ANALYSING MANUFACTURING WASTE IN THE ILLAWARRA AND SHOALHAVEN FOR SUPPLY CHAIN AND BUSINESS INNOVATION

FINAL REPORT

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Contents

APR FINAL REPORT TEMPLATE

SUMMARY OF PROJECT

Manufacturing industries have been traditionally known for their linear production supply chain model of take-make-dispose. However, with the recent implementation of the Chinese national sword policy and shifts in consumer behaviour, manufacturing companies are evolving to rethink design and production, due partially to the impact on the environment but primarily due to the high costs of disposal[1].

Australia's manufacturing sector has over the years been the largest contributor to the country's gross domestic product (GDP) and the largest employer[2]. In regional areas, manufacturing companies have been documented to be the highest employer and contributor to the regional economy of most states. In New South Wales, the third largest economy in the state is the Illawarra and Shoalhaven region which houses 954 manufacturing companies, employing 10,000 people in the regional areas[3]. In this region, the dominant industries have been steel manufacturing and fabrication, aluminium fabrication and mining. While these industries have large volumes of waste, they already have established circular material flows.

In order to facilitate increased diversion of waste from landfill the Illawarra Shoalhaven Joint Organisation (ISJO) partnered with the University of Wollongong to undertake research on other large industry sectors and their logistics and supply chains.

15% of the total manufacturing companies in the ISJO region comprise of kitchen joineries and cabinet makers. Over a series of interviews and correspondence with joineries and cabinet makers in the region, this research identified the amount of waste medium density fibre board (MDF) and particleboard (PB) produced each fortnight ranges from $7m^3$ to $15m^3$. Averaging these figures, $11m^3$ of waste is produced fortnightly across the kitchen and joinery sector accumulating to around $42{,}042m^3$ annually. Further tours and observations of work sites confirmed kitchen joineries and cabinet makers waste stream as the largest clean waste stream.

Disposal of waste MDF, PB and sawdust is either landfilled, used as waste to energy in an industrial setting (dependant on EPA regulations) or exported as a processed engineered fuel. While waste to energy reduces the amount of waste to landfill, it limits any other use of the material as a resource. Therefore, to address this gap, this research undertook a qualitative methodology to develop a scenario-based business model illustrating the highest realised net value when waste MDF, PB & sawdust is diverted from landfill Interviews were conducted with 28 kitchen joinery and cabinet making business owners, major suppliers of MDF & PB into the Illawarra and Shoalhaven region and business owners/managers, academics and experts in different manufacturing industry to capture a holistic view on the costs, challenges, disposal practices and flows of waste.

Over a period of five months, desktop research, interviews and site inspections were conducted identifying the following scenarios for diversion from landfill. These scenarios are presented in order of possible implementation with all requiring a centralised collection and processing centre.

[1] C Foley & K McLean, 'The Australian manufacturing industry is not dying, it's evolving CSIRO study', The Conversation, 2016, <http://theconversation.com/the-australian-manufacturing-industry-is-not-dying-its-evolving-csiro-study-69398>, viewed 2 March 2020.

[2] Productivity Commission 2003, Trends in Australian Manufacturing, Commission Research Paper, AusInfro, Canberra

[3] Regional New South Wales, Western Sydney and Illawarra Shoalhaven Roadmap to Collaboration, Regional New South Wales, <https://isjo.org.au/assets/4c28918964/Western-Sydney-and-Illawarra-Shoalhaven-Roadmap-to-Collaboration>, viewed 2 March 2020.

- **Processing of MDF, PB and sawdust into a fuel**. Converting this material into fuel is the easiest and cheapest means to divert this material from landfill making it currently the Highest Realised Net Value (HRNV) for waste MDF, PB and dust.

- **The manufacture of new PB using waste PB**. Interviews with two of the three onshore PB manufacturers confirmed 20% of waste PB can be remanufactured back into new PB. Interviews confirmed companies have established the logistics for the collection of this waste for remanufacturing, however in this region it is currently only the collection of a small amount of construction PB,

- **Development of a composite material**. Mechanical processing technology developed by the University of New South Wales (UNSW) offers the opportunity in mixing waste MDF, PB & sawdust with waste glass, plastic or textile to form a composite material that has many potential uses. The glass, plastic or textiles form a seal over the waste engineered timber and also offer an aesthetic finish. Testing is still being carried out to determine weight bearing and water holding capabilities as well as emissions from drilling or cutting the material once sealed.

- **Recovery of fibres from waste MDF through MDF Recovery technology**. A UK based company, MDF Recovery has developed a patented concept to recover fibres from waste MDF. Through email exchange with the company director, it is understood that the technology has been developed in line with requirements from manufacturers and is nearing commercialisation in the EU.

While these scenarios could be applied in theory, the major challenges inhibiting the reprocessing of waste MDF, PB and sawdust include logistics, composition of the material and legislative drivers. Most board manufacturers are located in regional areas resulting in barriers for the collection and transport of waste from individual sites. The materials themselves are composites of timber, melamine, and contain formaldehyde-based resins as binding agents leading to complexity in recycling. Finally, NSW is currently reviewing legislation that could help drive commercial and industrial businesses to consider their waste, innovation in resource use and management of materials at end of life.

This research sits as a unique opportunity to provide manufacturers with alternatives to landfill which in turn provide them with an improved triple bottom line. Currently, it is conservatively estimated to be costing local cabinet makers and joineries over $1.4 million per annum for the collection and disposal of EOL MDF, PB and sawdust. Beyond extending the life of local landfills, a circular approach to waste management provides employment (9.2 full time equivalents (FTE's) per 10,000 tonnes of waste diverted from landfill versus 2.8 FTE's through landfilling[4]; efficient resource use; opportunities for innovative partnerships; and flow on effects to the local economy. This issue is not unique to the ISJO region or to cabinet makers and joineries specifically. Scenarios presented through this research provide a scalable opportunity for other regions and manufacturing industries utilising MDF and PB.

SUMMARY OF RESEARCH

LITERATURE REVIEW

Manufacturing industries have been traditionally known for their linear production supply chain model of take-make-dispose. However, with the recent implementation of the Chinese national sword policy and change in consumer behaviour, most manufacturing company's' have had to adapt and rethink better ways of designing and producing their products, due to the impact to the environment and high costs of disposal.

[4] Access Economics, Employment in waste management and recycling, commissioned by the Department of Environment, Water, Heritage and the Arts, <https://www.environment.gov.au/protection/waste-resource-recovery/publications/employment-waste-management-and-recycling> viewed 3 March 2020

Manufacturing in Australia peaked in the 60's, where the industry contributed to 25% of the country's gross domestic product (GDP) and employed over 1 million people[5]. Over the years the sector has fallen due to high wages, geographical remoteness and change in consumer consumption, dropping the country's GDP from manufacturing by 18.95% and employing 856,000 people. Experts suggest that unless manufacturing industries across Australia transform into highly integrated, collaborative and export-focused "ecosystem" that provides high-value customised solutions contributing to global supply chains over the next 20 years, the country can expect a further drop in its GDP[6].

Anecdotally in NSW, the export of manufactured goods has been growing by 7.5% annually with over 30% registered manufacturing businesses accounted for, higher than any other state or territory. In regional NSW, leading manufacturers are thriving and attracting international manufacturing companies due to presence of skilled local workforce, low-cost environment, ease of access to markets and world –class research and development centres[7]. By the end of the 2018-2019 financial year, the manufacturing sector in regional NSW contributed $9.5 billion to the Australian economy and employed 89,600 people[8].

Therefore, despite well publicised closure of some manufacturing sectors and supporting literature over the years exploring similar angles of the phasing out of manufacturers across Australia[9], exports, GDP growth and trends around the world indicates otherwise. A study by CSIRO determined the Australian manufacturing sector is undergoing a period of significant change as new, disruptive technologies, changes in consumer behaviour and economic realities take hold of new emerging markets[10].

Also, review of literature on manufacturing sectors in Australia show that most industries mainly focused on improving supply chain efficiency and reducing costs[11] [12]. This is necessary and important for companies to consider with the increase in demand for consumer goods in a fast-growing world population. Globally behaviour studies and trends show consumption shifting from buying easily available products to prioritizing products from companies with

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[5] Productivity Commission 2003, *Trends in Australian Manufacturing,* Commission Research Paper, AusInfro, Canberra

[6] Foley, C & McLean K, *'The Australian manufacturing industry is not dying, it's evolving CSIRO study',* The Conversation, 2016, < http://theconversation.com/the-australian-manufacturing-industry-is-not-dying-its-evolving-csiro-study-69398>, viewed 2 March 2020.

[7] New South Wales Office of Regional Economic Development, *Advanced Manufacturing: A Thriving and Innovative Sector,* Dubbo, New South Wales Office of Regional Economic Development, 2019, https://www.investregional.nsw.gov.au/sectors/advanced-manufacturing, viewed 02 March 2020.

[8] Department of Foreign Affairs and Trade, *Where NSW manufactured products are exported to - country and TRIEC pivot table 1990 to 2018,* October 2019, Barton, <https://www.dfat.gov.au/about-us/publications/Pages/trade-statistical-pivot-tables.aspx>, viewed 02 March 2020.

[9] J Ramsey, 'GM kills Holden', *autoblog*, 17 February 2020, < https://www.autoblog.com/2020/02/17/gm-kills-holden-brand-australia> , viewed 3 March 2020.

[10] Foley, C & McLean K, *'The Australian manufacturing industry is not dying, it's evolving CSIRO study',* The Conversation, 2016, < http://theconversation.com/the-australian-manufacturing-industry-is-not-dying-its-evolving-csiro-study-69398>, viewed 2 March 2020.

[11] R Mohanty & A Prakash, 'Searching for definitions and boundaries in sustainable production system', *International Journal of Services and Operations Management*, vol. 27, no. 1, p. 122-143.

[12] J Hagel, J Brown, D Kulasooriya, C Giffi & M Chen,' The future of manufacturing – making things in a changing world', *Future of the Business Landscape*, Deloitte University Press, Westlake, OH, p. 4-18.

social and environmental objectives. This is evident in countries that have prescriptive supporting legislation[13] [14]. As a result, manufacturers globally have redesigned supply chains from a push-centric model to a social and legislative pull. This has led to significant changes in operating business models of water usage, energy consumption and negative social and economic impacts, specifically waste produced across the supply chain[15]. More companies are implementing zero waste or circular economy business models, initially to increase competitiveness in the market but soon after as means of cost savings and optimization of daily operation[16] [17]. There are examples of major manufacturing industries as well as smaller, emerging and niche businesses implementing sustainable change to remain competitive.

As previously noted, waste circularity exists in major manufacturing across the region in the steel, aluminium and mining sectors. However, literature and the regional industry profile indicates a significant volume of manufacturing waste generated outside of these larger circular sectors. Regional data from the Australian Business Registry (ABR)[18] aligned with a regional project identifying cabinet makers and joinery businesses as a large industry sector. There was limited academic literature confirming the volume and type of waste generated from these businesses however industry reports indicated MDF and PB as the primary outputs. This material type was also identified as a significant waste output from the residential hard waste stream.

Internationally, literature identified that MDF and PB recycling is a global problem with majority of its waste sent to landfill or incinerated for fuel. In the United Kingdom (UK) for example, around 350,000 tonnes of manufacturing offcuts and discarded products are being burned or sent to landfill every year[19].

With more than 87% of MDF and PB manufactured locally in Australia[20], there are limited alternative pathways to divert waste PB from landfill. Industry websites document that there are recycling opportunities for PB through large board manufacturers[21] however, this is more commonplace for construction PB with no surface finish and limited opportunities exist for smaller cabinet makers and joineries. There are only two options for MDF, landfill and waste

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[13] R Haapala, F Zhao, J Camelio, W Sutherland, J Skerlos, A Dornfeld, S Jawahir, A Clarens & J Rickli,' A review of engineering research in sustainable manufacturing', *Journal of Manufacturing Science and Engineering,* vol. 135, no. 4, p. 41013-41029.

[14] D Allen, D Bauer, B Bras, T Gurowski, C Murphy, T Piwonka, P Sheng, J Sutherland, D Thurston & E Wolf, 'Environmentally benign manufacturing: trends in Europe, Japan, and the USA', *Journal of Manufacturing Science and Engineering*, col. 124, no. 4, p. 908-920.

[15] A Shamraiz & K Yew Wong, 'Sustainability assessment in the manufacturing industry: a review of recent studies', *Benchmarking*, vol. 25, Iss. 8, 20018, p. 3162-3179.

[16] J. P Wilson, ' The triple bottom line: Undertaking an economic, social and environmental retail sustainability strategy', *International Journal of Retail & Distribution Management*, vol. 43, no. 4, p. 432-447.

[17] C Gimeniez, V Sierra & J Rodon, 'Sustainable operations: their impact on the triple bottom line', *International Journal of Production Economics, vol. 140, no. 1, p. 149-159.*

[18] Australian Bureau of Statistics, *Australian and New Zealand Standard Industrial Classification (ANZIC) 2006*, cat.no.1292.0.55.002, ABS, Canberra, 2006, < https://www.abs.gov.au/ausstats/abs@.nsf/mf/1292.0>, viewed 17 January 2020.

[19] M Frost, 'MDF recycling solution is a world first for British Firm', *The Daily Express,* 15 March 2017, <https://www.express.co.uk/finance/city/779497/MDF-Recovery-recycling-solution-world-first-British-firm>, viewed 03 March 2020.

[20] Industry Edge, *Residential Flat-Pack Joinery Import Market Study*, Forest & Wood Products Australia, October 2017,<https://www.fwpa.com.au/images/Newsletter_Images/Statistics-count/2017/Flat-Pack_Joinery_Imports_Market_Study_Final_Oct2017.pdf>, viewed 05 April 2020.

[21] The Design Partnership, Response to submissions timber processing facility (Particle Board), https://www.borgmanufacturing.com.au, December 2016, <https://www.borgmanufacturing.com.au/documents/oberon/1.%20RTS.pdf>, viewed 25 May 2020.

to energy[22][23]. Industry reports document this material type as having a high calorific value and suitable as an input to Process Engineered Fuel (PEF)[24]. In Australia currently, there are limited end market opportunities for PEF and a fluctuating export market[25]. Due to restricted data availability for this material type, this research could not quantify the volume or weight of MDF or PB being diverted from landfill as PEF.

Desktop analysis of international best practice and interviews with experts and local timber manufacturing businesses in the Illawarra and Shoalhaven region, further inform the viability of implementation of a business model with the highest realised net-value and demand for the recovered waste products.

PROJECT BACKGROUND

Over the past quarter century, the consumption trend of medium-density fibreboards (MDF) and particleboards (PB) has been on the rise. In the past 5 years alone, the Food and Agricultural Organisation (FAO) reported over 200 million m^3 was produced across the world[26] with over 80% of the production used in the construction and furniture sectors[27]. The model in figure 1 below show trends of MDF and PB consumption over the years with closed diamonds being actual data whereas open green diamonds populated at the bottom of the graph are by predicted values based on 1995-2016 trends on the consumption in the mid 70's to mid-90's[28].

[22] Wood Based Panels International, '*Recycling MDF: are we there yet?*', Wood Based Panels International, England, March 2012, < https://www.wbpionline.com/features/recycling-mdf-are-we-there-yet/> , viewed 02 April 2020.

[23] P Beele, *Demonstration of end uses for recovered MDF fibre*, Waste Resources Action Program (WRAP), Germany, 07 September 2009, pp. 9, <http://www.mdfrecovery.co.uk/wordpress/wp-content/uploads/2015/02/WRAP-MDF_Recycling_-_demonstration_of_end_uses.pdf>, viewed 15 April 2020.

[24] Wood Solutions, *Environmental Product Declaration: Medium Density Fibreboard*, Forest and Wood Products Australia Limited, Canberra, December 2017, <https://www.woodsolutions.com.au/search/site/MDF>, viewed 07 February 2020.

[25] B Sawley, *The future of high-quality PEF*, Sustainability Maters, 30 September 2019, <https://www.sustainabilitymatters.net.au/content/waste/article/the-future-of-high-quality-pef-1015771305>, viewed 25 May 2020.

[26] Food and Agricultural Organisation, *Forestry Production and Trade,* FAOSTAT, 2015, h <http://www.fao.org/faostat/en/#data/FO/visualize>, viewed 18 March 2020.

[27] P Beele, *Demonstration of end uses for recovered MDF fibre*, Waste Resources Action Program (WRAP), Germany, 07 September 2009, pp. 9, <http://www.mdfrecovery.co.uk/wordpress/wp-content/uploads/2015/02/WRAP-MDF_Recycling_-_demonstration_of_end_uses.pdf>, viewed 15 April 2020

[28] M Irle, F Privat, G Deroubaix & C Belloncle, 'Intelligent recycling of solid wood', *Pro Ligno*, vol. 11, no. 4, 2012, pp. 14-20.

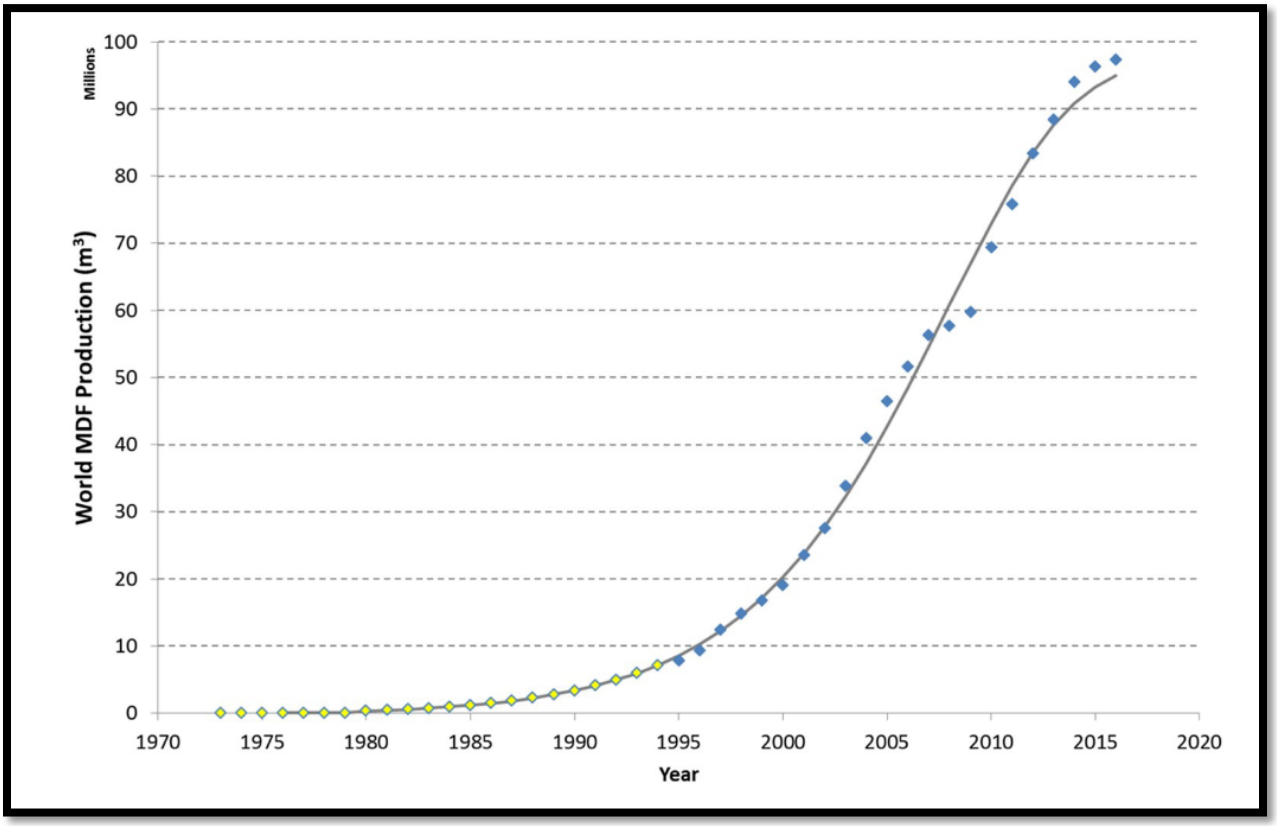

Figure 1: MDF Production Trend in the World[29].

Figure 1 above closely mirrors the increase in consumption of MDF and PB in Australia end of 2016 which was estimated to have increased by 12.3% (181,300m^3) and predicted to increase by a further 40% in the coming years[29]. Although MDF was a breakthrough in the timber and wood industry with regards to cheaper and more flexible building material, the forestry production and trade database estimated that over 97 million m^3 of MDF waste was produced around the world close of 2016[30]. The report further suggested that newly manufactured MDF will eventually be converted to waste at a faster rate than its 40-60-year life span as depicted in Figure 2 below[31].

[29]Industry Edge, *Residential Flat-Pack Joinery Import Market Study*, Forest & Wood Products Australia, October 2017, <https://www.fwpa.com.au/images/Newsletter_Images/Statistics-count/2017/Flat-Pack_Joinery_Imports_Market_Study_Final_Oct2017.pdf>, viewed 09 April 2020.

[30] Food and Agricultural Organisation, *Forestry Production and Trade,* FAOSTAT, 2015, h <http://www.fao.org/faostat/en/#data/FO/visualize>, viewed 09 April 2020.

[31] A Mitchell & G Stevens, A life cycle assessment of closed loop MDF recycling using the microrelease process to produce recycled wood fibre from MDF waste, WRAP, September 2009, <http://www.wrapni.org.uk/sites/files/wrap/MDF%20LCA%20FINAL%20version.pdf>, viewed 15 April 2020.

Figure 2: Proportion of MDF waste after production[31 34].

In 2015-2016, over 1.5 million m^3 of MDF and PB was manufactured in Australia[32]. According to HIA, a total of 605,466m3 of joinery (MDF and PB) was installed in Australian residential dwellings in 2016-2017 financial year[33]. Literature suggests due to this demand of MDF and PB, more than 87% of boards for household joinery are produced locally with only a small amount (14.3%) imported as shown in Figure 3.

It is assumed that during the first year, around 25% of the production is converted to waste in the form of off-cuts, machining errors, transport and storage losses[34]. The assumption agrees with a 2009 study that estimated while processing MDF and PB waste equates to 18% in board volume, and after 45 years, it's assumed that 99% of production becomes waste. Following these studies, Australia threatens to send most waste MDF and PB to landfill, unless better alternatives are sought. Figure 3 below represents a breakdown of MDF value streams to waste for MDF and PB use in the dwelling industry[35]. Currently in the UK, more than 50% of waste MDF and PB is sent to landfill

[32] Wood Solutions, *Environmental Product Declaration: Medium Density Fibreboard*, Forest and Wood Products Australia Limited, Canberra, December 2017, <https://www.woodsolutions.com.au/search/site/Particleboard>, viewed 07 February 2020.

[33] Housing Industry Association, Housing Australia's Future: A Demographic Analysis of Australia's Housing Requirements, www.hia.com.au, 2018, <https://hia.com.au/-/media/HIA-Website/Files/IndustryBusiness/Economic/publications>, viewed 18 March 2020.

[34] M Ire, F Privat, L Couret, C Belloncle, G Deroubaix, E Bonnin & B Cathala, 'Advanced recycling of post-consumer solid wood and MDF', *Journal of Wood Material Science & Engineering,* 2019, vol. 14, no. 1. p.19-23.

[35] Housing Industry Association, Housing Australia's Future: A Demographic Analysis of Australia's Housing Requirements, www.hia.com.au, 2018, https://hia.com.au/-/media/HIA-Website/Files/IndustryBusiness/Economic/publications, viewed 22 March 2020.

whereas the rest is burned with or without energy reclamation[36]. For industry in Australia, the increased economic impact of these waste disposal options is significant, especially with the annual increase of landfill levy and disposal costs[37] and alternatives such as waste to energy are increasingly becoming popular though is not sustainable environmentally or socially, long-term.

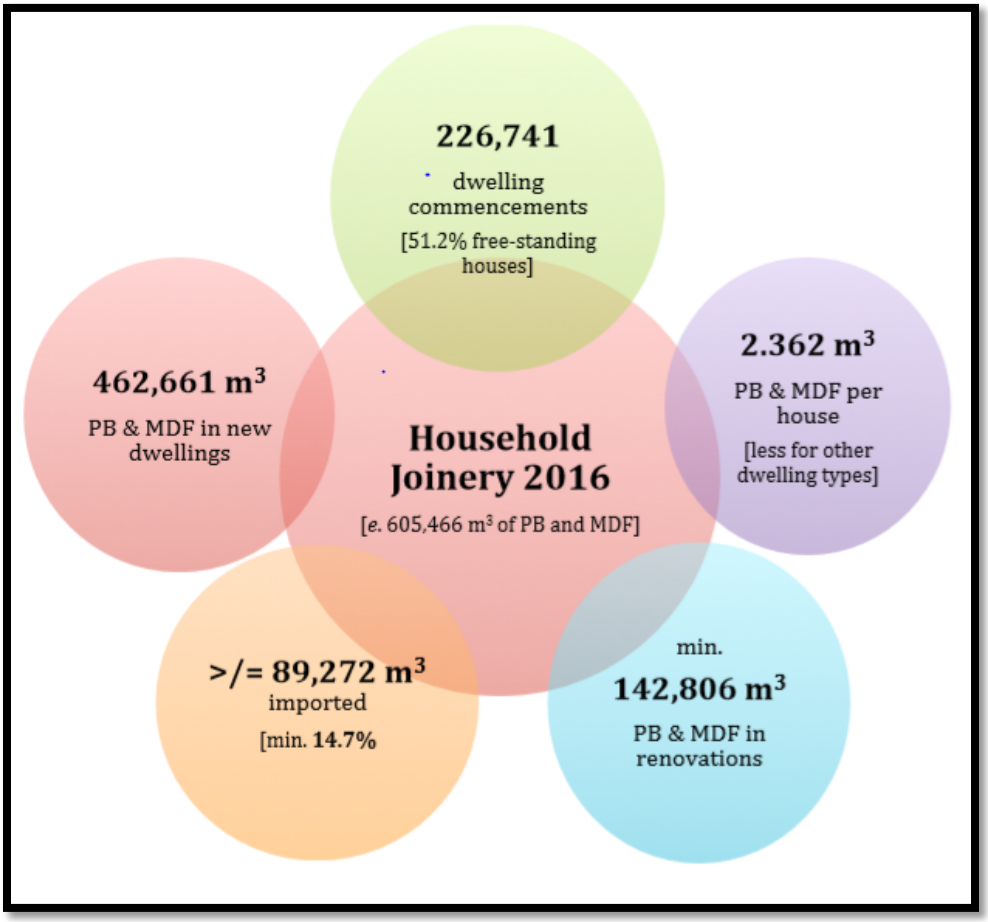

Figure 3: Consumption of MDF and PB in dwelling industry[33]

ILLAWARRA AND SHOALHAVEN REGION

Home to 954 manufacturing businesses, the Illawarra and Shoalhaven region is the third largest regional economy of NSW. The manufacturing sector employs just under 10,000 people in the region with 60% of their workforce having a trade certificate or higher[38]. Further desktop analysis and physical mapping of manufacturers currently in operation in the region revealed that 15% (147) of manufacturing businesses are cabinet makers and kitchen joineries accounting for over 42,042m^3 of waste engineered timber per month, currently going to landfill or converted into energy. The

[36] P Beele, *Demonstration of end uses for recovered MDF fibre*, Waste Resources Action Program (WRAP), Germany, 07 September 2009, pp. 9, <http://www.mdfrecovery.co.uk/wordpress/wp-content/uploads/2015/02/WRAP-MDF_Recycling_-_demonstration_of_end_uses.pdf>, viewed 15 April 2020

[37] WRAP, 2018.

[38] Regional New South Wales, *Western Sydney and Illawarra Shoalhaven Roadmap to Collaboration,* Regional New South Wales, <https://isjo.org.au/assets/4c28918964/Western-Sydney-and-Illawarra-Shoalhaven-Roadmap-to-Collaboration>, viewed 2 march 2020.

region comprises of 4 local government areas (LGA) with varying models to manage waste including the management of transfer stations and landfill facilities.

The ISJO delivers on waste management initiatives under the umbrella of the regional Waste Avoidance and Resource Recovery Strategy. This strategy is informed by the NSW EPA Waste Less Recycle More framework based on the waste hierarchy (figure 4); and more recently reviewed in line with the 2018 National Waste Action Policy and the 2019 NSW Circular Economy Policy Statement *Too Good To Waste.* Further, the NSW 20-Year Waste Strategy discussion paper "Cleaning up our act: The future of waste and resource recovery in NSW" aims to market waste as a resource and attract investment opportunities especially in regional areas.

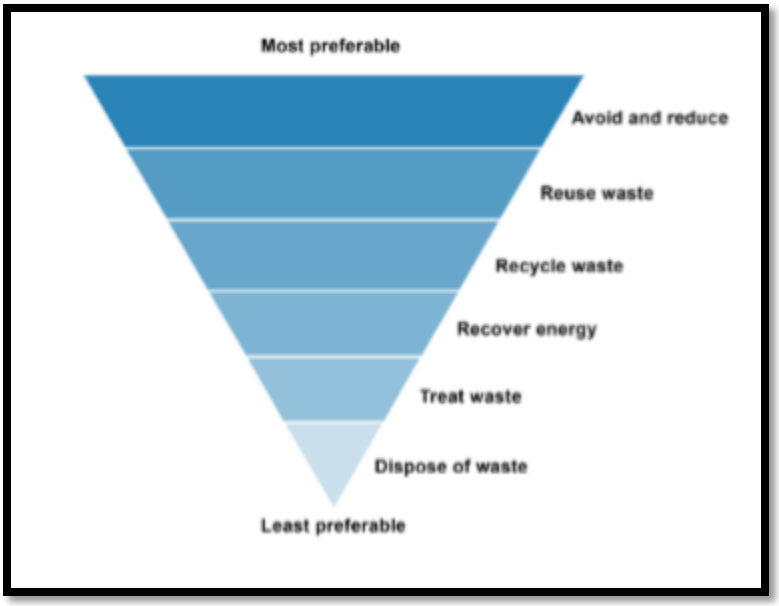

Figure 4: Waste Hierarchy[39].

Waste literature explores and discusses the hidden opportunities of employing more people if waste streams are diverted from landfill and opting for the most preferable means of utilizing waste as depicted in figure 4. It is further estimated that waste sectors could employ 9.2 full time equivalent (FTE's) per 10,000 tonnes of waste diverted from landfill, rather than the 2.8 FTE's usually employed in landfill[40][41]. As most manufacturing waste streams in the region have been documented, a pattern of circularity is present in more long-standing manufacturers in the region such as steel manufacturing and fabrication, aluminium fabrication and mining. Small to medium enterprises (SME's) have established around them to facilitate collection and circularity of waste streams.

There is limited documentation on waste from other SME's operating outside of these supply chains such as the cabinet makers and joineries. This industry in particular has seen a major rise in the region following rapid medium to high density apartment development. Increase in demand for cheaper, aesthetically pleasing timber products for kitchen,

[39] Waste Avoidance and Resource Recovery Act 2001.

[40] Access Economics Pty Ltd, *Employment in waste management and recycling*, The Department of the Environment, Water, Heritage and the Arts, 02 July 2009, <https://www.environment.gov.au/system/files/resources/5cc6a848-a93e-4b3f-abf7-fc8891d21405/files/waste-and-recycling-employment.pdf>, viewed 18 April 2020.

[41] Australian Government, state and territory governments & Australian Local Government Association, *National Waste Policy: Less Waste, More Resources*, Commonwealth of Australia, 2018, < https://www.environment.gov.au/system/files/resources/d523f4e9-d958-466b-9fd1-3b7d6283f006/files/national-waste-policy-2018.pdf>, viewed 17 April 2018.

laundry, bathroom and decking spaces have led to the rise in manufacture of MDF and PB for fitting and aesthetic purposes.

Formaldehyde is contained in the resin and surface finish of MDF and PB. The Forest and Wood Products Association (FWPA) set the standards for the amount of formaldehyde emitted from MDF and PB products and is represented by an "E" rating certificate[42]. Innovation in advanced manufacturing onshore is being limited partly by the fact that the same rating standards do not apply to imported board or imported furniture made from MDF and PB.

Waste PB can be added to virgin chips to create a new PB product with board manufacturers limited by waste product surface finishes. When new PB is cut to size, the included surface finish causes friction sparks when in contact with the cutting tools limiting the input of waste PB with surface finish to 20%. There is no limitation to the input of construction PB with no surface finish and future projects will seek to determine the value for board manufacturers in receiving additional waste PB in their supply chain[43].

Based on this literature, this project applies a mixed methodology approach to identify and model a disruptive case for alternative waste collection pathways in the Illawarra and Shoalhaven area in which waste MDF and PB can be directed. In doing so, this research will inform future projects to identify a solution to waste MDF as there are currently no pathway options in Australia outside of waste to energy.

Additionally, this project draws from best practice currently being implemented in Europe and the USA and provides 3 scenarios to investigate as possible opportunities in the Illawarra and Shoalhaven region.

RESEARCH METHODOLOGY

Often, traditional manufacturing does not consider the extended life cycle of a product. Cradle-to-grave perspectives of most manufacturers has narrowed the insight of achieving a true closed-loop supply chain or circular material flow of most products. To gain better insight and identifying opportunities that could stimulate circular economy (CE) of waste MDF and PB, this research project embarked on a qualitative research through case study analysis of an industrial cluster in the Illawarra and Shoalhaven region.

To clarify the research questions, an extensive systematic literature review was conducted[44]. For this purpose, journals as well as databases and business reports were evaluated. The databases Google Scholar, EBSCO, Science Direct and Scopus were searched. The keywords "Circular Economy", "Waste Streams", "Medium Density Fibreboards", "Particleboard" and "Manufacturing" were also searched for in titles, keywords, abstract and reports were collected in a folder. The literature gathered was further used to develop qualitative face-to-face surveys and interview questions which were deemed to be the most effective method to collect data on waste stream volumes along the processed timber industry and local landfill sites[45][46][47]. The interviews were conducted over the telephone, through site visits and

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[42] Industry Edge, *Residential Flat-Pack Joinery Import Market Study*, Forest & Wood Products Australia, October 2017,<https://www.fwpa.com.au/images/Newsletter_Images/Statistics-count/2017/Flat-Pack_Joinery_Imports_Market_Study_Final_Oct2017.pdf>, viewed 09 April 2020

[43] National Timber Product Stewardship Group, *Company Environmental and Product Stewardship Programs,* D&R Henderson, 2011, https://www.timberstewardship.org.au, viewed 01 May 2020.

[44] J Webster & R Watson, 'Analysing the past to prepare for the future: Writing a literature review', *MIS Quarterly*, Vol 26, 2002, pp. 2.

[45] S Parsons & L Kriwoken, 'Report: Maximizing Recycling Participation to Reduce Waste to Landfill: A Study of Small to Medium-sized Enterprises in Hobart, Tasmania', *Waste Management & Research*, vol. 28, 2010, pp. 472-477.

[46] J Redmond, B Walker & C Wang, Issues for Small Business with Waste Management, *Journal of Environmental Management*, vol. 88, 2008, pp. 275-285.

[47] B Walker, J Redmond & C Wang, Waste Recycling: Local Methods for Successful Interaction with Small Business, *International Journal of Environment and Sustainable Development,* vol. 7, no. 4, 2008, pp 362-382.

via email exchange. While conducting interviews through site visits, observational data was also collected in the form of photographs and physical waste material.

Consultation was undertaken with 28 cabinet maker and joinery businesses, 3 board manufacturers, 5 industry experts and 4 academics. The adopted sample size is suitable as the aim of the project was to describe the MDF and PB manufacturing sector in an exploratory way. Research interviews and site visits were completed between end of February and April 2020. Interviews provided valuable insights about the quantity of MDF and PB waste produced and its management in the industry. Data was provided by participants through email exchanges, telephone conversations, website information and geographical mapping. This research, however, acknowledges the limitation on sample size compared to the proportion of companies in the Australian cabinet making and joinery industries which share same experiences.

To avoid any inadvertent damage to the companies canvassed throughout the project and to ascertain full confidentiality, all companies' and participants were referenced in pseudo-names. The interview was undertaken by visiting and observing the company's production sites with the aim to:

- Establish the type, quantity and origin of waste MDF and PB.
- Estimate the current cost encountered with waste MDF and PB disposal.
- Describe and illustrate supply chain issues increasing waste MDF and PB through production and distribution; and
- Illustrate scenarios guided by the waste hierarchy (avoidance, reuse, recycle, recover, treat and disposal) for existing waste MDF and PB utilization and any follow up actions during the product life (repair/remanufacture) and end-of life (reuse of residues).

RESULTS AND OUTCOMES

RESULTS

The results from desktop analysis conducted over the research period identified that there are currently 147 registered cabinet makers and kitchen joineries in region that are in operation per the Australian Business Registry[48]. Further findings identified that combined, they make up 15% of the manufacturing industry in the region and produce an estimated 42,042m³ of MDF and PB waste inform of offcuts and sawdust.

Circular waste system examples can be clearly identified in other manufacturing industries in the Illawarra and Shoalhaven region. For example, the steel fabrication industry have established partnerships in the region with small scrap metal dealers and larger recyclers for the fabrication of new products with recycled steel. In the Agricultural sector, commercial composting facilities provide an example of organic waste circularity. This research identified the challenges of implementing a similar model for industries manufacturing products from MDF and PB as these products contain multiple materials and complex resins. However, waste to energy has been identified as a current viable alternative to landfill.

During site visits with cabinet makers and joineries, the process of board ordering, processing, manufacturing and waste disposal was observed. On average, the majority of these businesses in the region are small scale employing 5-10 people and manufacture 2-3 kitchens weekly. There are two major suppliers of board in this region which is important to note in understanding the composition of the waste stream as we explore opportunities for circularity of this material. Discussions with cabinet makers and joineries revealed each business generates an average of 11m^3

[48] Australian Bureau of Statistics, *Australian and New Zealand Standard Industrial Classification (ANZIC) 2006*, cat.no.1292.0.55.002, ABS, Canberra, 2006, < https://www.abs.gov.au/ausstats/abs@.nsf/mf/1292.0>, viewed 17 January 2020

per fortnight of pre consumer waste, the majority of which is offcuts and dust from MDF and PB. Another stream of waste generated by cabinet makers and joineries is through the demolition and removal of renovated kitchens. Depending on condition, there is a potential reuse market for these kitchens however it is not core business for cabinet makers and joiners to seek that market and therefore dispose of them in landfill.

Operationally, once the boards are received and unloaded, the material is taken to separate stations where they are cut using CNC machinery or by hand, finished and partially assembled. Each station has a waste container which is added to the larger front lift bin at the end of each day where it is mixed with other forms of waste. Businesses indicated that it would be a simple process to maintain segregation of MDF, PB and dust from other waste however at the moment this is of no value to the business as there is no separate collection or legislative drivers for separating materials.

Interviews with experts, manufacturers, suppliers and end users were also conducted to determine why recycling waste MDF and PB is not common practice across the country. These interviews identified a number of challenges in enabling circularity of waste MDF, PB and sawdust. These include;

1. Lack of legislative incentives or requirements that provide for the re-use or recycling of waste materials. With no alignment between State legislation and no Federal policy targets requiring the use of recycled content in manufacturing, there are limited drivers for industry to invest in new or innovative processes or products.
2. Composite nature and the resin used in MDF and PB manufacturing. Formaldehyde based resins used as binding agents within MDF and PB create emissions and complexities in material handling during recycling or reprocessing. All MDF and PB manufacturers within Australia adhere to Australian/New Zealand Standards, labelling and certification for formaldehyde emissions from engineered wood products. However, with 14.7% of Australia's MDF and PB products imported and sold through large retail chains, there is reduced certainty on materials meeting those same standards. As a result, further testing of MDF and PB products from unknown sources is required to understand the formaldehyde emissions during and after reprocessing. Interviews with chemists identified opportunity to conduct a TGA analysis. The tests use heat and pressure levels to determine the melting point of various components in the wood material.
3. Limitations on end markets. The highest realised net value use of waste MDF and PB is currently waste to energy (WtE). The research found at least one board manufacturing plant is recycling a small percentage at their own site to produce energy. It was also discovered that both waste MDF and PB are being processed into fuel for use onshore and for the export market. Through interviews with board manufacturers and suppliers, it is understood that at least two manufacturers are currently manufacturing new PB with 20% recycled PB content. Surface finishes limit an increased ratio of recycled content however opportunities are readily available for pre consumer construction PB. The board manufacturers have therefore established strict guidelines and procedures within their supply chains to create seamless collection and transportation of waste PB during delivery of new orders. This system is in place in the greater Sydney region from cabinet makers and joineries although in this region it is only occurring with a small volume of pre consumer construction offcuts. European research has resulted in technology currently at the pre commercial phase, to process waste MDF using ohmic heating to remove surface finish and resins resulting in a fibre with a variety of end market applications.
4. Logistics. The board manufacturers are located in remote regional areas, a considerable distance from the cabinet makers and joineries generating waste MDF and PB. While there is some collection from waste generators close to the main distribution centres, the costs and other environmental impacts of transport from outlying areas are barriers to closing the loop on the supply chain and returning this material to the board manufacturers.

OUTCOMES

The reduction and diversion of waste from landfill involves the essence of improved and innovative approaches to traditional manufacturing supply chains[49]. Demand for MDF and PB end-products in dwellings and in its use in the furniture industry[50], requires improved and effective pathways especially at the end-of life cycle stages. Through this research, participating cabinet makers and joineries confirmed literature claims regarding the considerable volume of waste during processing and product end-of-life, that is both bulky and costly to dispose of. As 99% of manufactured MDF and PB is regarded as waste after 45 –60 years[51], alternative pathways need to be considered other than landfill or waste to energy, to enable a circular economy.

Many challenges have been identified that contribute to the lack of waste MDF, PB and sawdust reprocessing and recycling in the region. These have been discussed with all participants in the supply chain to identify possible scenarios to structure a circular economy for these materials. An almost unanimous response in academic and industry reports and participant responses, confirms the industry requires prescriptive legislation and improved logistic systems to overcome these challenges for re-use of waste material in this supply chain process.

The waste hierarchy (figure 4) defines a preference to achieving sustainable outcomes by reducing the amount of waste that is generated, reusing what cannot be reduced and recycling what cannot be reused, with disposal as the final option. In this section, this research considers and distinguishes three different types of recycling as identified by the 2005 Ensis report[52].

- Direct Recycle – where products are recycled back into the same products
- Indirect Recycle - where products are recycled into a different product type e.g. composite material
- Energy recovery – currently accessible in Australia, where the calorific value (heat energy) of products is recovered

BUSINESS RECOMMENDATIONS

Based on these findings, this research aims to model a centralised direct and indirect recycling system which can be used to explore selected scenarios for diversion of waste MDF, PB and sawdust from landfill and energy recovery. The aim of this section is to discuss and illustrate scenario-based centralised business model opportunities derived from current good-practice occurring globally and locally Although this may be a breakthrough in traditional manufacturing, there are a variety of considerations relevant to the issue of MDF and PB products and it is pertinent to examine some of these separately.

OPPORTUNITY 1: WASTE TO ENERGY

As identified through this research, board manufacturers are currently utilising waste PB created as a result of the manufacturing process as a fuel to provide energy for their own manufacturing sites. This is circular in its own right however has limited opportunities in terms of volume and removes the material from the value chain.

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[49] T Bohme, A Escribano, E Heffernan & S Beazley, Causes and mitigation for declining productivity in the Australian mid-rise residential construction sector, *Built Environment Project & Asset Management,* vol. 8, no. 3, 2018, pp. 239 -252.

[50] Industry Edge, *Residential Flat-Pack Joinery Import Market Study*, Forest & Wood Products Australia, October 2017,<https://www.fwpa.com.au/images/Newsletter_Images/Statistics-count/2017/Flat-Pack_Joinery_Imports_Market_Study_Final_Oct2017.pdf>, viewed 09 April 2020

[51] M Irle, F Privat, L Couret, C Belloncle, G Deroubaic, E Bonnin & Bernard Cathala, 'Advanced recycling of post-consumer solid wood and MDF, *Wood Material Science & Engineering*, vol 14, no. 1, 2018, pp. 19-23

[52] J. Taylor, R. Mann, M. Reilly, M. Warnken, D. Pincic & D. Death, "*Recycling and End-of-Life Disposal of Timber Products*", Forest & Wood Products Research & Development Corporation, Victoria, 2005.

Additionally, there are companies operating within Australia manufacturing processed engineered fuel (PEF) as an alternative to fossil fuels from separated, dry non-recyclable material. While they have established markets for high energy users both locally and internationally, export of waste products (including PEF) following the implementation of the China Sword Policy, have seen an increase in restrictions across Asia. Locally, regulations and social licence on further development and operation of waste to energy facilities equates to a much smaller market demand. Therefore, this does not represent an opportunity for consistent diversion of MDF and PB from landfill.

OPPORTUNITY 2: CONVERTING PARTICLEBOARD BACK INTO PARTICLEBOARD

The research investigated the current process of recycling PB into new PB product. Through desktop analysis, this research identified approximately 70% of PB manufactured in Western Europe, recycles waste such as edgings, offcuts, shavings, sawdust and board obtained from sawmills and furniture works[53]. MDF cannot be recycled in the same way due to the fibre size. According to UK manufacturer websites, PB now consist of approximately 83% total recycled material. 74% post-industrial material from other sawmill waste, sawdust, wood chip and residues, and 9% post-consumer recycled wood waste chip material.

Discussions with local suppliers confirmed the same. Email correspondence with one major onshore board manufacturer suggested that there is no limit to how much pre consumer recycled product (without a surface finish) can go into a new product. They confirmed they are currently adding up to 20% to their PB mix without removing the surface finish. They also noted that overseas board manufacturers are using up to 80% recycled PB in their mix.

PB manufactured in Australia on average contains between 5-7% urea formaldehyde and 6-11% melamine urea formaldehyde. This is a challenge for indirect recycling limiting the manufacture of a different product. However, it is a benefit for direct recycling PB back into PB. The value of the formaldehyde-based material is captured in the new PB as a result of the additional of recycled content.

This opportunity avails itself to a centralised collection model providing economies of scale for board manufacturers and collective negotiation on price for cabinet makers and joineries.

OPPORTUNITY 3. MDF AND PB INTO A COMPOSITE MATERIAL

Wood composites blend wood waste (sawdust, fibres, flakes or flour) and other waste materials such as plastic, glass or textile into a compound product combining the properties of both the wood and other waste material. The wood waste serves as a filler to reduce the composite production costs. Discussions with academic experts in the field estimate at least 60% of recyclable MDF, PB and sawdust to other waste material for a wood composite material.

While there are no secure end markets locally for a composite material, there in an opportunity for a market demand analysis across a number of industrial sectors. This is supported by legislation and innovative production techniques with literature indicating an uptake of wood composite materials in the US and European markets.

Piloting this opportunity locally would require significant infrastructure investment and testing of standards depending on the market application.

OPPORTUNITY 4: CONVERTING WASTE MDF BACK INTO FIBRE - UK BASED COMPANY

A UK based organisation has identified a commercial solution which has passed the proof-of-concept trials and is progressing to develop a novel, propriety process to recover wood fibre from waste MDF. The six-year research has identified technology that deploys a technique known as “ohmic heating”, which is common in large scale food-processing, that heats a substance by passing an electric current through it. As part of the process, the material requires

[53]R Czarnecki, D Dziurka & J Lecka, ‘The use of recycled boards as the substitute for particles in the centre layer of particleboards’, *Electronic Journal of Polish Agricultural Universities*, vol. 6, Iss. 2, 2003, p. 2.

to be shredded into fine pieces and placed in a water bath before electricity is passed through it. This way, the fibres are freed from the resins and laminates, leaving a mulch that fluffs up after it dries[54]. According to the founder, the process is highly energy efficient as it uses steam power generated in the process. The output is a fibre with qualities equal to that of virgin wood with multiple end market opportunities from MDF based products to home insulation. Recent interviews confirmed that licencing would be available early 2022 to establish a local facility using this technology. This would require significant investment, collaboration and regulatory approvals.

FUTURE RESEARCH

Further discussions and desktop research identified possible future alternative pathways for the re-processing of waste MDF and PB. Emerging technology has demonstrated that at a technical level, high value products can be made using recovered MDF and PB material. However, further exploration to determine impact and optimal pathways to the following opportunities is required.

MEDIUM DENSITY FIBREBOARDS INTO NANO-CRYSTALINE CELLULOSE

MDF to Nano-Crystalline Cellulose (NCC) can be used for rheology modification, optical films, thin barriers, composite enhancement and emulsion stabilisation. Current retail price for NCC is $1000/kg for an 8% solution, however the challenge lies in production. According to the company's business report current production is relatively small scale and future prices are predicted to fall to about $6/kg persuading investors negatively[55].

Similar to composite material, the lack of short-term market potential and fear of price drops limits the growth and further exploration of the business opportunity.

RECYCLED MDF FIBRE APPLICATION

According to literature, MDF fibre application identified commercial opportunities for the panel product to develop new products. The ability to tailor bio-resins or low emission adhesives for recycled fibres could lead to developing highly innovative products. Business reports from manufacture website confirms that tests indicated that recycled MDF fibres have improved functional performance over virgin materials[56][57], however, this is yet to be optimised or fully understood. Further investigation would be required to understand the plausibility of recycled MDF fibres and their durability in developing materials for high-hazard applications.

FINAL COMMENTS

The Illawarra and Shoalhaven region is uniquely positioned to take full advantage of the opportunities presented having access to well-connected transport and logistics services. ISJO is well placed to facilitate the modelling of a centralised collection system and facilitate supply chain negotiations with industry both within and outside of the region. Successful circularity of waste MDF and PB requires economies of scale and innovative partnerships, both of which exist within the Illawarra Shoalhaven region.

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[54] M Frost, 'MDF recycling solution is a world first for British Firm', *The Daily Express,* 15 March 2017, <https://www.express.co.uk/finance/city/779497/MDF-Recovery-recycling-solution-world-first-British-firm>, viewed 03 March 2020

[55] M Irle, F Privat, L Couret, C Belloncle, G Deroubaic, E Bonnin & Bernard Cathala, 'Advanced recycling of post-consumer solid wood and MDF, *Wood Material Science & Engineering*, vol 14, no. 1, 2018, pp. 19-23

[56] M Frost, 'MDF recycling solution is a world first for British Firm', *The Daily Express,* 15 March 2017, <https://www.express.co.uk/finance/city/779497/MDF-Recovery-recycling-solution-world-first-British-firm>, viewed 03 March 2020

[57] L Couret, M Irle, C Belloncle & B Cathala, 'Extraction and characterization of cellulose nanocrystals from post-consumer wood fibreboard waste, *Cellulose,* vol. 24, 2017, pp 2125 – 2137.

APR.INTERN EXECUTIVE SUMMARY TEMPLATE

To be completed by the Intern, submitted to APR.Intern, and Reviewed by the Industry Partner

Manufacturing industries have been traditionally known for their linear production supply chain model of take-make-dispose. However, with the recent implementation of the Chinese national sword policy and shifts in consumer behaviour, manufacturing companies are evolving to rethink design and production, due partially to the impact on the environment but primarily due to the high costs of disposal.

Australia's manufacturing sector has over the years been the largest contributor to the country's gross domestic product (GDP) and the largest employer. In regional areas, manufacturing companies have been documented to be the highest employer and contributor to the regional economy of most states. In New South Wales, the third largest economy in the state is the Illawarra and Shoalhaven region which houses 954 manufacturing companies, employing 10,000 people in the regional areas. In this region, the dominant industries have been steel manufacturing and fabrication, aluminium fabrication and mining. While these industries have large volumes of waste, they already have established circular material flows.

In order to facilitate increased diversion of waste from landfill the Illawarra Shoalhaven Joint Organisation (ISJO) partnered with the University of Wollongong to undertake research on other large industry sectors and their logistics and supply chains.

15% of the total manufacturing companies in the ISJO region comprise of kitchen joineries and cabinet makers. Over a series of interviews and correspondence with joineries and cabinet makers in the region, this research identified the amount of waste medium density fibre board (MDF) and particleboard (PB) produced each fortnight ranges from $7m^3$ to $15m^3$. Averaging these figures, $11m^3$ of waste is produced fortnightly across the kitchen and joinery sector accumulating to around $42{,}042m^3$ annually. Further tours and observations of work sites confirmed kitchen joineries and cabinet makers waste stream as the largest clean waste stream.

Disposal of waste MDF, PB and sawdust is either landfilled, used as waste to energy in an industrial setting (dependant on EPA regulations) or exported as a processed engineered fuel. While waste to energy reduces the amount of waste to landfill, it limits any other use of the material as a resource. Therefore, to address this gap, this research undertook a qualitative methodology to develop a scenario-based business model illustrating the highest realised net value when waste MDF, PB & sawdust is diverted from landfill Interviews were conducted with 28 kitchen joinery and cabinet making business owners, major suppliers of MDF & PB into the Illawarra and Shoalhaven region and business owners/managers, academics and experts in different manufacturing industry to capture a holistic view on the costs, challenges, disposal practices and flows of waste.

Over a period of five months, desktop research, interviews and site inspections were conducted identifying the following scenarios for diversion from landfill. These scenarios are presented in order of possible implementation with all requiring a centralised collection and processing centre.

- **Processing of MDF, PB and sawdust into a fuel**. Converting this material into fuel is the easiest and cheapest means to divert this material from landfill making it currently the Highest Realised Net Value (HRNV) for waste MDF, PB and dust.
- **The manufacture of new PB using waste PB**. Interviews with two of the three onshore PB manufacturers confirmed 20% of waste PB can be remanufactured back into new PB. Interviews confirmed companies have established the logistics for the collection of this waste for remanufacturing, however in this region it is currently only the collection of a small amount of construction PB,
- **Development of a composite material**. Mechanical processing technology developed by the University of New South Wales (UNSW) offers the opportunity in mixing waste MDF, PB & sawdust with waste glass, plastic or textile to form a composite material that has many potential uses. The glass, plastic or textiles form a seal over the waste engineered timber and also offer an aesthetic finish. Testing is still being carried out to

determine weight bearing and water holding capabilities as well as emissions from drilling or cutting the material once sealed.

- **Recovery of fibres from waste MDF through MDF Recovery technology**. A UK based company, MDF Recovery has developed a patented concept to recover fibres from waste MDF. Through email exchange with the company director, it is understood that the technology has been developed in line with requirements from manufacturers and is nearing commercialisation in the EU.

While these scenarios could be applied in theory, the major challenges inhibiting the reprocessing of waste MDF, PB and sawdust include logistics, composition of the material and legislative drivers. Most board manufacturers are located in regional areas resulting in barriers for the collection and transport of waste from individual sites. The materials themselves are composites of timber, melamine, and contain formaldehyde-based resins as binding agents leading to complexity in recycling. Finally, NSW is currently reviewing legislation that could help drive commercial and industrial businesses to consider their waste, innovation in resource use and management of materials at end of life.

This research sits as a unique opportunity to provide manufacturers with alternatives to landfill which in turn provide them with an improved triple bottom line. Currently, it is conservatively estimated to be costing local cabinet makers and joineries over $1.4 million per annum for the collection and disposal of EOL MDF, PB and sawdust. Beyond extending the life of local landfills, a circular approach to waste management provides employment (9.2 full time equivalents (FTE's) per 10,000 tonnes of waste diverted from landfill versus 2.8 FTE's through landfilling; efficient resource use; opportunities for innovative partnerships; and flow on effects to the local economy. This issue is not unique to the ISJO region or to cabinet makers and joineries specifically. Scenarios presented through this research provide a scalable opportunity for other regions and manufacturing industries utilising MDF and PB.

SUMMARY OF RESEARCH PROJECT BACKGROUND & OBJECTIVES

In about 100 words, please provide a description of the purpose and expected outcome of the project that is suitable for media or other publicity material.

The Illawarra Shoalhaven Joint Organisation (ISJO) represents the interests of Local Government in the Illawarra and Shoalhaven regions and provides a way for local Councils, State Government and industry to collaborate to deliver on regional priorities.

There are currently no legislative drivers to encourage research or investment into the establishment of circular opportunities or end markets e.g. product stewardship; no requirements for recycled content on imported products. While there are significant social, economic and environmental drivers for avoidance of waste to landfill, disposal still presents an easy and accessible solution for both residents and industry in terms of materials that do not have another viable recycling stream or end market.

Pressures on Local Government exist in the management of existing facilities and future planning especially in terms of trending usage and disposal of resources; the limited lifespan on landfills; and no prospects of approvals for future similar facilities. Currently the only viable alternative to landfill is in waste to energy where resources are burned in place of a fuel thereby removing any ability to reprocess or reuse that resource. Whilst this may be one alternative, this study anticipates greater social, economic and environmental benefits in exploring alternative circular models.

While Councils service the community's waste collection and disposal needs, they do not have the capacity to investigate opportunities for reuse and reprocessing of the resources currently going to landfill from industry. Likewise, most SME's do not see waste reprocessing, avoidance or recycling as core business. This research explores real world examples of supply chain analysis and industrial ecology, to value resources in these waste streams and identifies models for circular opportunities, thus diverting them from landfill.

The objective of study is to analyse manufacturing waste streams currently going to landfill in the Illawarra and Shoalhaven and identify opportunities to establish a commercial or social enterprise to enable a circular economy.

SUMMARY OF RESEARCH UNDERTAKEN

In about 300 words, please provide a description of the research undertaken, in terms of methodology and your contribution to the research as an intern.

For this research purpose, journals as well as databases and business reports were evaluated. The databases Google Scholar, EBSCO, Science Direct and Scopus were searched. The keywords "Circular Economy", "Waste Streams", "Medium Density Fibreboards", "Particleboard" and "Manufacturing" were also searched for in titles, keywords, abstract and reports were collected in a folder. The literature gathered was further used to develop qualitative face-to-face surveys and interview questions which were deemed to be the most effective method to collect data on waste stream volumes along the processed timber industry and local landfill sites. he interviews were conducted over the telephone, through site visits and via email exchange. While conducting interviews through site visits, observational data was also collected in the form of photographs and physical waste material.

Consultation was undertaken with 28 cabinet maker and joinery businesses, 3 board manufacturers, 5 industry experts and 4 academics. The adopted sample size is suitable as the aim of the project was to describe the MDF and PB manufacturing sector in an exploratory way. Research interviews and site visits were completed between end of February and April 2020. Interviews provided valuable insights about the quantity of MDF and PB waste produced and its management in the industry. Data was provided by participants through email exchanges, telephone conversations, website information and geographical mapping. This research, however, acknowledges the limitation on sample size compared to the proportion of companies in the Australian cabinet making and joinery industries which share same experiences. To avoid any inadvertent damage to the companies canvassed throughout the project and to ascertain full confidentiality, all companies' and participants were referenced in pseudo-names.

Through this process, I contributed accessing academic journals from university databases, reviewing literature and conducting interviews with the participants including follow-up. I then collected and analysed data which further informed the written report.

SUMMARY OF THE EDUCATIONAL OUTCOMES

In about 100 words, in plain language, summarise how the internship contributed to your professional development as a researcher. Discuss any challenges translation of research, research environment etc. that occurred during the internship?

Through this internship, I have been able to hone my ability to quickly home in on important information, allowing me to make the most out of the short time I had to connect with others, especially at conferences and meetings. I was barely a week old before my first conference in Adelaide, which I had to present. This was a good learning curve that helped me improve my skills for taking part in panel interviews and presenting at the NSW circular economy think tank. It also helped me greatly while preparing for the RENEW Illawarra webinar which provided a lot of insights to our viewers and in preparation for the Coffs Harbor Waste Conference which was unfortunately cancelled due to the Covid-19.

The internship has strengthened my writing skills and ability to deal with feedback. Getting different reviews from different backgrounds and then having to go through it with your supervisor line by line and defend everything you've done, has certainly changed how I write papers and how I communicate with co-authors. Also, being exposed to different topics and a range of stakeholders including council/government representatives, policymakers, and nongovernmental organizations, helped me become more well-rounded. The attendance of meetings with other regional joint organisations gave me a real appreciation for ISJO and the work Yvette, Nicole and James do.

INTERN IMPACT STATEMENT

In about 75 words, please outline the impact that the internship has had on you in terms of work-readiness and competitiveness for future employment.

I am certain that this experience will help me in future with job searches, especially due to experience working somewhere other than my Ph.D. I am also certain that in future, when I put together a research/project proposal as part of an application, everything I have learnt about formulating, planning and communicating in a 'non-science-nerd' way will truly help.

FINAL COMMENTS

Insert any additional comments if applicable

I am very grateful for the time, patience and how accommodating Yvette, Nicole and James were during this time. They literally included me in every important aspect beyond the project and genuinely wanted me to learn. They have also continued to support me during this "Covid-19" time as we all worked from home.

I also want to thank Dr Tillmann Bohme. He has been very supportive and dedicated through the entire project, by being a mentor and supervisor.

Lastly, thank you to the APR team, Mark Ovens and Alex for following up and making sure I am progressing well. I am truly grateful.

INDUSTRY PARTNER IMPACT STATEMENT

ISJO has traditionally held links with strategic stakeholders including member Councils, State Government agencies and relevant project based experts. It is not generally considered business as usual to partner with a research organisation or create major industry links within the region.

The ISJO waste team have a comprehensive understanding of waste management and current waste initiatives relevant to municipal waste streams and a broad overview of industrial processes. This research project provided an opportunity to undertake a detailed review of processes around a material that currently has no viable circular outcomes. This expanded on prior ISJO baseline research around waste material flows from manufacturers locally that provided an alignment with a municipal waste stream – bulky household waste.

It was of great value as an industry partner to workshop the supply chain with our research intern and in doing so, highlight the opportunity for negotiations with board manufacturers to take back PB into their manufacturing process, potentially creating a viable circular economy.

We plan to continue our research around MDF to determine viable pathways for this material type to be reused or recycled.

Finally, this partnership has broadened our scope for future research opportunities both with UoW and futher afield.

APPENDIX

GLOSSARY

EOL – End of Life
FTE – Full-time Equivalent
LGA – Local Government Areas
MDF – Medium Density Fibreboard
PB- Particleboard
WtE – Waste to Energy

METHODOLOGY TABLE

Step	Stages of Research	Data Collected	Data Analysis	References
1	Desktop Literature Analysis from the ABR public and private, published government reports, google scholar and UOW library for peer-reviewed journal articles and yellow pages.	Number of manufacturers in the Illawarra and Shoalhaven region. Current material and waste flows in the region. Largest waste stream sent to landfill and with limited to no diversion pathways. Best practices worldwide currently under implementation and opportunities for disruptive circular processes on the largest waste flow within the Illawarra and Shoalhaven areas.	Tabulation of manufacturers, material and waste flows in Illawarra and Shoalhaven region. Identification of waste streams with high waste to landfill streams. Separating high waste stream to landfill manufacturers into different excel sheet and identifying number of manufacturers in that waste stream/supply chain	Journal Articles Yellow Pages Government Reports Australian Business Registry data Google Maps
2	Physical mapping of cabinet makers and kitchen joinery manufacturers/companies across the Illawarra and Shoalhaven region	Identification of number of manufacturers currently in operation in the region. Current start and endpoint of waste streams.	Completion of excel sheet with the identified number of manufacturers in the highest waste stream – identified as kitchen joineries and cabinet makers Process mapping of waste flows in the kitchen joinery and cabinet making industry supply chain.	Google maps Physical drive across industrial areas in Illawarra and Shoalhaven.
3	Email introduction to all listed cabinet makers and kitchen joineries on nature of research and request of participation	Contacts of business owners and managers in the kitchen joinery and cabinet making industry interested in the research.	Spreadsheet update on waste streams, coast and current opportunities. Follow-up with remaining participants.	Industry feedback

		Volumes of waste currently being produced by kitchen joineries and cabinet makers in the region. Complicated waste type/waste stream that cannot be recycled/re-used. Confirmation of where these type of waste flows end. Waste disposal costs. Alternative pathways joineries and cabinet makers are currently taking towards reducing or re-using waste MDF and PB.	Informing process map of waste flows.	
4	Interviews, follow-up phone-calls and site visits to interested parties who contacted us and who we followed up with.	Contacts of business owners and managers in the kitchen joinery and cabinet making industry interested in the research. Volumes of waste currently being produced by kitchen joineries and cabinet makers in the region. Complicated waste type/waste stream that cannot be recycled/re-used. Confirmation of where these type of waste flows end. Waste disposal costs. Alternative pathways joineries and cabinet makers are currently taking towards reducing or re-using waste MDF and PB.	Spreadsheet update on waste streams, coast and current opportunities. Follow-up with remaining participants. Informing process map of waste flows.	Industry feedback
5	Consolidation of data in spreadsheet – calculation of waste MDF, PB and sawdust	Costs of waste disposal Volume of waste MDF and PB currently going to landfill and waste to fuel. Challenges faced by cabinet makers and	Process mapping of waste streams Identification of opportunity in the waste flow map for disruption and	Industry feedback Calculation

		kitchen joineries in recycling MDF and good practices implemented in the industry. Contractors servicing the industry. Other waste produced in by the joineries and cabinet making industry and the endpoint.	implementation of alternatives on waste hierarchy model.	NSW Regional Government reports Journal Articles – best practice diversion of waste MDF and PB from landfill globally.
6	Interviews with industry experts, managers, academics & staff of various levels in different manufacturing industries and landfill sites	Other manufacturing waste stream processes. Opportunities for waste MDF and PB in other manufacturing sectors. Chemical testing and equipment required for waste MDF and PB diversion from landfill. Policies currently in place to support waste MDF and PB diversion from landfill.	Informing business model scenarios for various case studies. Process mapping modification reflecting diversion from landfill and use of landfill in waste MDF circularity. Alternative waste to energy options. Calculation of highest net value of waste diversion from landfill	Industry feedback Ellen McArthur circular business model NSW Regional Government report
7	Consolidation of data in spreadsheet – comparing waste stream flows and informing the circularity of waste products in various manufacturing industries	All steps (1 –6) collated and consolidated.	Report and scenario-based business models for different pathways in waste MDF and PB diversion to landfill.	All references used (steps 1 – 6)