4.3 Survey: "Circularity of the American Wood Pallet Industry"

Eight individuals in leadership positions within wood pallet businesses responded to the survey out of a total of 952 impressions, resulting in a capture rate of 0.82%. All eight respondents represented independent manufacturers and recyclers, while no poolers were represented.

Five respondents declared a role of "President," one respondent declared a role of "Operations Manager," one respondent declared a role of "General Manager of Accounting," and one respondent did not declare a role.

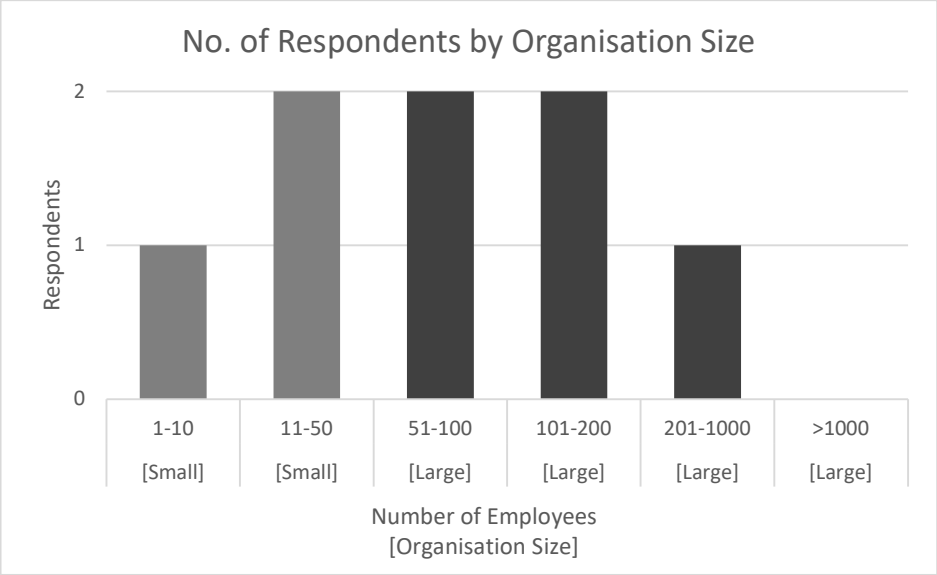

Figure 4-12. Survey respondents by organisation size.

Three respondents (38%) represented small organisations having fewer than 50 employees, which comprise more than 99% of organisations in the American wood pallet industry (Roy et al., 2016). The remainder (62%) represented large organisations having 51 or more employees. No respondent represented an organisation with more than 1000 employees.

Throughout the rest of Section 4.3, distinctions between small and large organisations are made where relevant to illustrate the effects of organisation size on various life cycle practices.

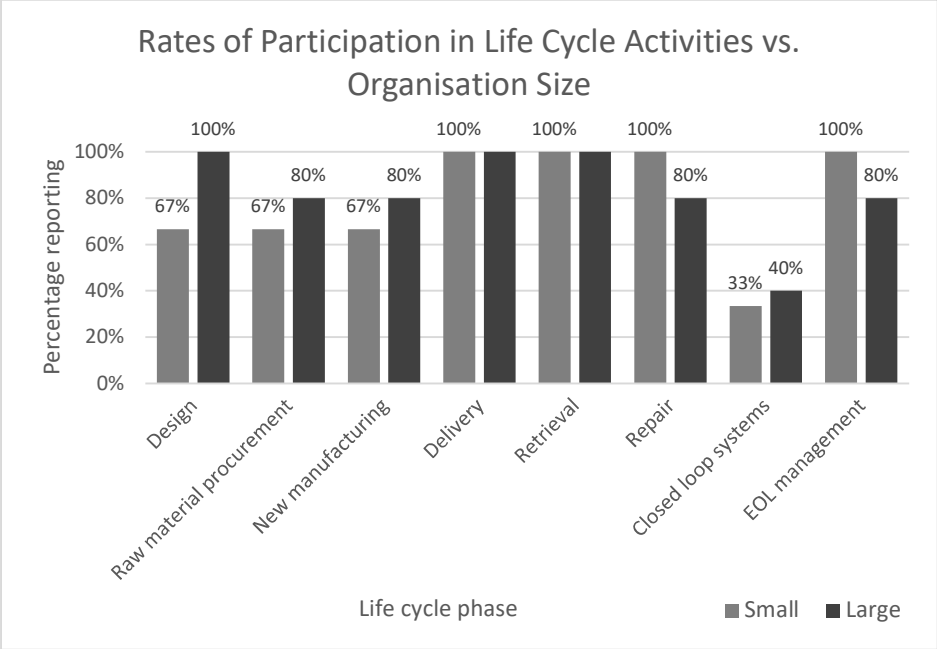

Figure 4-13. Respondents' rates of participation in life cycle activities by organisation size.

There is a relative difference between the participation of small and large organisations at different stages of the wood pallet life cycle. Rates of participation among large organisations are relatively higher in earlier phases (design, raw material procurement, and new manufacturing), while small organisations have higher rates of participation in later phases (repair and EOL management). All organisations are shown to participate in the delivery and retrieval of pallets equally (100%), while participation in closed loop systems is low across all organisations (38%). These findings indicate a possible transference of responsibility over value-added activities from large, centralised operations early in the product life cycle to smaller operations late in the product life cycle. In other words, large organisations tend to create the products whose continued use tends to become the responsibility of smaller organisations as the products near end-of-life.

4.3.1 Design

Seven out of eight respondents (two small and five large) reported participation in the design phase and provided the following information about their product design practices:

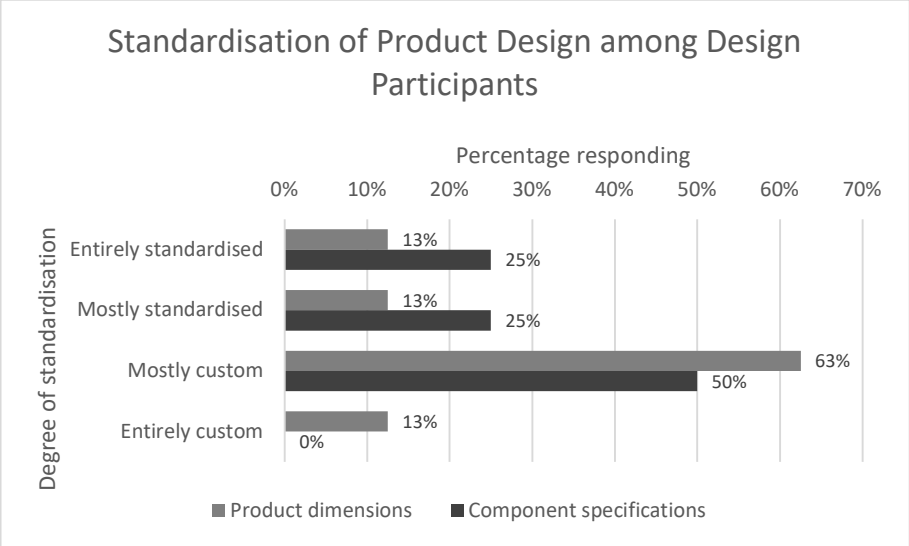

Figure 4-14. Levels of product design standardisation among design phase participants.

Standardisation of wood pallet designs supports life cycle extension and material value retention in both one-way and returnable pallet systems. Product dimension standardisation enables a greater degree of direct reuse between distinct users, whose packaging and material handling operations are likely only compatible with a narrow range of product designs. Component standardisation increases the possibility that components salvaged from decommissioned pallets can be utilised directly in repair activities with minimal material loss.

Component specifications show a higher degree of standardisation (50% mostly or entirely standardised) than product dimensions (25% mostly or entirely standardised). The most common response for product dimensions (63%) and component specifications (50%) is "Mostly custom." A fraction of participants works with entirely standardised product (13%) and component (25%) designs, indicating that a highly standardised product offering is practically achievable for wood pallet designers.

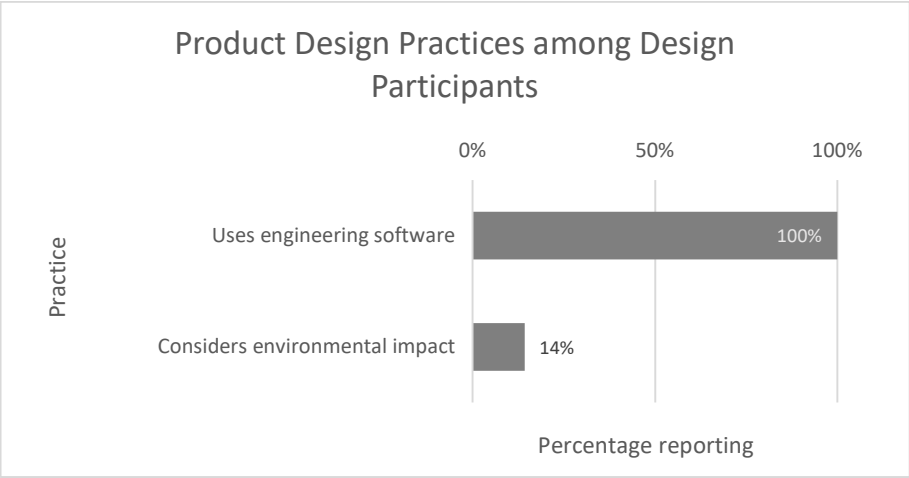

Figure 4-15. Prevalence of selected product design practices among design phase participants.

Commercially available unit load engineering software can be used to improve performance, extend service life, and reduce material consumption of wood pallet designs. 100% of design

phase participants use such software to create their designs, but only 14% consider environmental impact reduction as an important factor in their design process. Informing wood packaging designers and consumers about existing capabilities for, and potential benefits of, environmentally conscious design practices could contribute to a circular transformation of the American wood packaging industry.

4.3.2 Raw material procurement

Seven out of eight respondents (two small and five large) reported participation in the raw material procurement phase and provided the following information about their new wood raw material procurement practices:

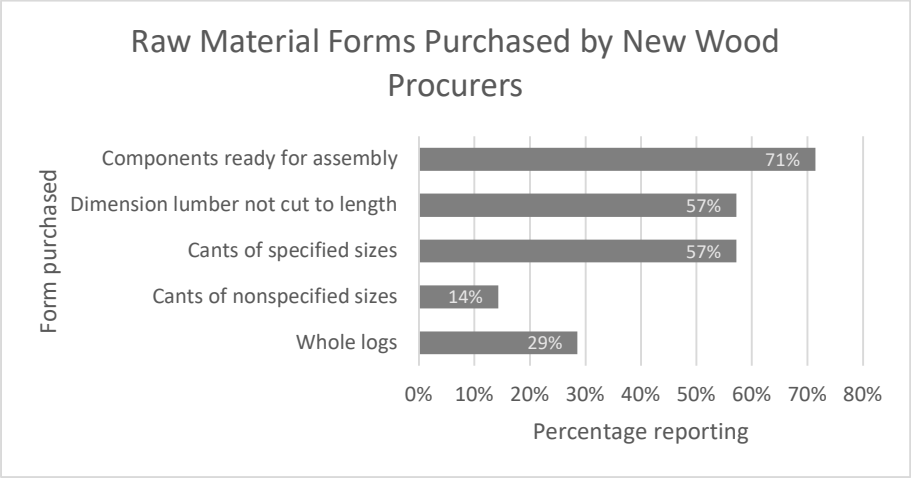

Figure 4-16. Prevalence of selected new wood raw material forms among procurement phase participants.

When manufacturers purchase wood raw material in a more processed form from the sawmill, the scrap produced from processing the wood into a usable form is generated in a more concentrated stream and unnecessary transportation of scrap material from the sawmill to the manufacturers is avoided. Therefore, it could often be most resource efficient for wood pallet manufacturers to purchase new wood raw material in a form that is as close as possible to its assemblable form without sacrificing volume utilisation in shipping, though this hypothesis is inferential.

The most commonly purchased form of new wood raw material among procurement phase participants is the most processed form, components ready for assembly (71% of participants report purchasing). Dimension lumber not cut to length, which only requires the manufacturer to make a single cut to process the raw material into a usable component, is almost as commonly purchased (57%). Whole logs, the least processed form of new wood material, are purchased by 29% of participants.

Cants, which are larger rectangular lengths of timber cut from the lower grade wood from the centers of logs and large branches, are also commonly purchased (57% specified sizes, 14% nonspecified sizes). Cants require more processing to form into usable components than does dimension lumber but have the distinct resource efficiency advantage over other forms of wood raw material of utilising a byproduct of high-grade timber processed for other industries such as construction and furniture manufacturing. For this reason, the cant is arguably the most resource efficient form of new wood used in wood pallet manufacturing.

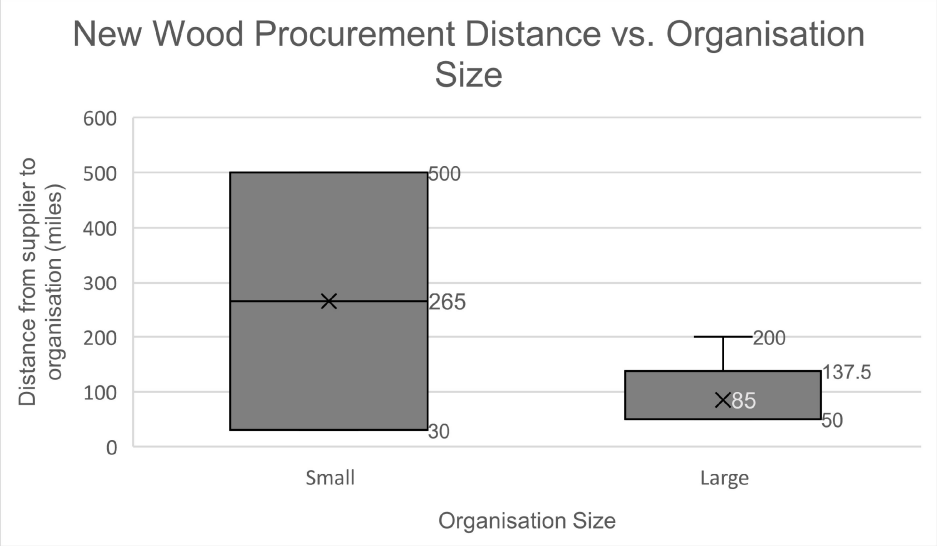

Figure 4-17. New wood raw material procurement distances by organisation size among procurement phase participants.

Raw material transportation impacts were not accounted for in the expanded relative cost model, but they are an Important consideration. Small organisations had a much greater variance in new wood procurement distances (range: 30–500 miles) and a higher mean procurement distance (265 miles) than large organisations (range: 50-200 miles, mean 85 miles). This indicates that the marginal costs and impacts of new wood raw material transportation are lower for large organisations than for small organisations.

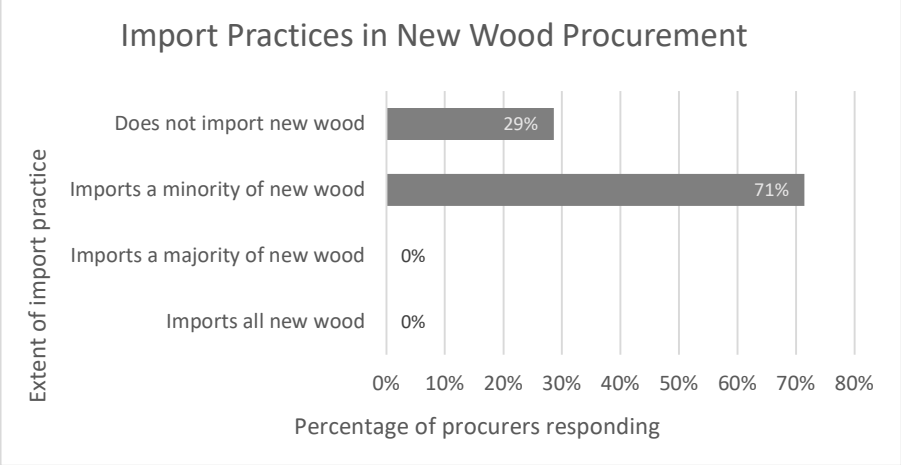

Figure 4-18. New wood import practices among procurement phase participants.

The International Standard on Phytosanitary Measures No. 15 requires all wood packaging material which crosses national borders to undergo heat treatment or chemical fumigation to prevent the spread of diseases and invasive species (*ISPM 15. Regulation of Wood Packaging Material in International Trade*, 2018). Heat treatment is an energy-intensive process and fumigation carries environmental and human toxicity risks. Imported wood has likely been transported over much longer distances than has domestically available wood. Therefore, it is environmentally advantageous to avoid the importation of new wood for wood pallet manufacturing. No procurement phase participant reported importing more than half of their new wood, but most

participants (71%) reported importing a minority fraction of their new wood. The remainder (29%) reported that they did not import any new wood.

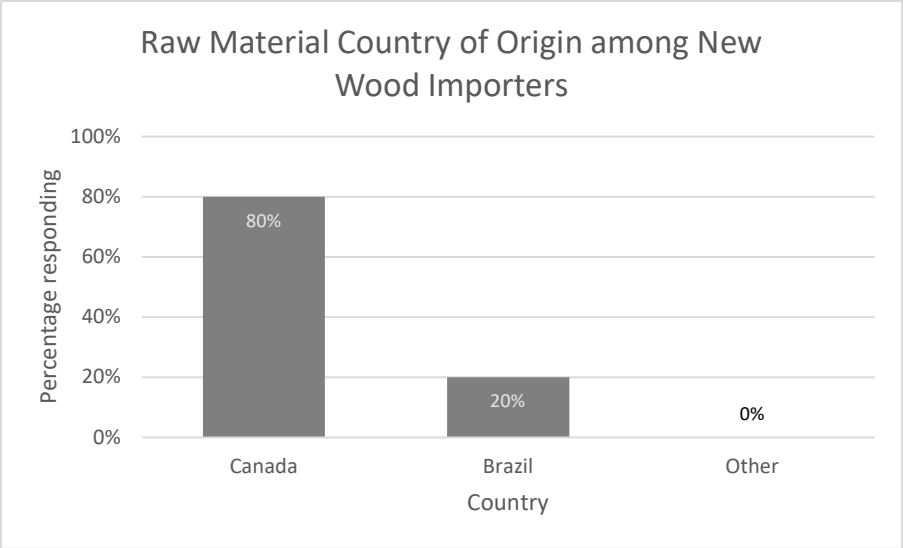

Figure 4-19. Countries of origin of imported new wood among procurement phase participants.

Of the five participants who import new wood, four (80%) import from Canada and one (20%) imports from Brazil. No other countries were represented among new wood exporters in this sample.

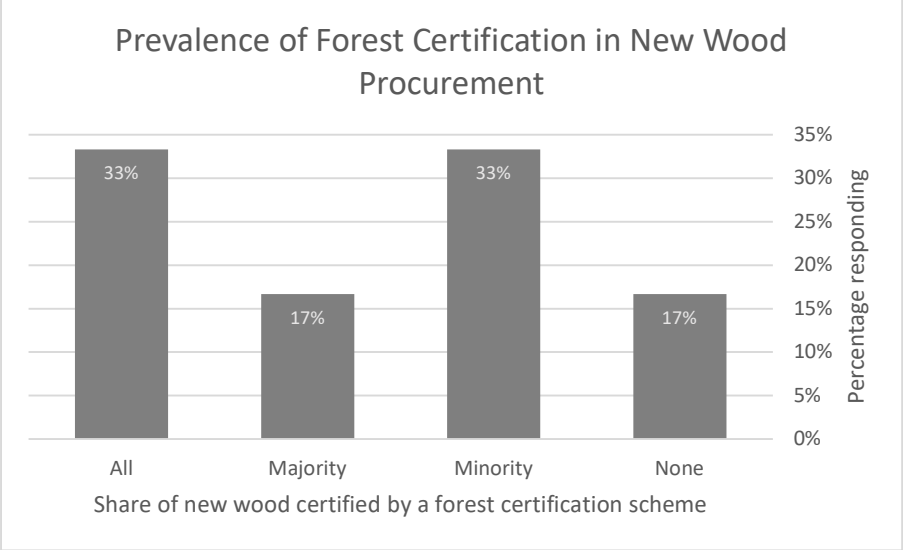

Figure 4-20. Prevalence of forest certification of new wood among procurement phase participants.

Forest certification is a voluntary practice among timber producers which seeks to promote ecologically and socially sustainable forest management practices. It has been shown to have generally positive effects on deforestation, forest degradation, and the economic viability of forest industries across a variety of geographic contexts (Wolff & Schweinle, 2022). There has been a considerable increase in certified wood procurement among American wood pallet manufacturers between 2011 and 2016 (Gerber et al., 2020).

Participants demonstrated varying degrees of certified wood procurement practices; 50% reported purchasing most or all new wood from certified sources, while 50% reported purchasing a minority or none of their new wood from certified sources.

4.3.3 New manufacturing

Six out of eight respondents (two small and four large) reported participation in the manufacturing phase and provided the following information about their new wood pallet manufacturing practices:

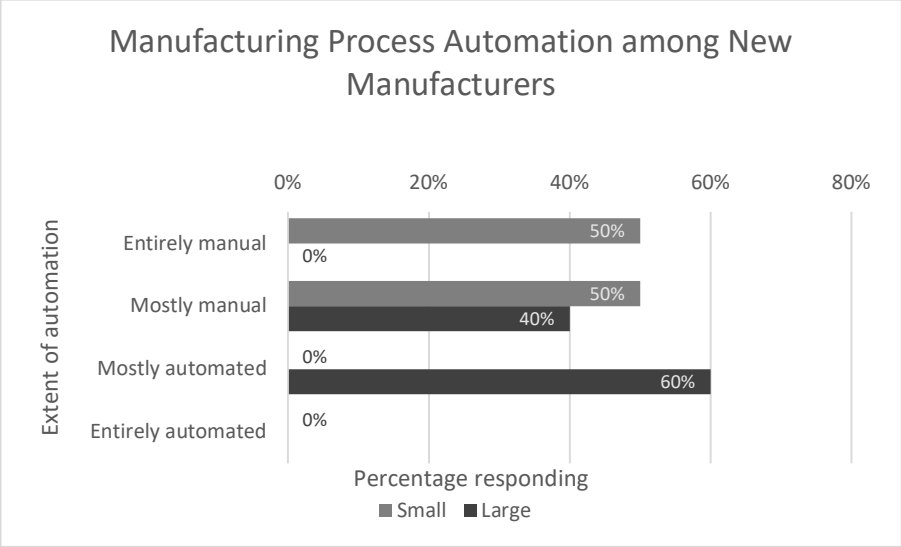

Figure 4-21. Levels of manufacturing process automation among new manufacturing phase participants.

Standardisation of wood pallet manufacturing and repair processes contributes to an increased level of mechanical performance (Clarke & Araman, 2005). Automation of manufacturing processes could enable a greater degree of standardisation, which can lead to more material-efficient designs and reduce the incidence of damages, prolonging product lifespans.

Large organisations reported a greater degree of automation in their manufacturing processes (60% mostly automated, 40% mostly manual) than did small organisations (50% entirely manual, 50% mostly manual), indicating that consolidation could drive manufacturing process automation and standardisation in the wood packaging industry. Most particpants in new manufacturing also reported maintaining some form of quality control scheme in their facilities to maximise product consistency and minimise material losses.

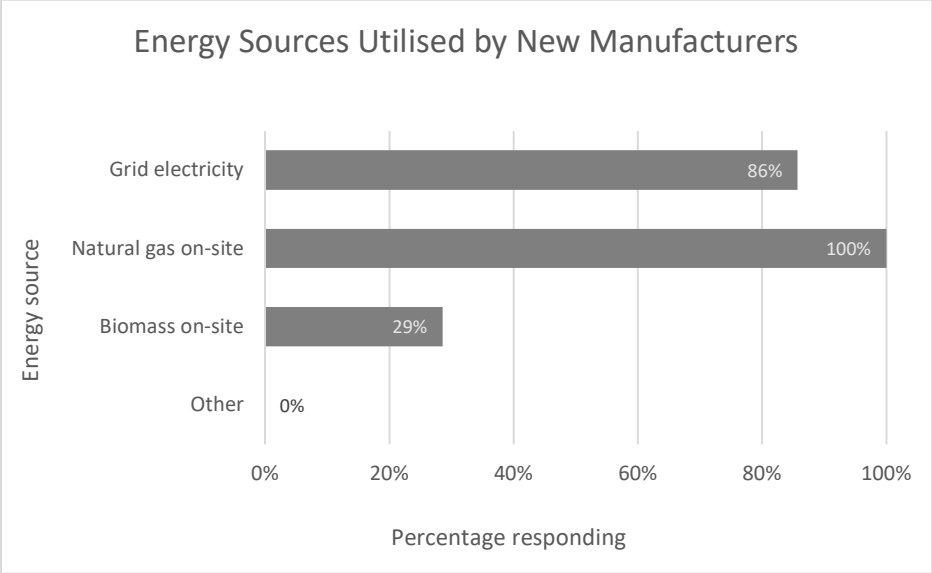

Figure 4-22. Energy sources utilised in manufacturing by new manufacturing phase participants.

For use phase transportation distances under 950 km (590 miles), the manufacturing phase has the highest contribution to the global warming potential of American wood pallet systems out of any life cycle phase (Alanya-Rosenbaum et al., 2021). It is important to consider the GHG intensity of energy consumed by wood pallet manufacturing processes.

100% of new manufacturing participants reported using natural gas for energy production, while 86% reported using grid electricity, a majority of which is generated from fossil fuel sources in the U.S. Despite the availability of wood biomass at pallet manufacturing facilities, only 29% of participants reported generating energy (heat or electricity) from biomass on-site, which is higher than the prevalence of 11% reported in one recent publication on wood pallet repair processes in the U.S. (Park et al., 2016). No participant reported the use of any alternative energy source, such as on-site solar or wind electricity generation.

These results point to an opportunity to reduce the GHG intensity of wood pallet manufacturing in the United States, particularly via the adoption of on-site biomass energy generation practices, but adoption is likely limited by the relatively low value of fuel as a destination for wood waste compared to alternative applications, such as its use as a feedstock for engineered wood products (America, 2002).

4.3.4 Delivery and retrieval

All eight respondents reported participation in the delivery and retrieval phases and provided the following information about their delivery and retrieval practices:

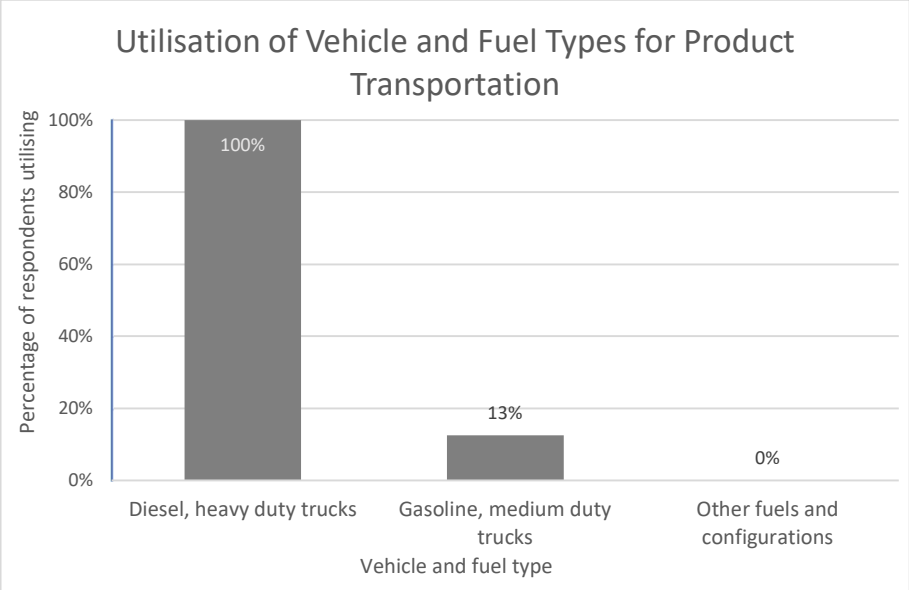

Figure 4-23. Vehicle and fuel types used by respondents.

For use phase transportation distances over 950 km (590 miles), the use phase has the highest contribution to the global warming potential of American wood pallet systems of any life cycle phase (Alanya-Rosenbaum et al., 2021). It is important to consider the GHG intensity of fuels and vehicles used in wood pallet delivery and retrieval activities.

100% of respondents reported use of diesel fuels in heavy-duty trucks (e.g. tractor trailers), while 13% of respondents also reported use of gasoline fuels and medium duty trucks. No respondent reported use of other fuels, such as biofuel or electricity, nor vehicle types, including non-road vehicles such as trains and barges. It is predicted that alternative fuels and road vehicle configurations will not reach significant levels of use by year 2050 without the market influences of additional climate-oriented policy interventions (Kluschke et al., 2019).

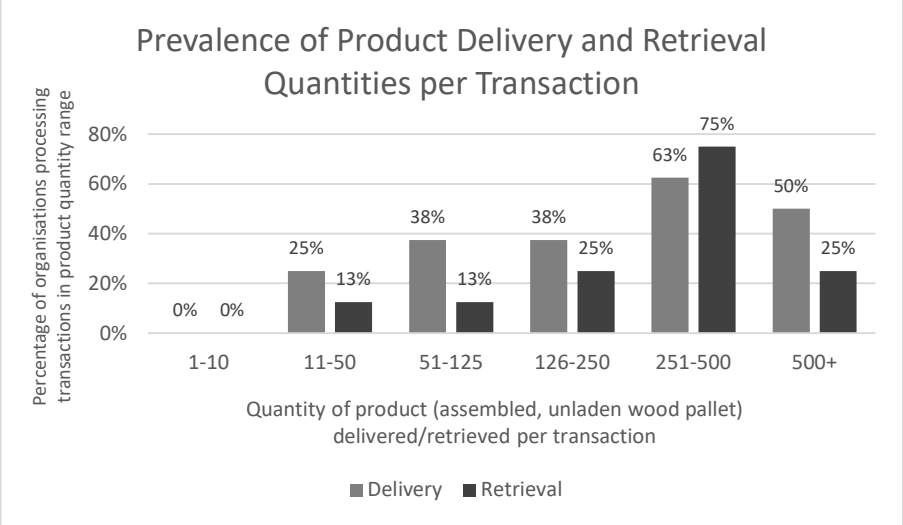

Figure 4-24. Prevalence of product quantities delivered and retrieved by respondents.

Respondents most commonly reported delivering (63%) and retrieving (75%) quantities of 251-500 pallets per transaction, a quantity roughly equivalent to one full heavy-duty truckload. Retrieval of quantities between 11 and 250 pallets was less commonly practiced (13-25%) than delivery of the same quantities (25-38%). 50% of respondents reported delivering and 25% reported receiving quantities of greater than 500 pallets in a single transaction. These results indicate that the delivery and retrieval of quantities as low as 11-50 pallets per transaction can be practically viable, demonstrating the possibility of organised pallet reuse for small-scale (LTL) pallet consumers.

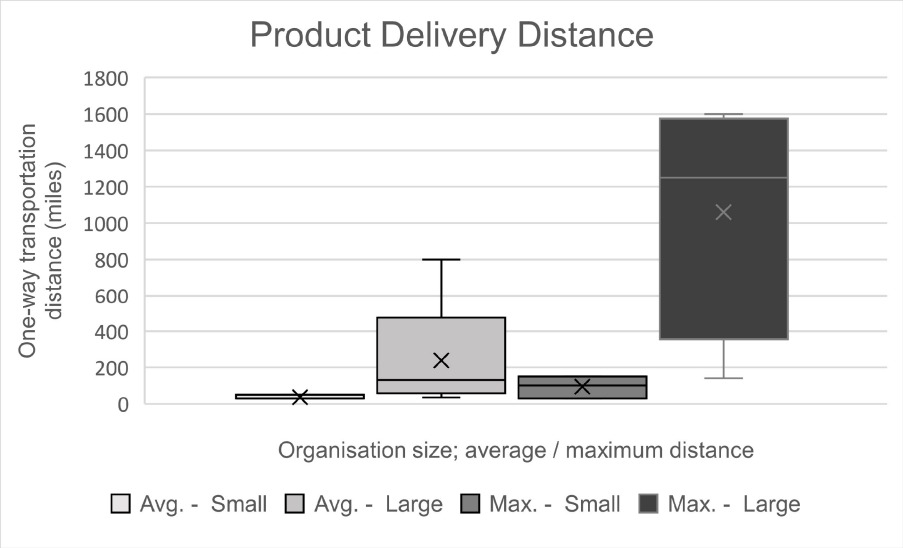

Figure 4-25. Average and maximum product delivery distances by organisation size among respondents.

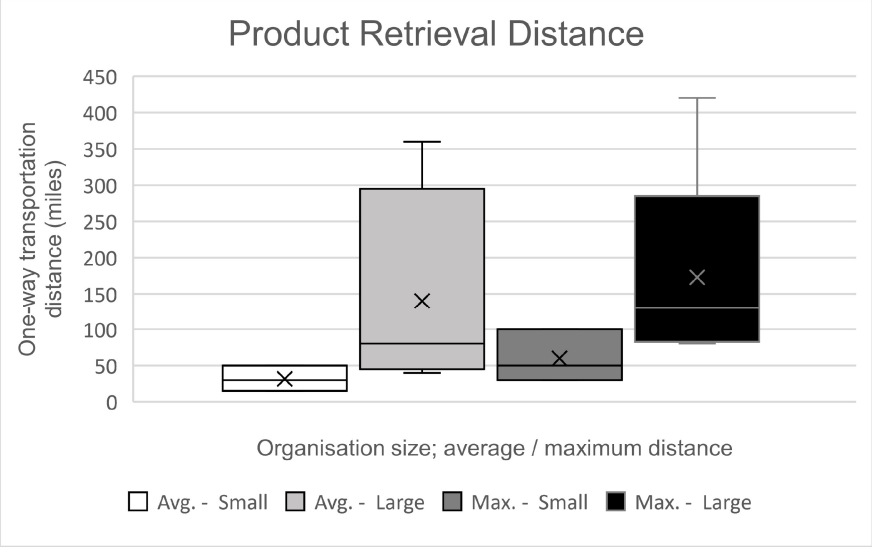

Figure 4-26. Average and maximum product retrieval distances by organisation size among respondents.

Table 4-5. Summary of mean and maximum reported delivery and retrieval distances by organisation size.

Legend: Mean of set [Range], miles	**Organisation size**			
	Small (1-50 employees)		**Large (>50 employees)**	
	Reported mean	Reported max.	Reported mean	Reported max.
Delivery	37 [30-50]	93 [30-150]	239 [35-800]	1060 [140-1600]
Retrieval	32 [15-50]	60 [30-100]	140 [45-360]	173 [80-420]

The global warming potential of American wood pallet systems has been shown to be highly sensitive to use phase transportation distance (Alanya-Rosenbaum et al., 2021). It is important to consider the distances over which wood pallets are transported while unladen with goods.

Mean reported delivery distances were on average much greater than mean reported retrieval (mean response: 163 vs. 94 miles), as well as maximum reported distances for delivery and retrieval (mean response: 646 vs. 131 miles), indicating that wood pallet delivery is practically viable over a much larger geographic service area than is retrieval. Small organisations reported much lower delivery and retrieval distances than did large organisations, as seen in Table 4-5 above.

These findings indicate that a decentralisation of delivery and retrieval activities across a great number of small organisations, each serving a relatively small geographic area, as opposed to a centralised organisation of these activities amongst fewer service points serving larger areas at greater scale, could be effective at decreasing use phase transportation distances, and in turn, reduce the GHG emissions of American wood pallet systems.

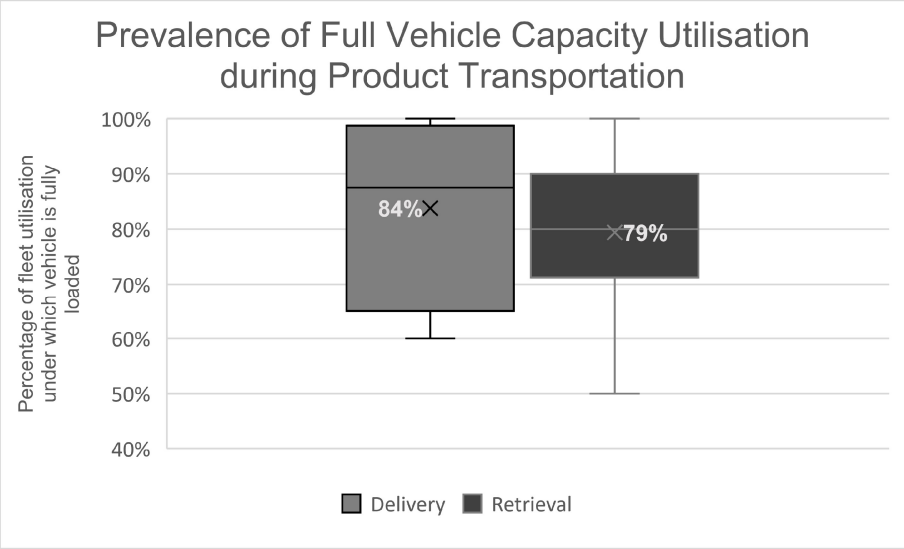

Figure 4-27. Rates of full vehicle capacity utilsation among delivery and retrieval phase participants.

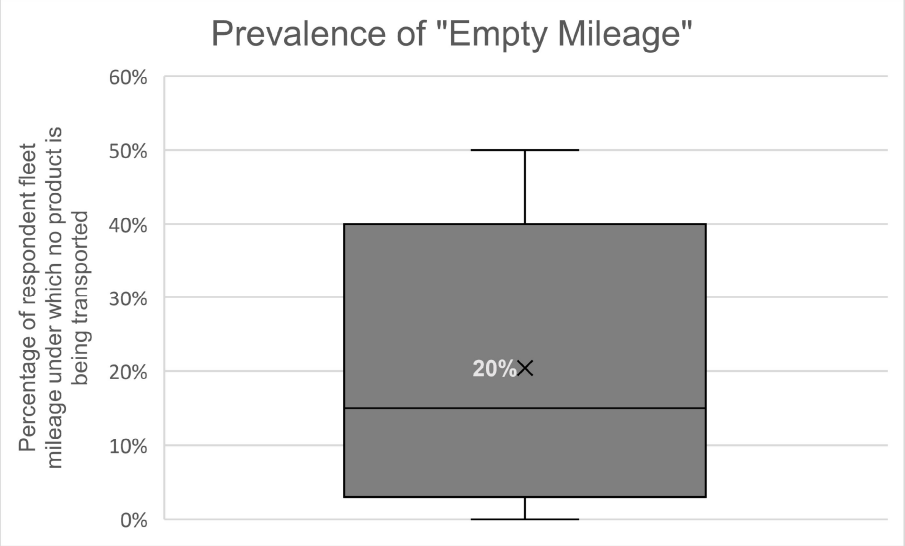

Figure 4-28. Prevalence of "empty mileage" among delivery and retrieval phase participants.

Increasing the utilisation of vehicle capacity during delivery and retrieval reduces the GHG intensity of delivery and retrieval activities, as emissions from fuel consumption are distributed amongst a greater number of products in transit. Delivery activities show a slightly higher prevalence of full capacity utilisation (84% for delivery vs. 79% for retrieval), as seen in Figure 4-27. There is a high variance in the prevalence of "empty mileage," vehicle transport mileage under which no product is moved, among respondents (range: 0-50% of total fleet mileage, mean: 20%). One respondent could not determine a prevalence of empty mileage.

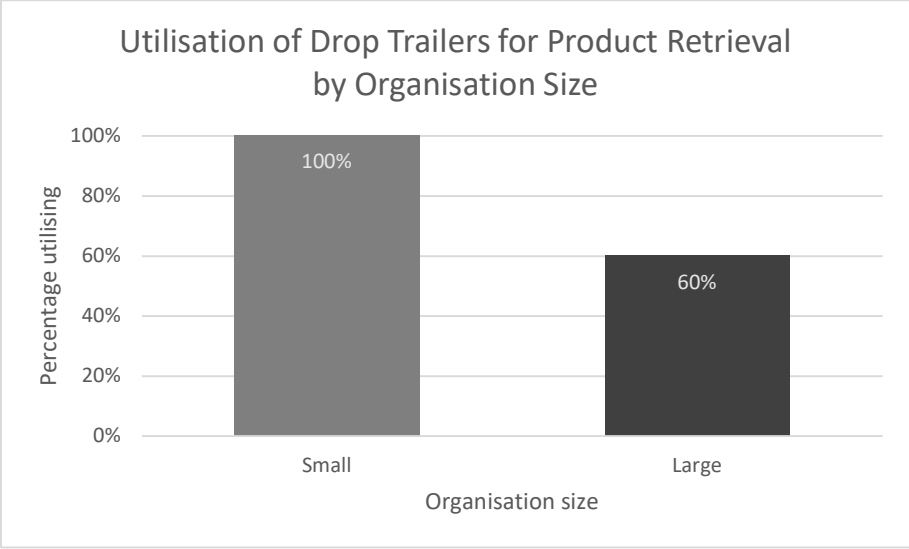

Figure 4-29. Prevalence of drop trailer utilisation by organisation size among retrieval phase participants.

One strategy commonly used by wood pallet recyclers during product retrieval is the use of "drop trailers," which are empty trailers left at a customer location and gradually filled with empty pallets as the customer generates them. The pallet recycler retrieves the trailer once it is full. This practice can reduce the demand for retrievals of LTL quantities of pallets at customer locations, leading to higher vehicle capacity utilisation. 100% of respondents in small

organisations and 60% of respondents in large organisations reported the use of drop trailers for pallet retrieval.

Other strategies reported by respondents to optimise delivery and retrieval practices include the tracking of vehicles using GPS and enterprise resource planning systems, consolidation of several LTL delivery orders into a single vehicle, and staging delivery and retrieval activities sequentially without intermediate return trips to the service point (a practice colloquially known as "milk run deliveries").

The fraction of wood pallets in the U.S. economy which are unrecovered after each use cycle is unknown [A1], but not all wood pallets are recovered for reuse, repair, or EOL management. Reasons given by respondents for the refusal to retrieve pallets include insufficient quantity, poor condition, non-standard dimensions, unsafe loading conditions, and presence of contaminants in the forms of chemicals and metal shavings. It is currently unknown what happens to these lost pallets at EOL, but it is likely that a majority are allowed to decompose, incinerated without energy recovery, or repurposed.

4.3.5 Repair

Repair of damaged wood pallet components is practised to extend the useful life of wood pallets and maintain their resource value. Wood pallet repair and remanufacturing activities in the United States conserve roughly 90% of dry wood mass per repair cycle, with the remainder being ground for recycling or incinerated (Alanya-Rosenbaum et al., 2022). Seven out of eight respondents (three small and four large) reported participation in the repair phase and provided the following information about their wood pallet repair practices:

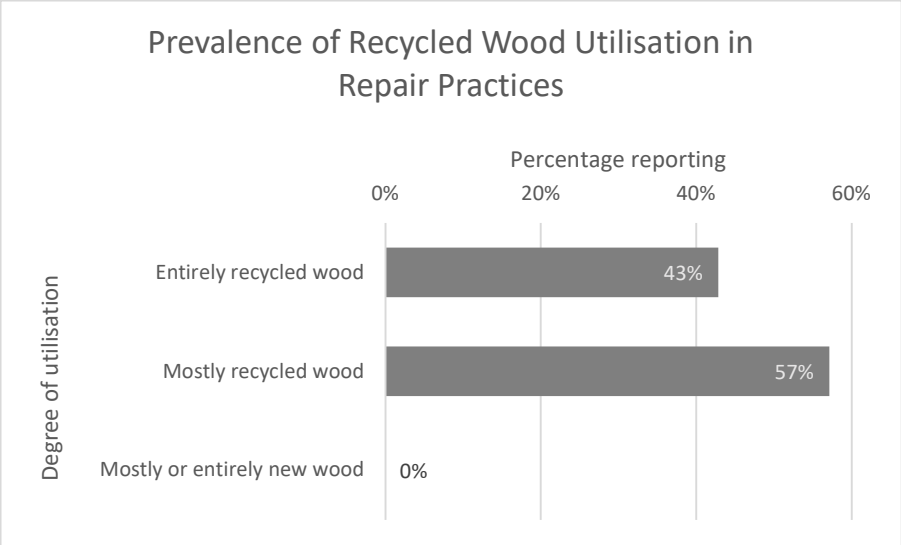

Figure 4-30. Degree of recycled wood utilisation in repair activities among repair phase participants.

All repair phase participants reported a high degree of utilisation of recycled wood, commonly obtained from dismantled cores reaching EOL, in repair activities. All firms used more recycled wood than new wood in repair activities. A large fraction (43%) reported using entirely recycled wood in repair, suggesting that new wood inputs are not strictly necessary for viable wood pallet repair operations.

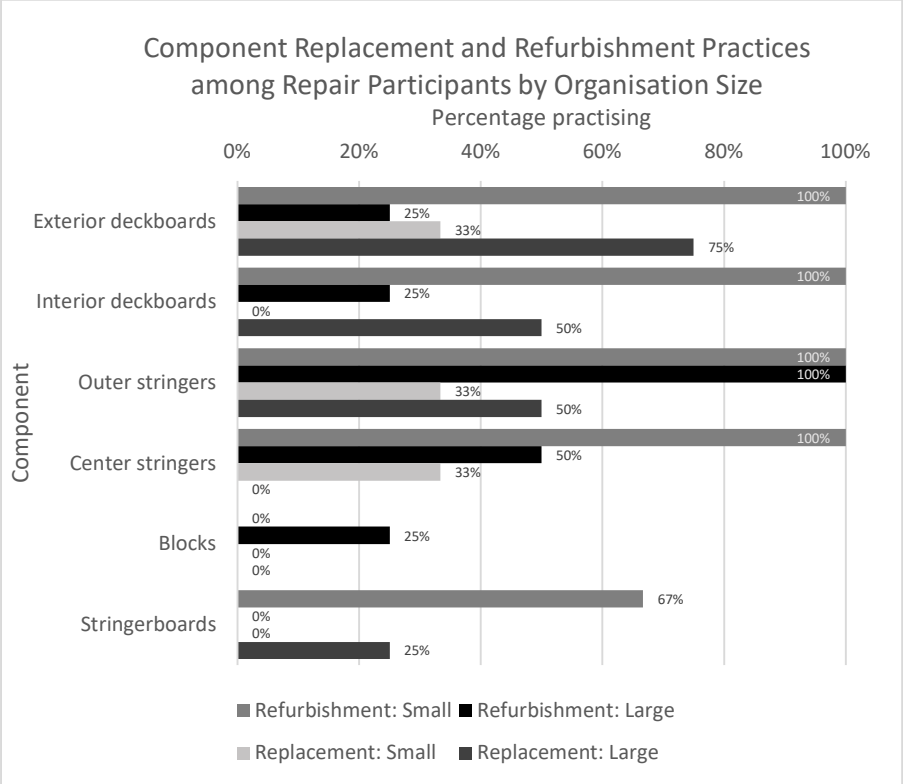

Figure 4-31. Prevalence of selected component refurbishment and replacement practices by organisation size among repair phase participants.

Repair practices can be classified into refurbishment; which involves the fastening of additional material such as lumber, metal plates, or staples to damaged wood components to maintain their integrity; and replacement of damaged wood components with full intact wood components of equivalent dimensions.

Participants reported a higher prevalence of refurbishment practices than replacement practices. Stringers and deckboards were repaired more commonly than blocks and stringerboards, but at least one participant reported refurbishment or replacement of each component type. All participants reported using a grading scheme to classify repaired pallets by quality for resale, but the grading systems were not consistent across participants.

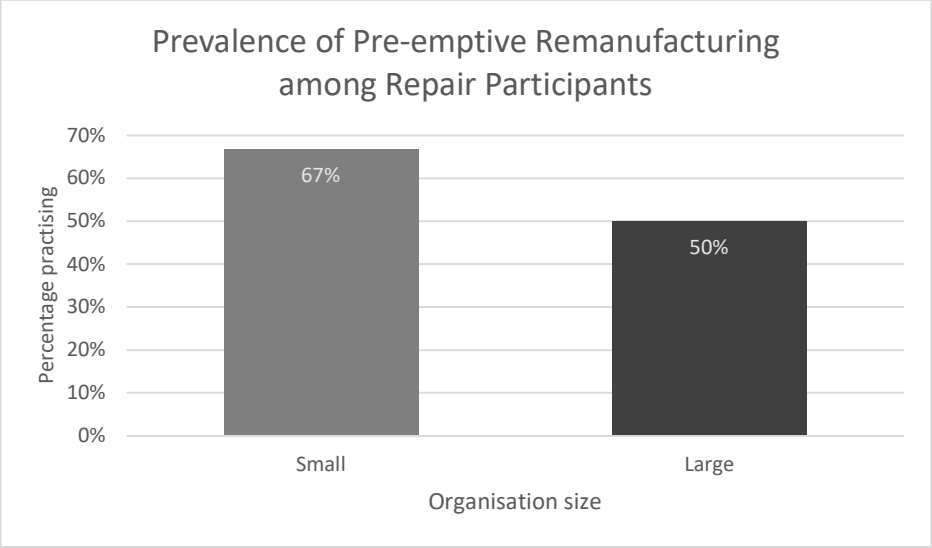

Figure 4-32. Prevalence of pre-emptive remanufacturing practices by organisation size among repair phase participants.

Pre-emptive remanufacturing refers to the practice of repairing undamaged components with a low remaining service life at the same time as damaged components in order to reduce the incidence of component damage and frequency of repairs. When optimised against opportunity loss from prematurely replaced components, pre-emptive remanufacturing reduces the GHG emissions of wood pallet repair activities by 11-41% (Tornese et al., 2016). 67% of small organisations and 50% of large organisations participating in repair reported practising pre-emptive remanufacturing.

4.3.6 Closed loop systems

Three respondents (one small and two large) reported participating in closed loop (returnable) wood pallet systems and provided the following information about their best practises:

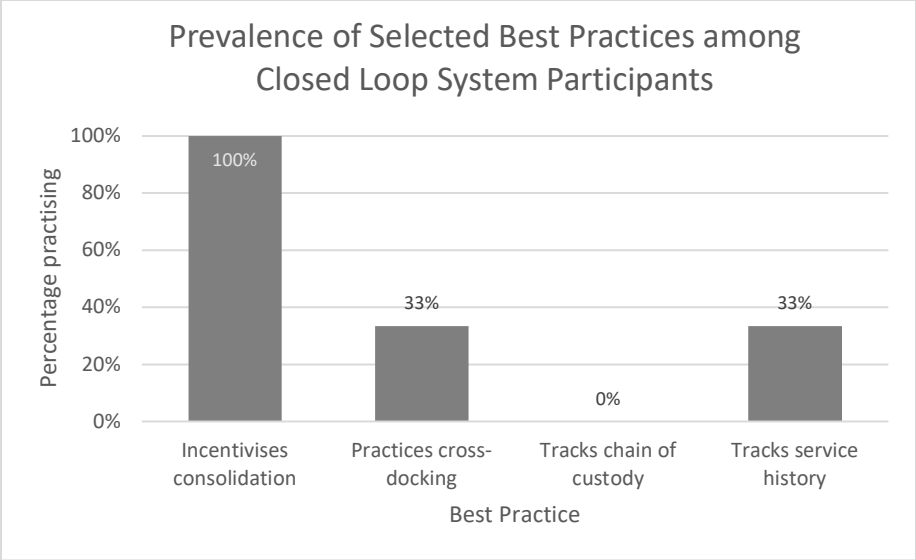

Figure 4-33. Prevalence of selected best practices among closed loop system participants.

Consolidation of empty pallets into FTL quantities within pallet users' supply chains before pooler retrieval has been shown to reduce total system emissions in a simulated Italian retail supply chain by up to 60% compared to a system with only endpoint pooler retrievals (Accorsi et al., 2019). All survey participants report a high degree of consolidation in their closed loop supply chains, in one case incentivising the practice by refusing to retrieve LTL quantities of empty pallets from their customers.

Cross-docking, the practice of inspecting returnable pallets at the collection point and routing undamaged pallets directly to the next user, has been shown to reduce the emissions of returnable wood block pallet systems by 17-73% (Tornese et al., 2016). Only one survey respondent reported this practice, wherein customers perform inspection and sorting of damaged pallets on the recycler's behalf before retrieval.

Detailed information about the locations and service histories of returnable containers has great potential to improve the efficiency of logistics, minimise the incidence of lost and damaged containers, and influence the behaviour of packaging users (Gnimpieba et al., 2015; Kroon & Vrijens, 1995; Wu et al., 2021). These factors are critical for minimisation of the GHG emissions of returnable container systems (Bottani & Casella, 2018). Despite this, the capabilities of surveyed participants to collect this information are limited: No participant can track the chain of custody (or location) of individual pallets, and only one participant maintains service histories of individual pallets within their closed loop systems. This participant reported that tracking service history helped them reduce the incidence of lost and damaged pallets within their system.

4.3.7 End-of-life management

Seven out of eight respondents (three small and four large) reported participation in the end-of-life management phase and provided the following information about their management of wood pallets at EOL:

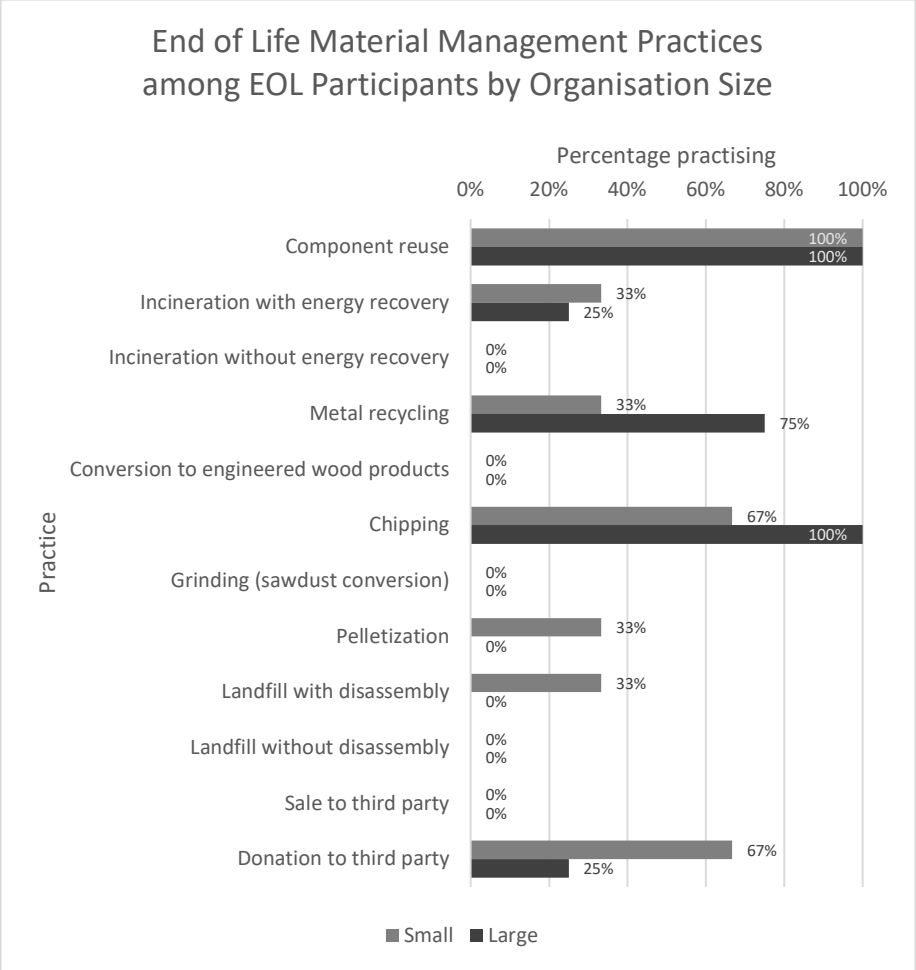

Figure 4-34. Prevalence of selected EOL material management practices by organisation size among EOL phase participants.

The EOL practice which retains the greatest resource value of wood waste, direct reuse of components in repair activities, was also the most widely practised: 100% of participants reported component reuse. Incineration with energy recovery, the EOL practice with the greatest potential for global warming mitigation (Alanya-Rosenbaum et al., 2021; Carrano et al., 2015), was practised by relatively few participants (33% small, 25% large). No participant reported conversion of wood waste into engineered wood products despite its relatively high value compared to other wood waste destinations (America, 2002).

Larger organisations show a higher prevalence of chipping and metal recycling (100% and 75%) than do small organisations (67% and 33%). Small organisations show a higher prevalence of landfilling (33% vs. 0%) and donation to third parties (67% vs. 25%), which are both undesirable EOL practices in regard to maintaining resource value. Participants reported that contamination

from oil, chemicals, metal shavings, and mold can cause wood pallets to reach EOL prematurely in their operations.