damaged residuals, followed by abandoned logs (3.75%), stumps (10%), tops and branches (33.75%), and butt trimmings (2.5%). The results of a survey[23] that was conducted by Zero Waste SA in 2007 showed that C&D timber waste accounts for 21.03% of the total timber waste received in seven landfills and transfer stations; the remaining part (79%) was contributed by the C&I waste stream.

7.2 Waste during manufacturing

During manufacturing timber, approximately 50% is recovered as viable board and plank products[24], with the remaining dust, shavings and fibre byproducts typically used as biomass fuel or as fibre in engineered timber panel products. A study in Ghana[25] identified the major sources of timber waste including low-quality logs with large defects, bark, off-cuts, sawdust, slabs and edged trimmings from sawn timber. However, there are new technologies for the utilization of low-quality logs, which can significantly reduce the timber wastage as well as specialised equipment that enables the maximisation of timber recovery[26]. One example of these technologies is Large Cone-Beam Computed Tomography[27]. In this technology, a computer is used to calculate the best way to cut it to avoid defects and increases yield by 8%, which adds up to a lot of wood. The logs fly through the machine at 590 feet per minute. It also gets the most out of "decadent", or old and decaying logs, which might otherwise go to waste. The CT log scanner chooses the cutting pattern that maximises the overall resale value of ALL boards cut out from a log, minimising waste.

Timber manufacturers can also utilise their timber production residual for their energy demands. For example, the US timber industry met over 65% of its energy needs through timber residuals, which in turn represented over 90% of total timber fuel usage by US manufacturing industries[28].

Another method to reduce C&D waste during manufacturing is to utilise C&D waste of other construction materials in the production of various timber products. For instance, in Brazil, it is proven that particleboard manufacturing industries can utilise C&D waste timber to produce MDF

[22] Daian, G. and Ozarska, B., 2009. Wood waste management practices and strategies to increase sustainability standards in the Australian wooden furniture manufacturing sector. *Journal of Cleaner Production*, 17(17), 1594-1602.

[23] Waste Audit and Consultancy Services (Aust) Pty. Ltd. 2007. Disposal Based Survey, Zero Waste SA, Oct. Nov. 2007133.

[24] Ramage, M.H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D.U., Wu, G., Yu, L., Fleming, P., Densley-Tingley, D. and Allwood, J., 2017. The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews*, 68, 333-359.

[25] Eshun JF, Potting J, Leemans R 2012 Wood waste minimization in the timber sector of Ghana: a systems approach to reduce environmental impact. *Journal of Clean Production* 26, 67–78.

[26] Adhikari, S. and Ozarska, B., 2018. Minimizing environmental impacts of timber products through the production process "From Sawmill to Final Products". *Environmental Systems Research*, 7(1), 1-15.

[27] Treehuggers. How to reduce timber waste: put your logs through a CT scanner. 2019. https://www.treehugger.com/green-jobs/how-reduce-timber-waste-put-your-logs-through-ct-scanner.html

[28] EPA. 2007. Energy trends in selected manufacturing sectors: opportunities and challenges for environmentally preferable energy outcomes. Report, Environmental Protection Agency.

inner layers (Azambuja et al., 2018). The following table (Table 5) summarises examples of manufacturing timber using other C&D waste materials.

Table 5. Application of other C&D wastes in the production of timber.

Waste material	Summary of study	Reference
Construction material packaging stuff (e.g. cardboard and paper).	Packaging stuff from C&D activities can be used to make flanks that can be used in the construction activities.	www.citymetric.com[29]
Particle obtained from four types of timber waste: MDF, MDP, plywood and solid timber.	The results proved that C&D timber waste has the potential to be used as raw material for particleboard. The properties of the resultant product were promising, and the industries are recommended to use these waste resources for the production of the inner layer of MDP products.	Azambuja et al. (2018)

Reviewing several studies on the use of timber waste in creating pasteboard, Hossain and Poon (2018) reported that these products meet the standards on mechanical performance and exhibited excellent noise reduction and low thermal conductivity. These features promote the potential application of pasteboards as lightweight acoustic and thermal insulating materials. Another timber waste-based product is cardboard timber, which was first launched in Norway, where over 1m tonnes of paper and cardboard are recycled every year. The wood is created by rolling up paper and solvent-free glue to create a log-shaped material, then it is chopped into usable planks. The timber can then be sealed so it is waterproof and flame-retardant and used to build anything that would be normally built with timber (Figure 11).

Figure 11. Cardboard timber.
Image source: www.citymetric.com: ViJ5

[29]CityMetric. 2015. 9 Building materials made entirely from waste product. www.citymetric.com. https://www.citymetric.com/skylines/9-building-materials-made-entirely-waste-products-932

7.3 Waste reduction opportunities during the design, planning, and contract

The design of the building has a huge impact on the quantity of timber waste generated. Generally, there is little opportunity to minimise timber waste on small construction sites due to the necessity of cutting standard sized timber to fit the project design and the unavoidable nature of waste originating from cutting[30].

7.4 Reducing waste during the procurement

Procuring timber products from recognised suppliers that provide timber materials from well-managed farms can lessen the quantity of timber waste. In the US[31] Forest Stewardship Council sets standards (called certified wood) that guide construction firms' procurement methodology to obtain high-quality timber products. Another strategy at the procurement stage to minimise waste is to source construction materials from suppliers that use other materials than wooden pallets for packaging. Furthermore, the implementation of stock control measures was identified to have the greatest potential for minimising waste on small scale construction projects[30]. Such measures are intended to avoid over-ordering of materials, and ensure that all materials are available when required.

7.5 Reducing waste during transportation and delivery

The waste generation during transportation and delivery can be notable. The transportation of timber product begins with shipping timber from the forest to sawmills, then carrying sawn timber from sawmills to manufacturing companies, and finally to end-users. At each of these stages, there is potential for waste generation.

7.6 Reducing waste during construction

Reduction of timber waste during construction proved to be a significant contributor to waste generation. Early defect studies often link the wood waste on-site with poor craftsmanship and negligence[32]. Several studies have also linked the occurrence of defects to the organisation and, more specifically, poor communication[32]. Therefore, organisational learning is a key ingredient for successful application of quality management procedures. Among different strategies, education can provide benefits to the industry to minimise waste during the construction phase. At the heart of strategies to reduce the waste generated at a C&D site are the human factors. Operators play a key role in minimising the waste generated and waste management systems can effectively guide and inform their waste minimisation attitudes and behaviour. Both of these factors can benefit from an educational program aiming to inform waste management system and thus human attitude and behaviour. In Australia, an educational program collaboration between Forest Wood Products Australia and the University of Tasmania's Centre for Sustainable Architecture with Wood was created to provide available-on-demand timber education and skills development opportunities. This program, called WoodSolutions Campus is for those who design and build with timber, study-related courses or work in Australia's timber and wood products supply chain. WoodSolutions is Australia's leading online resource for people designing and building with wood and wood products. Table 6 presents the courses now offered to applicants:

[30] Williams, I.D. and Turner, D., 2011. Waste management practices in the small-scale construction industry. https://eprints.soton.ac.uk/346322/1/003p_Williams.pdf

[31] Yates, J.K., 2013. Sustainable methods for waste minimisation in construction. Construction Innovation. *Construction Innovation*. 13 (3): 281-301.

[32] Johnsson, H. and Meiling, J.H., 2009. Defects in offsite construction: timber module prefabrication. *Construction Management and Economics*, 27(7), pp.667-681.

Table 6. The timber specific courses delivered by WoodSolutions Campus.

Course title	Theme	Description
Laying Timber Flooring	Construction, installation	A comprehensive introduction to timber flooring for professional and DIY'ers
NCC Design of Mid-rise Timber Building: Specific Requirements	Design, relevant to waste management	This course introduces the NCC's design requirements, terminology and specific fire requirements for the design of mid-rise timber buildings
NCC Design of Mid-rise Timber Building-Overview	Design, relevant to waste management	An overview of changes to the NCC's DTS provisions that allow the use of lightweight and massive timber construction systems
NCC Design of Mid-rise Timber Buildings: Fire, Sound and Non-Habitable Area Requirements	Design, relevant to waste management	This course covers fire, sound and non-habitable area requirements
Timber Inspection	Maintenance	This module course introduces Australian Standards and the process of inspecting and certifying timber for house construction
Timber and Wood Products	Manufacturing, relevant to waste management	An overview of products, their manufacture and major applications areas, generally available sizes and major standards controlling their manufacture or use
Introduction to Building Regulations and Standards	Design and procurement	Most aspects of the building are regulated. This course will help you understand how regulations and standards affect how timber is produced, specified and supplied for use in buildings in two key areas: timber product standards and building regulations
Design for Durability	Design, relevant to waste management	This topic introduces you to things you need to know for building in bushfire areas. It will help you choose and specify appropriate timber and wood products
Managing Timber's Moisture Content	Maintenance	This topic introduces you to things you need to know to determine an appropriate MC for timber in applications and handle and store timber and wood products to maintain that moisture content
Design for Bushfire	Design	This topic introduces you to things you need to know for building in bushfire areas. It will help you choose and specify appropriate timber and wood products
Timber Grades and Grading	Procurement	This topic introduces you to major grading methods, the structure and application of grades in industry, and their regulation through standards
Selecting Fit-for-purpose Timber for Applications	Procurement	This topic provides an overview of consumer law, and discusses the key questions to be asked of the customer,

		and the performance requirements for major application types.
Timber and Wood Properties	Design and procurement	This topic introduces you to the main things you need to know about timber and wood properties.
Environmental Characteristics of Timber	Design and procurement	This topic introduces timber and wood products' environmental characteristics, describes their potential contribution to sustainable development and compares them with those of major materials. As forestry practise can have significant impacts on the forest's renewability and other impacts, the benefits and limits of forest and chain-of-custody certification are discussed.

Use of timber material within modular-based construction technology proves to produce less waste than a traditional build. Studies in the UK demonstrated that application of off-site modular timber frame systems could save 50% and 35% of embodied carbon and energy respectively compere to traditional build[33]. Figure 12 exhibits an example of timber off-site construction in the US that was installed in five days in 2017.

Figure 12. Entekra's floor panels being lifted onto what will be a two-story, 260 m² house in Los Banos, US. Source: Enterka[34].

The other advantages of timber off-site construction involve reduced labour, reduced time, safer working conditions, and increased productivity[103]. In Australia, however, timber off-site construction has not been fully exploited and is still in its infancy. A source of timber waste generation identified at construction sites is the temporary use of timber materials. Temporary uses of the wood include formwork for concrete moulding, temporary offices on buildings sites, and installations for safety purposes (scaffolds and collective protective equipment). According to recent studies in China[35], the waste emerging from the formwork for concrete moulding in high-rise buildings is responsible for the greatest amounts of wood residue, and it represents about 30% (by volume) of construction waste. The use of alternative permanent materials for scaffolding, collective protective equipment,

[33] Wood for Good and PE International Ltd. Life Cycle Database, Glue Laminated Timber. Technical report, Wood for Good. 2013

[34] Probuilder. 2019. Entekra's Gerard McCaughey Aims to Disrupt the Industry's Stick-Build Mentality. [online] Available at: https://www.probuilder.com/mccaughey [Accessed 10 Oct. 2019].

[35] Lu, W., Yuan, H., Li, J., Hao, J.J., Mi, X. and Ding, Z., 2011. An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China. *Waste Management*, 31(4), pp.680-687.

and container offices can reduce wood waste generation by approximately 50%. The use of wooden formwork systems only can reduce75% of wood waste generation. The use of precast concrete structures could possibly reduce wood waste generation to approximately zero[36].

7.7 Reducing waste during demolition

Sorting the timber waste extracted during demolition can assist in further waste recovery. Sorting is an important phase in the utilisation of timber waste as it removes 'gross contamination' that can interrupt the recovery process. In the sorting process, contamination control is applied. Sorting methods also minimise the risk of wood contamination in wood waste utilisation. For example, the timber waste industry depends on quality parameters such as the potential of contamination from the residue of post-burning wood waste for energy generation[37]. However, the growth of automated demolition processes that are more economical for operators to run but result in more homogenous C&D waste to landfill will also contribute to less clean streams of timber waste. One study in the UK recommended the use of skips for segregation of specific materials and on-site sorting of wastes as the main strategies to reduce timber waste going into landfill[38]. However, sometimes this practice is difficult to implement due to the lack of space required for several waste skips. The resolution to this could be the provision of bulk bags rather than skips[39] which ensures waste minimisation practice without infringing on on-site space.

7.8 Reducing waste through reusing

Timber waste can be utilised easily and directly in other construction projects after cleaning, de-nailing and sizing. Undamaged wood can be reused as the plank, beam, door, floorboard, rafter, panel, balcony parapet and pile[40]. Furthermore, particleboard manufacture is increasingly utilising recycled wood packaging and offcuts in the production of new particleboards. However, one caveat to keep in mind is the use of coated timber waste in certain applications such as mulch or soil additives. Re-use of timber waste can particularly take place in infrastructure projects wherein timber waste is recovered in large quantities of almost similar quality. One example of this application is taking place is a project in Myanmar. The renovation of the world's longest teak bridge, the U Bein Bridge was planned to be accompanied with the reuse of timber waste. The old posts that support the deck of the bridge were successively replaced and were reused as handrails or rest benches along the 1.2 km footbridge (Figure 13).

[36] Kern, A.P., Amor, L.V., Angulo, S.C. and Montelongo, A., 2018. Factors influencing temporary wood waste generation in high-rise building construction. *Waste Management*, 78, pp.446-455.

[37] Lestari, R.Y 2015. Assessment of reusing and recycling wood waste for production of furniture and furniture components in Victoria. MSc. Thesis. School of Ecosystem and Forest Sciences, Faculty of Science. University of Melbourne.

[38] Williams, I.D. and Turner, D., 2011. Waste management practices in the small-scale construction industry. https://eprints.soton.ac.uk/346322/1/003p_Williams.pdf

[39] Fox, J. and Hilton, M. (2008). Evaluation of recycling feasibility trials to develop recycling services for SMEs. Waste and Resource Action Plan, Oxon, UK

[40] Hendriks C.F. and H.S. Pietersen.2000. Sustainable raw materials: construction and demolition waste. RILEM Publication, Cachan Cedex, France.

Figure 13. U Bein Bridge in Myanmar; the longest teak bridge
Source: The Myanmar Times: Phyo Wai Kyaw.

The literature also places emphasis on the on-site usage of timber waste to reduce timber waste landfilling. On-site usage can take place in the form of fuel. This is particularly attractive as it reduces the emissions associated with transportation, often by road, of timber waste to another site (for energy recovery or panel production), as well as the empty return journey of the transport vehicle.

7.9 Waste recovery (recycling and upcycling)

Recycling timber is a practice that was popularised in the early 1990s as issues such as deforestation and climate change prompted both timber suppliers and consumers to turn to a more sustainable timber source. Post-consumer timber can be recycled if it is not contaminated or treated. The recyclable timber should be kept separated from painted, coated and preservative-treated (timber) materials. Timber waste from infrastructure projects such as utility poles and bridges are now found to be more viable than landfill and energy recovery as the hardwood timber supplies are reducing[41].

In Australia, the latest statistics (2016-17)[21] show that timber waste recovery (recycling and upcycling) has gained some successes in some of the jurisdictions. However, the data gathered might not best represent the timber waste recycling activities and results in the ACT, NT and Tas should be noted with this caveat in mind. In general, the rate of timber waste recovery in the C&D stream was lower than the total waste streams. The exceptions are NSW and WA which have a marginally higher rate in the C&D waste stream. Among the jurisdictions, SA and NSW were the most successful states with 68.5% and 56.3% waste recovery rates, respectively.

[41] NSW's Office of Environment and Heritage. 2011. Protocols for recycling redundant utility poles and bridge timbers in New South Wales. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/waste/110617-recycled-timber.pdf?la=en&hash=943FF9CF3A234610A4E4F70265260F3BB3F86FB8

Table 7. Statistics on recycling/upcycling of timber waste in Australia.

States & territories	C&D waste	Total waste	C&D waste recycling /upcycling	Total waste recycled /upcycled	% C&D waste Recycling/ upcycling	% total waste Recycling/ upcycling
ACT	32,558	73,236	-	20,760	-	28.3
NSW	181,994	762,747	102,534	284,477	56.3	37.3
NT	7,422	13,771	-	-	-	-
QLD	92,255	413,549	-	102,758	-	24.8
SA	58,411	342,801	40,000	250,500	68.5	73.1
TAS	1,491	30,109	-	-	-	-
VIC	205,967	544,203	59,892	278,694	29.1	51.2
WA	31,873	189,264	10,699	61,024	33.6	32.2
Total	**611,971**	**2,369,680**	**213,125**	**998,213**	**34.8**	**42.1**

Timber waste can be recycled and upcycled for various purposes. There is overwhelming evidence about timber recycling and upcycling as tabulated in Table 8. The recovery product of timber waste can be used in wooden furniture and upholstered seat manufacturing, electric power industry, agriculture, and construction material manufacturing industry.

Table 8. Summary of studies investigating the applications of recycled brick waste

Application		Summary of findings	Reference
Upcycling	Use as a raw material to make furniture	In 2004, Japan developed a new technology in turning timber waste into furniture, shoring wooden pile for relocated pine trees, wood bench and timber stair	Hendriks and Pietersen (2000)
	Use of fuel or charcoal for power generation	In the Netherlands, 400,000 tonnes of wood from C&D activities are generated	Hendriks and Pietersen (2000)
	Use as soil additives and mulch	Timber waste can be recycled to be used in the landscape industry	EPA NSW (2012)[42]
	Ash from sawdust timber waste used as a cement replacement material	From the results obtained in this study, 10% replacement of cement with SDA shows good performance giving the desired workability and strength	Elinwa and Mahmood (2002)
	Animal bedding	Recycled timber can be converted into animal bedding	EPA NSW (2012)[43]

[42]EPA NSW. 2010. Industry fact sheet: Timber and furniture industry. Reducing business waste. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/managewaste/120348-timber-furniture.pdf?la=en&hash=7688F29D7DB9A7414997D2E1958584103BFED87E

[43]EPA NSW. 2012. Materials fact sheet: Wood and Timber. Reducing business waste. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/managewaste/120360-wood-timber.pdf?la=en&hash=626A707647CB7B5043452B34CD 56810DCE858F89

Recycling	Use as aggregate special lightweight concrete	The aggregate is made from a recycled small wood chunk that undertakes blast furnace deoxidization.	Tam and Tam (2006)
	Use of timber waste as particles to make construction particleboards.	Use of micro-factory technology to incorporate used wood and non-toxic mix waste plastics	SmaRT (2017)[44]
	Use of timber railway sleeper waste (TRSW) to create wood-cement composite materials (CWC)	TRSW is found to be technically suitable for building construction such as panelling, ceiling and partitioning	Ashori et al. (2012)
	Use of wood particles derived from construction waste for making CWC.	The results showed that the use of CCA-treated timber particles for making lightweight CWC panels would not create a compatibility issue. The use of timber waste resulted in better toughness index.	Wolfe and Gjinolli (1999)

However, it should be noted that not all types of timber waste can be recycled and there are restrictions for certain waste types. Timber wastes with the following features cannot be recycled:

- nails, metal connectors, plastic wrapping, dirt and sand
- paint, oil and other coatings, laminates, edge bandings, glues and resins
- plywood, medium-density fibreboard (MDF)
- timber treated with Copper Chrome Arsenate (CCA) preservative (Figure 27)
- other wastes (e.g. garbage, building rubble) within the same load

Figure 14. Evidence of application of preservatives in the timber products in infrastructure projects.

The most common source of timber waste contamination origins in CCA and several methods are used worldwide to remove this preservative from the wood waste. These include laser-induced breakdown spectroscopy (LIBS)[45], X-ray fluorescence (XRF)[46], ion mobility spectroscopy (IMS)[47], and near-infrared (NR)[48] technologies. These methods can detect the depth of timber waste to which the

[44] UNSW's SMaRT Group. 2017. SMaRT Construction Panels. http://www.smart.unsw.edu.au/green-manufacturing/smart-construction-panels

[45] Uhl, A., Loebe, K. and Kreuchwig, L., 2001. Fast analysis of wood preservers using laser induced breakdown spectroscopy. Spectrochimica Acta Part B: *Atomic Spectroscopy*, 56(6), pp.795-806.

[46] Fellin, M., Negri, M. and Zanuttini, R., 2014. Multi-elemental analysis of wood waste using energy dispersive X-ray fluorescence (ED-XRF) analyzer. European Journal of Wood and Wood Products, 72(2), pp.199-211.

[47] Velizarova, E., Ribeiro, A.B. and Ottosen, L.M., 2002. A comparative study on Cu, Cr and as removal from CCA-treated wood waste by dialytic and electrodialytic processes. *Journal of Hazardous Materials*, 94(2), pp.147-160.

[48] Feldhoff, R., Huth-Fehre, T. and Cammann, K., 1998. Detection of inorganic wood preservatives on timber by near infrared spectroscopy. *Journal of Near Infrared Spectroscopy*, 6(201), pp.A171-A173.

pollutants penetrate, therefore, recyclers can know how much surface material must be removed to eliminate them (Figure 15).

Figure 15. Timber waste contamination detection using XRF.
Source: Fraunhofer WKI/Simone Peist

In Europe, an EU-funded project called CaReWood (Cascading Recovered Wood) sets out to introduce an upgrading concept for recovered solid timber as a source of clean and reliable secondary wooden products for the European industry[49]. The CaReWood project aims to develop a business model for upcycled use of timber waste from C&D activities, the furniture sector and the packaging and transport industries. The main objectives of CaReWood include:

- present authoritative forecasts of volumes and qualities of post-consumer and post-industrial RW
- design guidelines to facilitate future reuse
- develop software supported reverse logistic models for recovery of wood
- develop, demonstrate and evaluate the feasibility of up-grading solid RW technologies
- adopt certification and labelling criteria to cascaded wood
- evaluate the environmental impacts and socio-economic viability of wood cascading

Researchers working on this project claim that it is possible to recycle timber waste without any loss of quality[50]. The necessary methods for detecting and removing contaminants are being investigated in this project. Timber waste recovery in C&D activities pertaining to infrastructure projects present a huge opportunity for sustainable waste management due to the large quantity and relative uniformity of waste generated. For instance, the use of timber railway sleepers waste can be recovered to produce cement wood composite (CWC) materials that can be used in construction activities[51,52]. NSW's Office of Environment and Heritage has published a guideline for recycling

[49] CaReWood: Cascading Recovered Wood - A WoodWisdom Net+ project Carewood.iam.upr.si. (2019). CaReWood: Cascading Recovered Wood - A WoodWisdom Net+ project. [online] Available at: http://carewood.iam.upr.si/ [Accessed 10 Oct. 2019].

[50] A Second Life for Recovered Wood Science and Technology Research News. (2017). A Second Life for Recovered Wood. [online] Available at: https://www.scienceandtechnologyresearchnews.com/second-life-recovered-wood/ [Accessed 10 Oct. 2019].

[51] Ashori, A., Tabarsa, T. and Amosi, F., 2012. Evaluation of using waste timber railway sleepers in wood–cement composite materials. *Construction and Building Materials*, 27(1), 126-129.

[52] Wolfe RW, Gjinolli A. 1999. Durability and strength of cement bonded wood particle composites made from construction waste. *Forest Production Journal*. 49(2),24–31.

redundant utility poles and bridge timbers[53]. In this guideline, the protocol of pre-during and post recycling activities are outlined.

Use of timber waste in the furniture-making industry is prevalent and has been long practised. In Australia, recycled furniture companies typically either use 100% wood waste or a mix of timber waste and new timber[54]. These companies supply raw materials from three major resources including demolition companies, private holders and wood recycling companies. Recycled furniture companies usually build partnerships with demolition companies.

Two major issues in timber waste management include treated timber waste presence in load and ash generated in EfW activities. It is proven that treated timber waste can be used for making CWC panels without any compatibility issue with cement[52,55]. Schmidt et al. (1994) found that the use of treated timber waste was more compatible than untreated waste. This result was based on an enhanced resistance to withdrawal of sticks embedded in cement and the elevated flexural toughness of CWC materials. The results from these studies demonstrate that the manufacture of CWC should be a promising and viable method of disposal for treated timber waste. The ash that is produced in large quantities as a by-product of timber's energy from waste extraction processes is a major issue. Traditionally this ash is sent to landfill, however, in recent decades a new application for its sustainable management was found: as a cement in mortar and concrete mix. A review study[56] found that the use of timber ash in the concrete mix is promising. They outlined that:

1. Blended cement with wood ash as a partial Ordinary Portland Cement (OPC) replacement material has a higher standard consistency, initial and final setting time.
2. It tends to have more soundness but a lower rate of heat development relative to neat OPC paste.
3. Concrete and mortar mixtures containing wood ash as a partial cement replacement material has higher water demands to achieve a given level of mix workability as compared to equivalent neat OPC mixtures, hence, it increases magnitudes of water absorption in concrete mixtures.
4. Inclusion of wood ash at low levels of cement replacement actually contributed towards the enhancement of compressive strength in concrete mixtures produced.

7.10 Waste energy recovery

Timber waste is of high calorific/heating value. Timber EfW is operated by a variety of means, such as combustion, combustion to produce steam or gasification to produce a combustible gas. Ethanol and methanol can also be produced from timber waste, but this is a complicated and difficult process, yet to reach commercial maturity. There are opportunities for timber waste to be used for energy generation in power stations, and emerging opportunities for engineered wood products to be used for both process heat in cement kilns and energy generation in power stations. Table 9 summarises these timber EfW methods:

[53] NSW's Office of Environment and Heritage. 2011. Protocols for recycling redundant utility poles and bridge timbers in New South Wales. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/waste/110617-recycled-timber.pdf?la=en&hash=943FF9CF3A234610A4E4F70265260F3BB3F86FB8

[54] Lestari, R.Y 2015. Assessment of reusing and recycling wood waste for production of furniture and furniture components in Victoria. MSc. Thesis. School of Ecosystem and Forest Sciences, Faculty of Science. University of Melbourne.

[55] Schmidt R, Marsh R, Balatinecz JJ, Cooper PA. 1994. Increased wood–cement compatibility of chromate treated wood. *Forest Production Journal*. 44(7/8), 44–6

[56] Cheah,C.B and M. Ramli. 2011. The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: An overview. *Journal of Cleaner Production*. 55, 669-685.

Table 9. Timber's EfW (bi) products.

Fuel	Description of method
Electricity	Generation of electricity can be accomplished in different ways: a) combustion boiler to produce steam and thereby drive a steam turbine b) combustion boiler to produce hot inert gas or heated air to drive a turbine c) gasification reactor to produce a gas to be combusted in a combustion boiler producing steam d) to drive a steam turbine e) gasification reactor to produce a gas to be combusted in a gas turbine f) gasification reactor to produce a gas to be combusted in internal combustion (IC) engine g) pyrolysis process to produce syngas for combustion in a gas turbine.
Liquid fuels	Other techniques can be used to generate liquid fuels from wood waste. Gasification followed by syngas reformation using a Fischer-Tropsch process is one route to synthetic diesel. Pyrolysis processing can provide 'biocrude' for processing into a diesel replacement. Technologies including enzymatic, thermal and acid hydrolysis are under active development for conversion of cellulosic materials to sugars and thence to ethanol; wood waste could form an important feedstock for any commercial manufacturing process.
Biochar	In addition to the production of gas and 'biocrude', pyrolysis processing also delivers a product referred to as biochar. This solid residue, or charcoal, is mainly composed of carbon and is what remains after processing woody biomass through pyrolysis. Biochar can be co-fired with coal in power stations as it has a similar chemical composition and calorific value, and can also be upgraded for metallurgical applications. It is also emerging as a useful agricultural supplement with potential as a soil remediator that increases water retention, nutrient retention and stimulates soil microbial activity. A potential by-product of its use in agriculture is as a high volume carbon sequestration solution.
Cement Kilns	A cement kiln runs at approximately 1200 degrees Celsius and is usually fired with coal dust. However, the substitution of other materials is possible in this process. For example, in Melbourne, 25 old tyres are used as feedstock material. The advantage of using alternative fuels such as this in cement kilns is the high temperature at which they operate, which in turn reduces the amount of emissions. The effectiveness of combustion is improved as particle size is reduced, thus making materials such as sawdust ideal.
Firewood	Firewood sales are extremely seasonal. However, there is undoubtedly a residential market for conveniently sized, consumer-oriented boxes, bags or bundles of kindling or logs. These are often sold at petrol stations, hardware stores and even supermarkets, provided they meet quality controls.
Process Fuel	Commercial and domestic use of pellets and briquettes as process fuel (for heat or power) manufactured from wood wastes are commercially viable. Wood 'pellets' as a fuel source are generally manufactured from sawdust and wood shavings from sawmills. Pellet fuel is generally standardised and substantially more uniform in composition than traditional firewood.

Source: Taylor and Warnken (2008)[57]

[57] Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

The standard practice is that clean waste is allowed to be burned in normal power stations or private stoves[58]; while contaminated wood such as treated wood, painted wood, or chipboards containing adhesives (e.g. formaldehyde glue) can only be used for energy generation in special stations equipped with appropriate combustion facilities[59]. In addition to using timber waste for energy recovery, some wood is used directly as fuel (or fossil-fuel substitution) for energy supply without serving as timber products. This material called 'wood fuel' has found a significant role in the EU energy system such that the European wood fuel production has raised by 20% from 2009 to 2013[60]. There are, however, concerns that this process is against the waste hierarchy system where energy recovery is only acceptable where there is no possibility for use in the industry. Currently, in the UK, the timber waste recovery rate is between 65-70% of which 35-39% belongs to energy recovery[61]. During 2013 and 2014, Italy re-used 95% of its waste wood to produce particleboard, while Germany holds a 34% recovery rate[62].

The Australian statistics for EfW for timber waste in the C&D waste stream are presented in Table 10. The figures show that EfW in Australia accounts for a small percentage of waste management of timber waste. The aggregated data from all jurisdictions show that only 4.9% and 2.3% of timber waste generated in Australia was energy recovered for all waste streams and C&D waste stream, respectively, in 2016-17. The most successful state in terms of EfW is SA wherein 57,800 (16.9%) of total timber waste was used to generate energy. However, in the C&D waste stream, the largest energy recovery occurred in the ACT and Vic, with 4% and 3.5% of C&D waste energy recovered, respectively.

Table 10. Statistics on timber EfW activities in Australia.

States & territories	C&D stream	Total waste	C&D EfW	Total EfW	%EfW C&D stream	%EfW (total)
ACT	32,558	73,236	1,294	2,086	4.0	2.8
NSW	181,994	762,747	2,735	16,460	1.5	2.2
NT	7,422	13,771	132	246	1.8	1.8
QLD	92,255	413,549	1,861	22,111	2.0	5.3
SA	58,411	342,801	448	57,800	0.8	16.9
TAS	1,491	30,109	35	705	2.3	2.3
VIC	205,967	544,203	7,266	13,206	3.5	2.4
WA	31,873	189,264	398	2,411	1.2	1.3
Total	**611,971**	**2,369,680**	**14,169**	**115,025**	**2.3**	**4.9**

Note: units are in tonnes

[58] DEFRA. Environmental permitting guidance: the waste incineration directive. Report, Department for Environment, Food and Rural Affairs (DEFRA). 2011.
[59] TRADA Technology and Enviros Consulting Ltd. Options and Risk Assessment for Treated Wood Waste. Technical report, TRADA.2005
[60] FAO. 2013 global forest products facts and figures. Technical report, Food and Agriculture Organization of the United Nations; 2013.
[61] Ramage, M.H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D.U., Wu, G., Yu, L., Fleming, P., Densley-Tingley, D. and Allwood, J., 2017. The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews*, 68, pp.333-359
[62] Garcia CA, Hora G .2017. State-of-the-art of waste wood supply chain in Germany and selected European countries. Waste Management. 70:189–197.

7.11 Illegal dumping and stockpiling

Timber waste illegal dumping and stockpiling occurs in Australia. However, there is extremely limited documented evidence that shows the prevalence of this incident in various states and territories. In 2018, a report by FariFax Media[63] unveil the secrete of waste companies that were using Qld recycling facilities to acquire paperwork exempting them from NSW regulations limiting the transport of metropolitan waste (incl. timber waste) by road more than 150 km from its source. Surveillance of Queensland recycling and dump sites by Fairfax Media over several weeks, including access inside one of the facilities on multiple occasions, showed that material tipped off by interstate trucks at the recycling facilities was immediately reloaded into local trucks and taken straight to landfill. The amount trafficked represented up to $70 million in missed waste levy to NSW taxpayers.

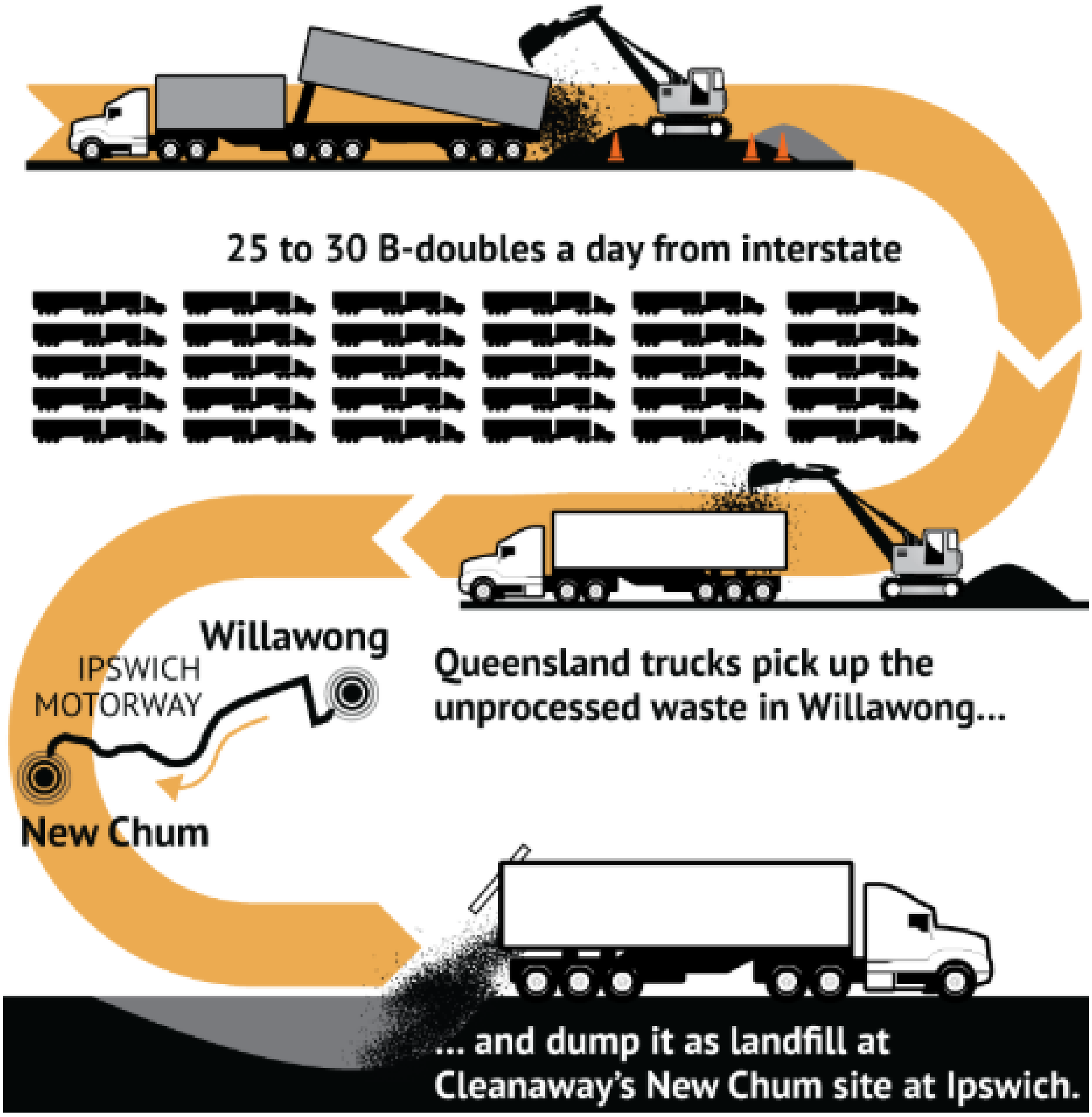


Figure 16. The plan for waste trafficking between Qld and NSW[63].

Graphic: Jamie Brown

[63] Solomons. M. 2018. The Sydney Morning Herald. The heap: Construction waste piled high. CREDIT: FAIRFAX MEDIA. https://www.smh.com.au/national/duped-at-the-dump-recycling-rort-as-the-truth-is-buried-20180219-p4z0v7.html

7.12 Landfill the waste

It is worth noting to know that the landfill is an integral part of the current waste management system in Australia and worldwide. Particularly, low-value timber waste landfilling is slightly preferred over other C&D waste materials for two reasons. Firstly, due to the combustible nature of timber waste, it can produce energy in landfills and, secondly, the contaminated timber wastes containing hazardous components and the ash disposed of from wood-burning have no place but the landfill. However, this trend is to change in future, as evidenced in some nations such as Germany, Sweden and Austria, where restricting policies on landfilling of wood waste are already implemented. Timber waste going to landfill typically consists of various types, including contaminated and non-contaminated waste. Wood waste should be sorted before it is sent to the landfill to determine whether it can be recovered or contains hazardous contaminants. Contaminated timber waste can leach hazardous constituents, such as CCA, and contribute water or soil pollution. Therefore, it is necessary for two designated specific landfills that can accept contaminated timber waste.

One study in Australia[64] demonstrated that per tonne of waste treated, recycling stimulates greater economic activity than landfill for timber waste. However, landfill operations generate less waste per tonne of waste treated than other waste treatments methods. However, this volume of waste is minor compared to the total amount of waste generated in the economy. Table 11 presents the data for timber waste in different Australian states and territories. Vic and NSW had the largest percentage of timber waste that ended up in landfill sites.

Table 11. Estimates for timber waste landfilled and recycled in various Australian states and territories in 2007.

State/territory	000 Tonnes (landfilling)	000 tonnes (recycling)
NSW	345	131
VIC	470	230
QLD	48 (Brisbane only)	20
WA	150-180	10.17
SA	173	255.72
TAS	20	N/A
ACT	17.3	2.35
NT	26	0

Source: Compiled by Taylor and Warnken (2008)

The more recent statistics in 2010/2011 indicated that the quantity of C&D-based timber waste sent to landfill in Australia was 120,2 kt that which is 35% of the gross weight of timber waste landfilled. Engineered timber products are replacing solid timber in a range of applications. The replacement rate is several times higher than solid wood production. It is expected that the volume and proportion of engineered wood products waste will keep increasing and take over the total proportion of C&D waste in landfill. The latest data about timber waste (Table 12) fate showed that a notable amount of timber waste during C&D waste activities ended up in landfill wherein their energy is not even recovered. On average, more than 53% of timber waste in all streams is landfilled in Australia. The rate of landfilling for timber waste from C&D activities is even higher occurring at 62.9%. Among the jurisdictions, NT (98.2%) and Tas (97.7%) had the highest percentage of landfilling for timber waste.

[64] Reynolds, C.J., Piantadosi, J. and Boland, J., 2014. A waste supply-use analysis of Australian waste flows. *Journal of Economic Structures*, *3*(1), 1-16.

Table 12. Timber waste landfilling status in various Australian states and territories.

States & territories	C&D stream	Total waste	C&D landfilled	Total landfilled	%landfilling (total)	% C&D landfilling
ACT	32,558	73,236	31,264	50,390	68.8	96
NSW	181,994	762,747	76,725	461,810	60.5	42.2
NT	7,422	13,771	7,290	13,525	98.2	98.2
QLD	92,255	413,549	90,394	288,680	69.8	98
SA	58,411	342,801	17,963	34,501	10.1	30.8
TAS	1,491	30,109	1,456	29,404	97.7	97.7
VIC	205,967	544,203	138,809	252,303	46.4	67.4
WA	31,873	189,264	20,776	125,829	66.5	65.2
Total	**611,971**	**2,369,680**	**384,677**	**1,256,442**	**53**	**62.9**

8 TIMBER WASTE MARKET

In Australia, recovered wood is used in various applications, although these markets are rather limited[22]. The main uses of recovered wood are landscaping mulch, fuel, salvaged (recycled) timber, animal bedding and recycling into particleboard. The main barriers to developing a market for timber waste as identified by Sustainability Victoria[65] include:

1. securing a cost-effective recycled waste stream due to competing demand for other uses of low-value timber (i.e. markets for mulch and potentially waste to energy).
2. price competitiveness and availability of substitute virgin timber.
3. costs of labour and capital required for suitable source separation

The following section casts some light on the Australian timber waste market.

8.1 Integrated supply chain

The supply chain of timber waste is rarely described in Australia. One example that provides some limited information is provided by Infrastructure Victoria[66]. According to this report, most timber is converted to landscaping mulch and soft-fall, with relatively small quantities going to energy recovery, animal bedding, kitty litter, biochar production and engineered timber products. Some waste timber (10k-20kt/year) from metropolitan Melbourne is being exported to SA for biochar production and composting. Around 30kt/year from metropolitan Melbourne and NSW is transported to the North East region for the production of engineered timber products. There are also limited data regarding the costing of timber waste management. The costing mechanism is largely affected by geographical location and market demand. The following table provides some information about the costing of timber waste in NSW and Vic.

Table 13. Supply chain characteristics of the waste collector

Business name	State	Pricing mechanism	Others
Bingo Industries	NSW and Vic	Recycling: NSW: $200/tonne (incl. GST) Vic: $200/tonne (incl. GST) Disposal: $380/tonne ex (excl. GST), accepted as a general waste	Waste is transferred to landfill or recycling facilities
Infrastructure Victoria report[66]	Vic	Recovery: $40/tonne Upcycling: $30-50/tonne Low value timber: $10-60/tonne.	Waste is recovered or upcycled, low-value timber is sold with low economic viability for recovery

Note: the prices tabulated above are current as of November 2019

[65] Sustainability Victoria. 2014. Market summary – recycled timber. https://www.sustainability.vic.gov.au/-/media/resources/documents/publications-and-research/research/market-analysis/market-analysis-timber-sept-2014-pdf.pdf

[66] Blue Environment Pty Ltd. 2019. Infrastructure Victoria: Victorian waste flows. http://www.infrastructurevictoria.com.au/wp-content/uploads/2019/10/Victorian-Waste-Flows-Blue-Environment-October-2019-FINAL-REPORT.pdf

8.2 Timber lifecycle models

In this section, different lifecycle models proposed in previous literature for timber waste are presented. Two models that are identified are based on industrial ecosystem thinking and EU Waste Framework Directive. In the end, the LowMor model that is adjusted for timber waste is reviewed.

A model based on industrial ecosystem thinking

The analogy is the creation of an 'industrial ecology' that is able to 'digest' the wood waste and return resources for use back into the economy (Figure 17). This model involves a network of collection capacity and infrastructure with the ability to transform the wrong time/place wastes into the right time/place resources. For example, the ability to return boutique recycled materials, provide a feedstock for an engineered timber product, supply animal bedding and recover energy could be part of a region-wide approach to wood waste value-adding. This model emphasises the role of the manufacturer in contribution to the cradle to cradle approach (through schemes such as extended producer responsibility) for management of timber waste.

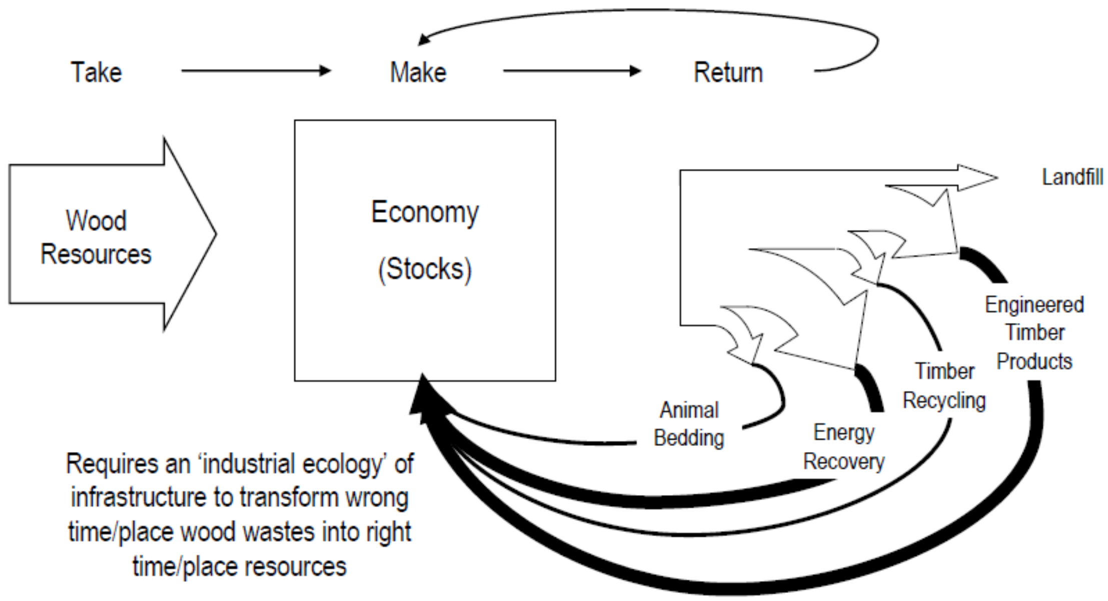


Figure 17. Timber's industrial ecosystem thinking proposed for sustainable Australia.
Source: Taylor and Warnken (2008) [67]

A model based on the EU's Waste Framework Directive

Drawing on the waste management hierarchy issued by the EU waste framework directive in 2008[68], and upcycling principle Ramage et al. (2017) developed a wood waste management conceptual model (Figure 18). This model only considers the end of life of wood in the timber lifecycle. According to this model, there are only three fates for timber waste: re-use, energy recovery or landfill. This model, however, does not primarily distinguish reusing from recycling and upcycling. One interesting concept used in this model, which is on the 'preparing for re-use' principle in the EU's waste framework directive, is the role of design. Timber manufacturers are recommended to design products with ease of disassembly and reusing in mind. Even if timber waste, after one service unit,

[67]Taylor J. and M. Warnken. 2008. Wood recovery and recycling: A source book for Australia. Forest & Wood Products Australia: Knowledge for a sustainable Australia. Market Access & Development: Project Number: PNA017-0708

[68] European Parliament. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.2008.

does not qualify for further use, it can still be reprocessed, as fibrous materials for making new timber products that are recycled.

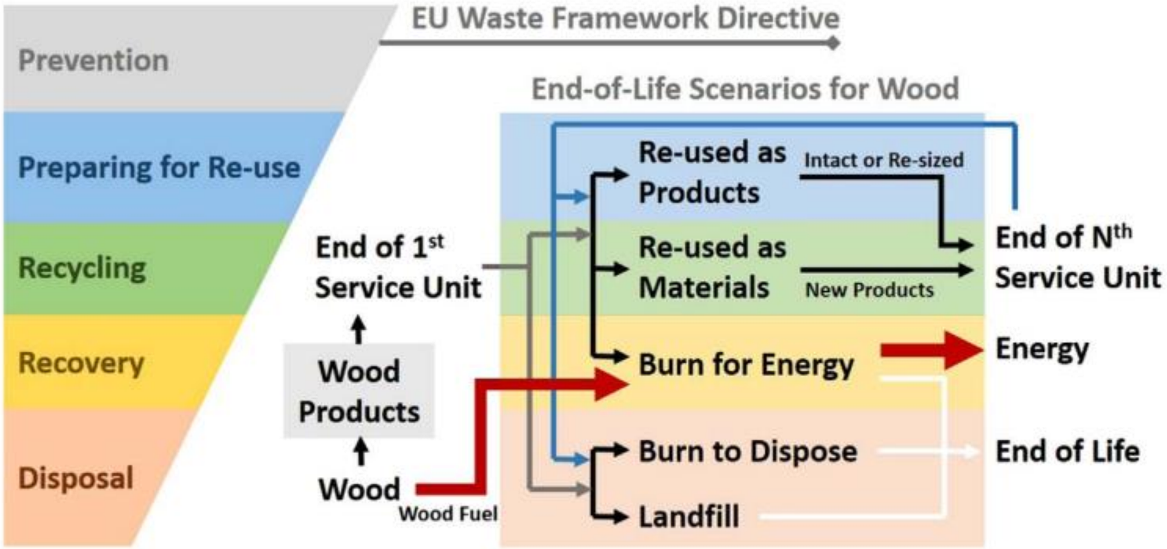


Figure 18. End-of-life scenarios for timber waste.
Source: Ramage et al. (2017).

LowMor model

Emerging from this research project and a review of strategies presented above, LowMore (Figure 19) identified 12 opportunities to manage timber waste. The aim of this supply chain model is to show how various stakeholders can contribute to first minimise and then reduce the volume of waste sent to landfill.

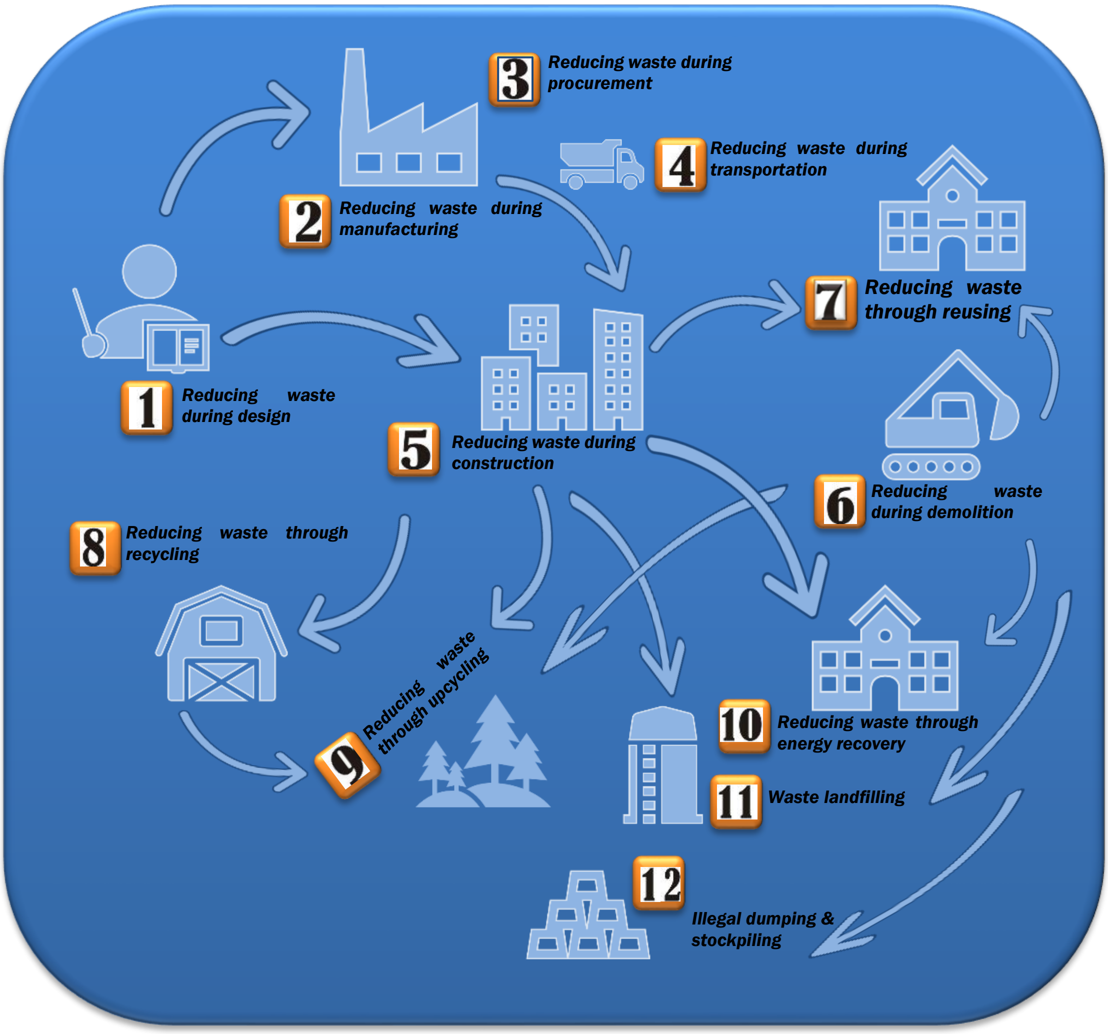


Figure 19. LowMor supply chain model for timber waste management.

Drawing on this model, the role of various stakeholders in the supply chain of timber waste management can be further highlighted.

Table 14. The role of various stakeholders in the effective management of brick waste

No.	Stage	Stakeholder(s)	Contributions
1	Design	Designers, construction firms, clients	• Reuse recycled timber waste in their design • Design a new building to facilitate its re-use in the future • Consider precast timber frames in the designs • Consider building standardisation to improve buildability and reduce the number of offcuts
2	Manufacturer	Manufacturers, recyclers, suppliers	• Develop an agreement where a contractor "sells back" the re-cycled waste from the original material supplier • Participate in the extended producer responsibility and product stewardship schemes • Use new technologies for processing harvested log to reduce wastage
3	Procurement and contract	Construction firms, quantity surveyors, government	• Construction firms should order bricks more accurately using the best take-off practice. • Alter the public contracts (purchasing) for timber waste-based materials used in public projects
4	Transportation & delivery	Construction firms, transporters, recycling companies	• Just-in-time delivery of materials to construction to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions • Do due diligence and exercise standard work practices
5	Construction	Construction firms, sub-contractors, waste collectors, recyclers	• Separate high-value timber waste for further use or recovery • Use nondisposable metal formwork instead of timber one
6	Demolition	Demolition contractors, waste collectors, recyclers	• Consider selective de-construction to maximising the reuse potential of its components. • Provide bulk bags rather than skips to ensure segregation of timber waste from other waste materials
7	Reusing	Construction firms, state and territory governments, EPAs and other equivalent organisations, waste collectors	• Facilitate market development • Adjust specifications in the favour of more usage of timber waste-based materials in new constructions project

8	Recycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Take timber left-overs away to use as landscaping mulch • Facilitate market development • Fund the development of waste energy recovery infrastructure • Adjust specifications in the favour of more usage of timber waste-based materials in new constructions project
9	Upcycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development • Adjust specifications in the favour of more usage of timber waste-based materials in new constructions project • Facilitate market development • Fund the development of waste recovery infrastructure • Find new applications for timber waste
10	Energy recovery	Energy recovery facility owners	• Use technologies that can safely burn low-value contaminated timber waste
11	Stopping illegal dumping and stockpiling	State and territory governments, EPAs and other equivalent organisations	• Reinforce activities that stop illegal dumping and stockpiling • Set stricter regulations with a higher rate of penalty fees to discourage illegal dumping and stockpiling • Strengthen controls over licensed landfill sites
12	Landfill	State and territory governments, EPAs and other equivalent organisations	• Design appropriate landfill levy schemes to discourage high-value timber waste landfilling

8.3 Relevant industry associations

The following table shows various associations, councils and agencies that are potential partners for developing an integrated supply chain life cycle model. These associations have multiple functions through which they can give a boost to the sustainable management of timber waste in Australia. They can bridge the gap between public and private sectors (e.g. manufacturers, suppliers, retailers, contractors etc), raise social awareness and contribute to making fair and well-received policies. Table 15 presents the main industry associations in the timber waste space.

Table 15. Industry associations relevant to the management of timber waste

Title	Scope	Vision	Webpage
Australian Forest Products Association (AFPA)	National	AFPA is the peak national industry body representing the resources, processing, and pulp, paper and bioproduct industries covering the forest products value chain. AFPA represents all elements of the value chain from the sustainable harvesting of plantations and multiple-use natural forest resource including forest establishment and management, harvesting and haulage, processing of timber resources and manufacture of pulp, paper and bioproducts.	https://ausfpa.com.au/
Australian Timber Importers Federation (ATIF)	National	The ATIF is the peak national body representing the business interests of timber and wood-based product importing and wholesaling companies. ATIF represents and advocates for the importing sector of the timber industry in national fora.	https://atif.asn.au
Engineered Wood Products Association of Australasia (EWPAA)	National	The EWPAA is a member association for manufacturers of engineered wood products, particularly plywood, laminated veneer lumber (LVL), particleboard and medium-density fibreboard (MDF).	https://ewp.asn.au/
Forest and Wood Products Australia Limited (FWPA)	National	The FWPA collaborates with government and industry stakeholders to determine strategy, invest in effective and relevant R&D and deliver programs designed to grow the market for forest and wood products, increase productivity and profitability across the value chain and ensure positive environmental and social outcomes	https://www.fwpa.com.au
The Australian Timber Flooring Association (ATFA)	National	ATFA helps Australasia's timber flooring industry to be more profitable, professional and publicised.	https://www.atfa.com.au/

Timber Development Association (TDA)	NSW	The Timber Development Association of New South Wales (TDA) is an industry-funded association representing all segments of the timber industry, from manufacture to supply	https://www.tdansw.asn.au/
Timber Preservers Association of Australia (TPAA)	National	TPAA represents the nation's wood preservation industry. It is made up of timber treaters, preservative suppliers, research organisations, and individuals and bodies having an interest in the production and use of preservative-treated timber	http://www.tpaa.com.au/
The National Timber Product Stewardship Group	National	NTPSG is an initiative of the timber and wood products industry to double the recovery of post-consumer timber and wood products to one million tonnes per year by 2017.	https://www.timberstewardship.org.au/
WoodSolution		WoodSolutions is an industry initiative designed to provide independent, non-proprietary information about timber and wood products to professionals and companies involved in building design and construction	https://www.woodsolutions.com.au

9 RECOMMENDATIONS

- To use non-disposable metal formwork instead of timber one in several construction projects
- To redefine and harmonise timber waste in national and jurisdictional regulations and policies
- To exclude timber waste recovered from construction activities from generic timber waste
- To improve the existing and employing new varieties of machinery instead of old and obsolete one help reducing the wood waste
- To fund the development of waste energy recovery infrastructure particularly those that are able to recover energy from chemically treated timber waste
- To consider precast timber frames in the designs

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