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# TOWARDS SUSTAINABLE TIMBER CONSTRUCTION: A CASE STUDY OF WASTE GENERATION, MANAGEMENT, AND CIRCULAR STRATEGIES IN AUSTRALIAN SAWMILLING AND PREFABRICATION MANUFACTURING.

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**ABSTRACT:** Timber production and construction processes generate substantial wood-based waste, posing significant economic and environmental challenges. This study investigates waste generation and management practices through two case studies in Victoria, Australia, focusing on key stages of the timber supply chain - sawmilling and prefabricated frame manufacturing. The findings reveal substantial residue generation at the sawmill level and high material efficiency in prefabrication through optimised cutting processes. International comparisons highlight opportunities for Australia to enhance sustainability by adopting advanced technologies, integrating residue enhancement practices, and implementing supportive regulatory frameworks. The study advocates for strategies that repurpose timber residues into high-value products and energy sources, emphasising circular economy principles. The study concludes with a set of strategic recommendations to advance toward near-zero waste outcomes in the Australian timber industry.

**KEYWORDS:** timber, sawmilling, prefabrication manufacturing, wood-based waste, circular economy

## 1 – INTRODUCTION

Timber is a fundamental construction material extensively employed in the Australian housing industry. However, substantial amounts of waste are produced across the timber supply chain, especially during forest harvesting, sawmilling, and prefabrication manufacturing processes. According to reports, approximately half of a harvested tree is effectively utilised for timber products, while the remaining volume becomes residual waste [1]. Additionally, sawmilling operations contribute to considerable material loss, with an estimated 45–55% of log volume classified as 'waste' or 'residue' [2].

Furthermore, traditional on-site timber construction often leads to significant waste generation, as offcuts and sawdust commonly end up in landfills, compounding environmental and economic concerns [3]. Prefabrication has gained recognition as a practical solution for waste minimisation in timber construction to address these sustainability issues. By shifting production into a controlled factory environment, prefabrication enhances cutting precision, significantly reduces offcuts, and optimises overall material utilisation [4].

Given the critical importance of sustainable resource management and environmental stewardship in the construction sector, it is essential to address timber waste generated throughout the production process. The study examines two case studies across Victoria, Australia: a sawmill at Yarram and a prefabrication facility at Drouin.

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These case studies offer valuable insights into existing industry practices, highlight current challenges in timber waste management, and discuss innovative approaches implemented to reduce material waste. Findings from these cases support broader sustainability goals by demonstrating effective strategies for utilising timber residues as raw materials or renewable energy sources aligning with circular economy principles within the timber construction sector.

## 2 – BACKGROUND

### 2.1 SAWMILLING INDUSTRY AND WOOD WASTE MANAGEMENT

The Australian sawmilling sector is diverse, comprising mills that vary considerably in scale, technological capabilities, and areas of specialisation. Due to this variability, sawmills exhibit differences in residue generation and management practices, resulting in distinct recovery efficiencies. The Australian sawmilling industry generated approximately 4.4 million cubic metres of timber residues during the 2021–2022 period [5]. The sawmilling sector can be broadly divided into hardwood and softwood sawmilling, with each generating a significant amount of waste during the process. Softwood sawmills typically achieve higher recovery rates of around 47%, while hardwood mills achieve a lower recovery rate of around 39 % [5].

The characteristics of residues, including species composition, moisture content, purity and particle size, play a significant role in determining effective waste management strategies [6]. Common sawmilling residues comprise bark, sawdust, wood chips, offcuts, and shavings, processed during different stages (Figure 1). A wet log processed in a softwood sawmill typically yields residues by weight as follows: 6% bark, 7% sawdust, 5% shavings, and 35% wood chips after debarking [5]. Understanding these residue characteristics and their implications is essential for developing sustainable and efficient resource management approaches in the timber industry.

Sawmills contribute to a circular economy by generating revenue from by-products, reducing landfill waste, and optimising resource use. Figure 2 illustrates an overview of different waste management approaches. Commonly implemented practices include on-site combustion of residues, which provides renewable energy for mill operations and reduces dependency on external energy sources. Wood chips and sawdust are used to manufacture wood-based panels, including plywood, fibreboard, and particleboard [7], or transformed into biofuels such as pellets, briquettes, and bioethanol [8]. Moreover, wood chips are mostly sold or exported for pulp and paper manufacturing, generating additional income for the sawmilling industry [9]. Innovative technologies such as biochar manufacturing and wood-plastic composites promote a more sustainable and resource-efficient sector [10].

### 2.1 PREFABRICATION INDUSTRY AND WASTE REDUCTION

Prefabrication in construction involves manufacturing building components off-site in controlled factory settings before transporting them to construction sites for assembly [11]. In timber-frame construction, this process typically includes the production of elements such as wall frames, roof trusses, and floor cassettes [12]. Driven by industry demands for increased construction speed, labour efficiency, quality control, and sustainability, prefabrication has become increasingly prevalent within the Australian construction sector [13]. A key environmental advantage of this approach is the substantial reduction of construction waste.

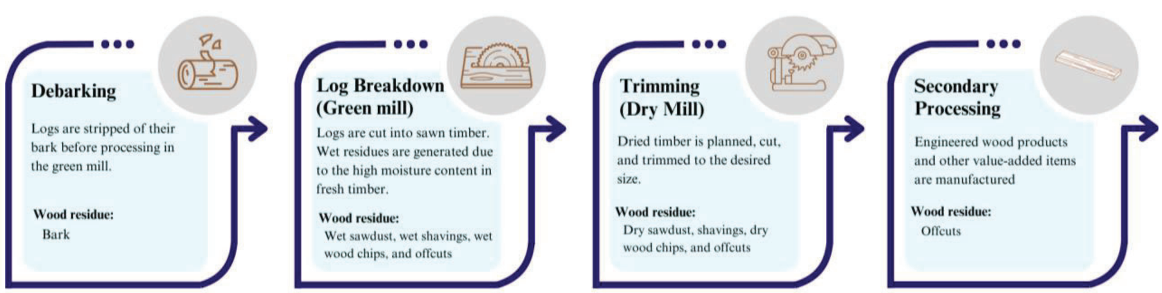


*Figure 1: Wood residues produced in different sawmilling processes*


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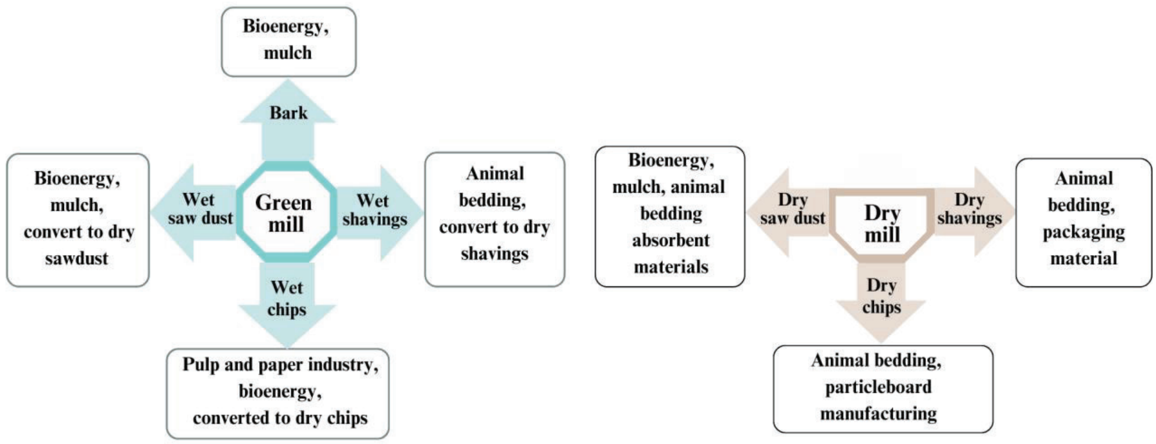


*Figure 2: General wood waste management practices*

Utilising computer-aided design (CAD) software coupled with precision-cutting machinery, such as Computer Numerical Control (CNC) saws, timber is accurately cut to exact dimensions, significantly minimising offcuts and optimising material usage.

Waste generated in prefabrication facilities typically consists of clean timber residues, making it considerably easier to separate and recycle compared to traditional on-site construction waste. To effectively manage these residues, prefabrication plants frequently establish structured recycling practices, such as reusing longer timber offcuts for structural applications like blocking and bracing. In Australia, numerous frame and truss manufacturers actively participate in recycling initiatives, using designated collection bins for offcuts and wood-based sheet scraps [14]. These recycled wood chips subsequently become essential raw materials in manufacturing particleboard and other engineered wood products.

Advanced prefabrication facilities further enhance sustainability by incorporating internal recycling technologies, such as on-site grinders and chippers that process scrap lumber into reusable wood chips. Additionally, innovative techniques such as finger-jointing have become increasingly prominent. Finger-jointing involves machining smaller wood offcuts into interlocking segments that are then bonded to form longer, structurally sound timber sections [15]. This practice not only significantly reduces timber waste but also contributes economically by transforming low-value offcuts into higher-value structural components, supporting the broader objectives of a circular economy.

## 3 – METHODOLOGY

This research utilised a qualitative case study methodology, enabling an extensive and detailed analysis of timber waste generation, management, and reduction practices within the Australian timber industry. Two representative case study sites in Victoria, Australia, were selected to provide comprehensive insights into critical stages of the timber manufacturing supply chain. The first case involved a regional sawmill located in Yarram, focusing on hardwood timber processing and associated residue management practices. The second case was a prefabrication manufacturing facility at Drouin, specialising in timber frame and truss production, highlighting waste reduction techniques and operational efficiencies within factory-based construction.

Data collection for both cases included structured site visits, detailed operational observations, and semi-structured interviews conducted with facility managers and technical personnel. These methods facilitated an in-depth understanding of each site's operational processes, resource management strategies, and existing waste management protocols. Observations specifically targeted the documentation of material flow, identification and quantification of various waste streams, and evaluation of current practices for waste minimisation, recycling, or reuse.

# 4 – CASE STUDIES

## 4.1 CASE STUDY 1: SAWMILL AT YARRAM, VICTORIA, AUSTRALIA

**Overview and Processing Operations**

The sawmill located at Yarram, Victoria, is a mid-sized hardwood processing facility equipped with a dedicated hardwood mill, a drying kiln, and a veneer plant. The facility specialises in producing high-quality timber products such as cladding, screens, and battens, utilising various hardwood species, including Silver Top Ash, Yellow Stringybark, Red Gum, Spotted Gum, and Blue Gum. Notably, the mill processes relatively small-diameter logs, averaging around 350 mm, which are typically overlooked by conventional sawmilling operations. This promotes more sustainable forestry practices through the effective utilisation of younger trees.

The processing sequence begins with debarking, where the bark is separated and collected as a distinct residue. Logs are irrigated prior to sawing to maintain a moisture content of 70–80%. The Green Mill employs radial sawing—a technique that cuts logs into eight wedge-shaped sections radiating outward from the centre. These wedges are then ripped into boards of varying thicknesses.

During the site visit, radial milling was observed to offer several advantages over conventional methods. It optimises material yield and minimises waste, achieving recovery rates of around 53% while also improving dimensional stability and reducing deformation to approximately 1.2–2%. The technique enables the processing of younger hardwoods, typically aged 15–20 years, thereby reducing reliance on older, larger logs and supporting more sustainable forestry practices. Although more time-intensive than traditional methods, radial milling was noted to require lower capital investment, making it a cost-effective option for mid-sized sawmills.

Following the initial milling, sawn timber boards are sorted by dimension and sticker-stacked to ensure uniform drying. This air-drying phase typically lasts seven to ten weeks. Timber is then kiln-dried for approximately two weeks to achieve a final moisture content of around 20%. Post-drying, secondary milling is carried out based on customer specifications, after which the products are packaged for distribution.

**Waste Generation and Management**

Several distinct residue streams emerge during production, including wood chips, sawdust, bark, shavings, and veneer trimmings. Offcuts account for approximately 11–13% of the total processed timber volume, while sawdust contributes an additional 13–17%. Bark residues are primarily repurposed for landscaping and bioenergy applications. Offcuts are chipped to produce wood chips, which can then be used in various industrial applications. Wet sawdust, wood shavings, and chips are collected daily and stored in shaded areas to prevent excessive moisture absorption, maintaining their suitability as feedstock for biochar production. The on-site biochar plant, a key innovation currently under trial, transforms sawdust, shavings, and chips generated from both the green mill and dry mill. According to operators, the plant requires approximately 30 litres of diesel to initiate combustion; however, once it reaches operating temperatures between 450°C and 500°C, the process becomes self-sustaining. The conversion process takes around 17 minutes and achieves a recovery rate of approximately 50%. Specifically, each tonne of processed waste yields about 0.5 tonnes of biochar and approximately 3.5 litres of wood vinegar. In addition to producing biochar, the facility hopes to generate electricity that is potentially suitable for charging sodium-nickel chloride batteries. Wood vinegar, captured as a by-product through vortex cooling, shows promise as a natural pesticide in agricultural applications. Liquid tar, another by-product, also has potential for future industrial use, reflecting the facility's broader commitment to sustainable waste utilisation and circular economy principles.

The veneer plant, currently in its pilot phase, is designed to process second-thinning logs, which are typically considered forest waste, into veneer sheets. Thin sheets are peeled from the logs, then glued and pressed into finished products. Energy generated from the biochar plant is used to power the drying and pressing process, further supporting sustainable operations.


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(a) (b)

*Figure 3: (a) Chipping of timber offcuts for reuse (b) Covered storage of collected wood waste*

## 4.1 CASE STUDY 2: PREFABRICATION YARD AT DROUIN, VICTORIA

### Overview and Processing Operations

The prefabrication facility located at Drouin, Victoria, specialises in manufacturing timber frames and trusses, predominantly serving residential and light-commercial construction sectors. The facility focuses on producing high-quality panelised building components, including wall frames, wall systems, roof trusses, and floor cassettes. Operations within the facility involve a combination of automated technologies and manual processes designed to optimise precision, quality, and production efficiency.

Structural components are designed utilising advanced Computer-Aided Design (CAD) software, which provides detailed three-dimensional models. The optimisation software uses these digital models to accurately calculate timber dimensions for elements like studs, plates, noggins and truss webs, significantly reducing material waste and offcuts.

One notable piece of equipment used at the facility is the WEINMANN multifunction bridge station, primarily employed for wall system manufacturing. This advanced machine integrates automated cutting processes, laser projection technology, and assembly systems, thereby significantly reducing human measurement errors and enhancing consistency and overall production accuracy. While truss elements within floor cassettes are precisely cut using automated machinery, the sheathing components undergo manual cutting. Subsequent assembly tasks, such as nailing and applying plate connections, are performed manually and guided by laser projection systems that ensure precise alignment during the installation of tongue-and-groove boards onto the floor trusses. The adoption of these advanced systems notably enhances production efficiency and contributes significantly to waste minimisation.

### Waste Generation and Management

Despite the high level of process optimisation and advanced machinery employed, some level of timber waste generation remains inevitable within the prefabrication operations. The primary types of residues generated at the facility include timber offcuts, sawdust, and rejected lumber due to defects such as knots or splits. However, the extent of sawdust production is considerably low owing to the predominance of straight-cutting methods enabled by modern saw technology.

Overall, the facility generates approximately 2–3% timber waste relative to total material input, demonstrating an effective level of waste minimization. Although detailed records specifically outlining waste volumes are not rigorously maintained, facility assessments primarily depend on automated machine-generated data to estimate waste streams.

The facility actively seeks to repurpose timber offcuts internally. Defective or unsuitable timber pieces initially rejected due to structural imperfections, such as large knots or splits, are commonly repurposed within the facility as temporary bracing during the transportation of prefabricated panels, particularly for larger openings that require additional structural support. Smaller timber offcuts, not suitable for structural applications, are typically collected for alternative uses such as packaging, storage support, and transport stabilisation of completed roof and floor trusses.

Due to regulatory restrictions, the on-site burning of timber residues is prohibited. Consequently, the management of generated timber waste represents an operational and commercial challenge, necessitating partnerships with third-party processors who purchase and subsequently process these residues into usable products.

The potential of producing additional value-added products, such as engineered panels or bioenergy, was evaluated during the site visit. However, it was concluded that the relatively small volume of generated residues was insufficient to justify the significant investments required to establish these secondary processing facilities economically. Additionally, options like pallet production were deemed financially non-viable due to limited demand and high labour costs associated with their manufacture.

Overall, the prefabrication facility at Drouin exemplifies effective timber waste management practices through strategic reuse and efficient operational practices. It highlights the importance of continued innovation and strategic partnerships in managing waste sustainably and economically, reinforcing broader industry sustainability objectives within the Australian timber construction sector.

## 5 – INTERNATIONAL BENCHMARKING AND STRATEGIC EVALUATION

### 5.1 TIMBER RECOVERY RATES AT SAWMILLS

Timber recovery rates serve as an indicator of sawmill efficiency, reflecting the percentage of lumber recovered from raw logs during the sawing process. While Australian sawmills typically achieve timber recovery rates ranging from 39% to 45%, the case study achieved a notably higher recovery rate of approximately 53% due to its efficient milling methods. Comparatively, global sawmill recovery rates exhibit significant variations, as shown in Table 1.

These international differences in recovery rates can be attributed to multiple interrelated factors. Technological advancements such as advanced scanning equipment, automated cutting systems, and precision sawing can significantly enhance lumber yield. Sawing techniques like radial sawing, quarter sawing, and optimised log positioning also heavily impact recovery rates. Species characteristics and log quality, including log diameter, taper, moisture content, and defects, considerably influence the overall recovery. Lastly, operational expertise, including skilled operator decisions and effective training programs, remains critical to maximising timber yield. Adopting international best practices will offer substantial environmental and economic benefits to Australia. For instance, enhanced log scanning, advanced sawing techniques, and better residue utilisation could improve recovery rates, dramatically reducing timber residues and enhancing resource efficiency [16].

*Table 1: Global comparison of timber recovery rates and influencing factors*

| Country/ Region | Recovery Rate (%) | Key Factors | References |
|---|---|---|---|
| Romania | ~71 | High recovery due to precise kerf widths, optimal lumber thickness, and superior log quality. | [17] |
| Philippines | ~ (39 – 52) | Bandsaw milling significantly outperforms chainsaw milling in recovery efficiency. | [18] |
| Ethiopia | ~ (43 – 56) | Quarter sawing of larger logs yields better recovery than through-and-through sawing of smaller logs. | [19] |
| USA | ~ (50 – 52) | Technological improvements in sawing have contributed to moderate recovery rates. | [20] |

### 5.2 PREFABRICATION AND TECHNOLOGICAL INTEGRATION

The prefabrication facility at Drouin, Victoria, showcases advanced use of CAD and CNC machinery, achieving material wastage rates as low as 2 to 3 percent. In comparison, countries like Germany, Austria and Sweden have adopted more extensive Industry 4.0 technologies, including robotic assembly, laser projection systems and digital twins, further enhancing precision, productivity and sustainability [21].

Although Australia is technologically well-positioned, greater integration of automated residue processing and resource recovery systems remains limited. Broader adoption of such technologies, supported by strategic incentives, industry partnerships and targeted training, could significantly strengthen both environmental and economic outcomes in the prefabrication sector.

### 5.3 RESIDUE MANAGEMENT

Residue management in Australia varies considerably due to regional market conditions and limited infrastructure. Wood chips are primarily exported, while some sawmill residues are repurposed locally for bioenergy and mulch. Australia lacks the integrated systems seen in countries like Germany, Sweden and Canada. These countries have established advanced approaches that convert residues into high-value outputs, including bioenergy [22] and engineered wood products such as laminated veneer lumber (LVL) and cross-laminated timber (CLT) [23].

Developing domestic and international markets for engineered timber products and bioenergy derived from residues could diversify revenue streams, mitigate market risks, and improve overall industry profitability [24].


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### 5.4 POLICY AND REGULATORY ANALYSIS

Australia currently lacks the comprehensive and integrated regulatory frameworks observed in Europe. European Union policy frameworks emphasise the integration of Industry 4.0 technologies across manufacturing sectors through coordinated national strategies and supportive regulatory environments. These approaches focus on enhancing digital transformation, promoting efficient resource utilisation, setting clear innovation targets, and providing strong incentives for industrial modernisation and sustainability efforts [21]. Australian policy can benefit significantly from adopting similar regulatory frameworks that standardise residue management practices, incentivise advanced technological investments, and encourage industry-wide collaboration towards sustainability.

### 5.5 SUSTAINABILITY AND CIRCULAR ECONOMY

Sustainability within the timber industry extends beyond resource utilisation and includes comprehensive circular economy practices aimed at minimising environmental impact and maximising resource efficiency. Globally, advanced circular economy models are prevalent in countries like Sweden and Germany, which promote extensive reuse, recycling, and recovery of timber residues, supported by strong policy frameworks and market-driven initiatives [24, 25]. These countries effectively incorporate timber by-products into secondary industries such as bioenergy, particleboard production, and engineered wood products, thereby significantly reducing waste streams and enhancing sustainable resource management.

To transition towards similar sustainable practices, Australia must prioritise policy-driven incentives and industry collaborations that encourage innovation in residue utilisation and recycling technologies. Establishing integrated supply chains and fostering collaborative platforms between sawmills, prefabrication plants, and secondary processing facilities can substantially reduce waste, increase economic returns, and support environmental goals. Adopting internationally recognised circular economy frameworks, combined with increased technological investments and comprehensive workforce training, will enable the Australian timber industry to align closely with global sustainability standards, achieving both ecological and economic resilience.

## 4 – DISCUSSION AND RECOMMENDATIONS

The findings from the case studies highlight substantial opportunities to improve sustainability across Australia's timber supply chain, particularly through enhanced waste management at the sawmilling and prefabrication stages. Based on these insights, the following recommendations are proposed to support more efficient resource use and reduce the environmental footprint of the sawmilling industry as in Figure 4.

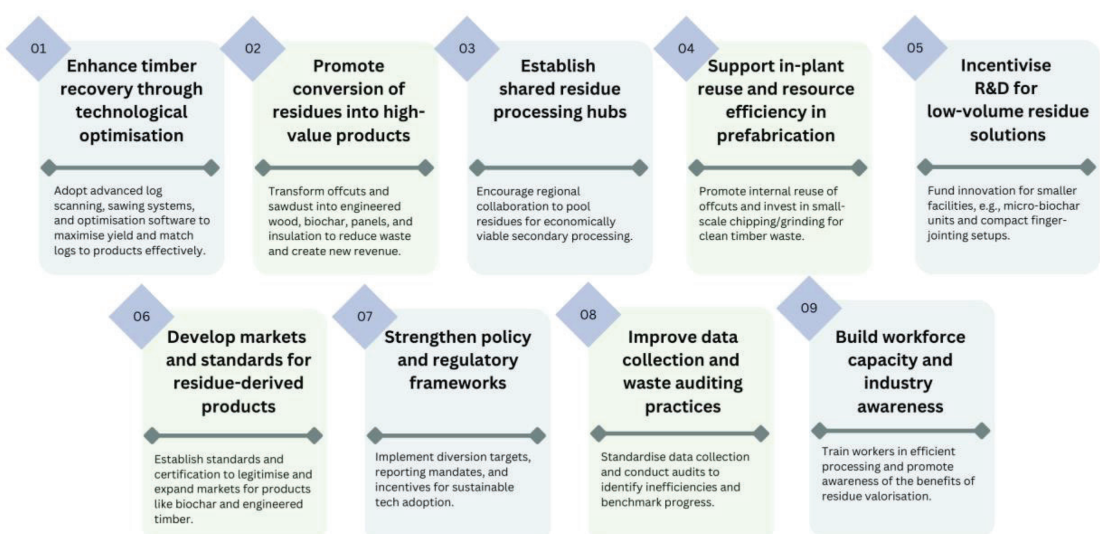


*Figure 4: Strategic Recommendations for Enhancing Timber Recovery and Residue Utilisation in the Australian Industry*

## 6 – CONCLUSION

This study highlights the significant potential to improve sustainability across Australia's timber industry through targeted waste reduction strategies. The Yarram sawmill demonstrates how radial sawing, the use of small-diameter logs, and biochar production can enhance material recovery and reduce environmental impact. Similarly, the Drouin prefabrication facility illustrates how digital design, optimisation software and precision cutting contribute to efficient material use and waste minimisation.

These case studies show that integrating innovation and effective residue management can deliver both environmental and economic benefits. By adopting best practices and technologies and aligning with international advancements, Australia's sawmilling and prefabrication sectors can progress towards near-zero waste, supporting national objectives around sustainability, emissions reduction and circular economy development in the construction and forestry industries.

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