APCO Packaging Material Flow Analysis 2018

February 28, 2019

Australian Packaging Covenant Organisation

This report was prepared by the Institute of Sustainable Futures (ISF) for Australian Packaging Covenant Organisation (APCO) with with a high level of care and thoroughness and recommend that it is read in full.

This report was prepared in accordance with the scope of work and for the purpose outlined in the project brief. The method adopted, and sources of information used are outlined in this report, except where provided on a confidential basis. The definitions used in this document are used in the context of this analysis only and do not apply beyond the scope of this document to other publications from APCO. This report has been prepared for use by APCO, and only other third parties who have been authorised by APCO. Neither the authors or APCO are liable for any loss or damage that may be occasioned directly or indirectly using, or reliance on, the contents of this publication. This report does not purport to give legal or financial advice. No other warranty, expressed or implied, is made as to the professional advice included in this report.

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Citation

Please cite as: Madden, B. and Florin, N. (2019). Characterising the material flows through the Australian waste packaging system, Institute for Sustainable Futures, University of Technology Sydney

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Foreword

Australia's approach to sustainable packaging has entered an era of significant change. China's policy on the acceptance of waste has introduced a new conversation about how we manage our own packaging waste here in Australia. This paradigm shift is driving Australian industry, government and consumers to ask how we can redesign our current packaging ecosystem and what will be required to move towards a circular economic model.

In 2018, Federal and State Environment Ministers, alongside industry leaders, announced the landmark 2025 National Packaging Targets. In the process, they also endorsed APCO as the organisation to facilitate the creation of a new vision of 100% reusable, recyclable or compostable packaging in Australia.

To achieve the 2025 targets, we need to first understand the journey packaging materials take along the entire supply chain and establish a baseline of data to measure change and the effect of interventions. This report, APCO Packaging Material Flow Analysis 2018, is the first step in that process.

Developed by the Institute of Sustainable Futures on behalf of the Australian Packaging Covenant Organisation, it combines data from government, industry and academic sources, expert interviews and peer review, with the application of mathematical modelling to understand the lifecycle of Australia's post-consumer packaging.

The report compellingly illustrates the interconnections between all packaging recovery systems and, for the first time, provides a holistic view of the impact of potential improvements. As Australia goes through an era of significant change in managing waste and recycling, this overarching perspective reinforces the need to redesign the way we consume, dispose of, recover and reprocess our packaging materials.

Looking to the findings, the report highlights a compelling need to improve packaging recovery and recycling rates across all material streams. It also highlights significant data and infrastructure gaps, which must be addressed. This initial diagnosis is a key starting point that will inform further action on packaging consumption and recycling to develop baselines for the 2025 National Packaging Targets.

The report also explores the potential impact of a range of intervention scenarios. The discussions these examples will encourage are important as they provide a deeper understanding of each recovery pathway. Whilst this report has explored a limited range of potential scenarios, it is vitally important to help model an evidence-based and economically sustainable approach across a range of potential interventions and design changes.

As we refine our understanding of the packaging waste system and the potential impact of policy decisions, the joint input of industry and governments will be essential to ensure these strategies can be implemented in practice. This research emphasises not only the need for improved data collection, but also a broader plan of action to fast track the transition to a more effective and efficient used packaging management system.

Key to the success of achieving the 2025 National Packaging Targets will be the willingness of all stakeholders to develop a collective, consistent and proactive approach to information sharing and problem solving within the packaging ecosystem. The challenge ahead of us requires a complete transformation of the current system.

Over the next 12 months, APCO will be co-ordinating and facilitating an ambitious agenda of projects to build on the findings of this report. These projects and the requisite working groups will provide analysis and resources to an overarching Collective Action Group (CAG). The CAG will facilitate the development of evidence-based analysis for key stakeholders across the packaging value chain. This will enable stakeholders to identify, leverage and lead the systemic opportunities and intervention points within a newly developed framework to successfully transition to a circular economy for packaging in Australia.

The group will be formed through an open recruitment process, designed to bring together representatives from across the value chain. The CAG will be facilitated by APCO and will be led by a non-executive Chair, skilled in the facilitation of industry directed change models and co-regulatory programs. The CAG will receive and consider the system improvement recommendations developed by a series of independently facilitated Working Groups across a range of projects and material flows.

At the culmination of the process, more than 150 industry and government representatives from all segments of the packaging materials supply chain will have contributed to the process. The CAG's objective is to deliver, at the close of 2019, a white paper that describes a systemic model for how Australia can transition to an advanced sustainable packaging ecosystem. This will include a performance and gap analysis of the current system with a broad economic, environmental and cultural analysis to understand current and future impacts. APCO looks forward to working closely with all stakeholders to ensure a collaborative stakeholder approach moving forward.

Brooke Donnelly
Chief Executive Officer
Australian Packaging Covenant Organisation

Executive Summary

On 27 April 2018, Commonwealth, state and territory environment ministers and the President of the Australian Local Government Association committed to set a sustainable path for Australia's recyclable waste. The announcement saw the endorsement of key circular economy principles that drive waste reduction, improve local resource recovery and increase demand for products that contain recycled materials.

Developing a circular economy for used packaging in Australia requires a fundamental system change, involving coordinated action across the whole supply chain from manufacturers, brand owners, consumers, and the resource recovery sector. Circular economies require a shift from a 'take, make, dispose' consumption model to a 'circular' model where resources are kept in use as long as possible. Shifting the management of used packaging is an important part of transitioning Australia to a circular economy. The recent challenges faced by our recycling sector in the wake of China's decision to halt the imports of large amounts of recyclable materials have helped focus the attention to our collective ability to recover greater value from used packaging materials.

Packaging waste is currently a poorly characterised waste stream in Australia and the materials from packaging – post-consumer glass, paper, metal and plastic – also have a very low rate of recovery for manufacturing new products, or for energy generation. A more detailed understanding of the material flows for packaging supports the development of appropriate management solutions and strategies to transition to a circular economy approach.

The Australian Packaging Covenant Organisation (APCO) commissioned the Institute for Sustainable Futures at the University of Technology Sydney (ISF) to characterise the waste material flows through the Australian waste packaging system, using material flow analysis (MFA) methodology. MFA assists in visualising the flows of packaging materials throughout the Australian waste system, from consumption through to reprocessing. This analysis provides a comprehensive understanding of the collection, sorting and recovery systems in Australia, identifying a range of potential strategies across the value chain to improve recovery of packaging.

Analysis was undertaken for the postconsumer glass, paper, metal, and plastic packaging waste systems in Australia for the 2017/18 financial year (July 1 2017 to June 30 2018). These material flow estimates were used as a baseline for evaluating future scenarios to improve packaging waste management in Australia, towards the implementation of a circular economy for packaging. Importantly, the results provide estimates for packaging currently being collected, sorted, recovered and recycled at the end of its useful life. Efforts to improve packaging design to make it recyclable are focused at the manufacturing stage of the packaging lifecycle, and thus fall outside of the scope of this analysis.

Results

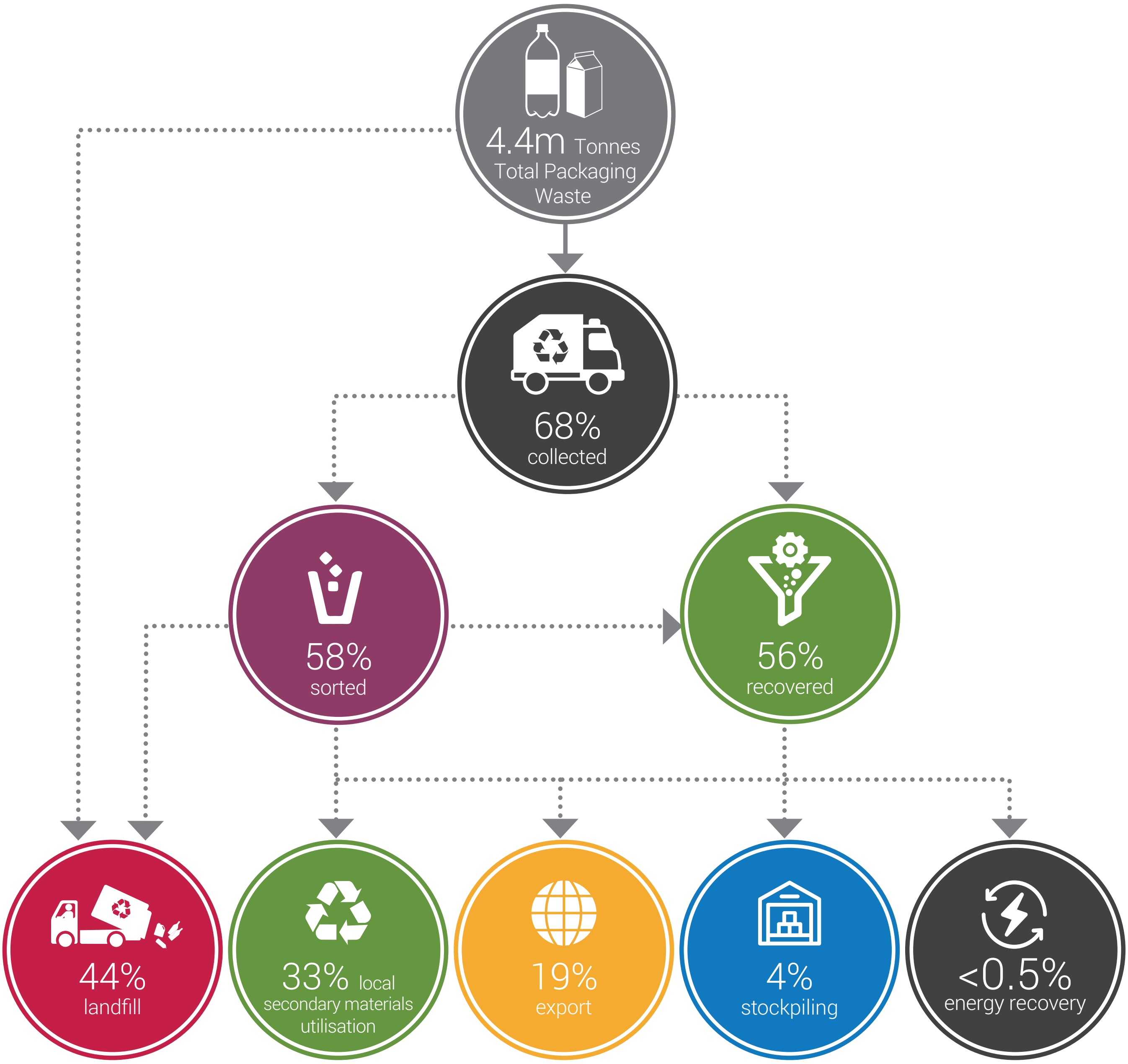
We estimate an overall packaging waste recovery rate of 56% for 2017/18 **(Figure I)**, ranging from an average 32% for plastics, up to 72% for paper streams – highlighting the significant opportunity to improve waste management practices to achieve higher recovery rates.

Total amounts of packaging waste generated and recovered for all streams is presented in **Table I** and a flow chart showing the fate of the packaging waste streams is given in **Figure I.** Waste exported overseas represents a significant proportion of the total waste recovered and this points to the importance of growing local utilisation of secondary materials to achieve greater resilience in the Australian packaging system to fluctuations in global markets.

Table 1 *Total amounts of packaging waste generated and recovered, based on our material flow analysis for the Financial Year: July 1 2017 to June 30 2018*

Waste Packaging Stream	Generated Packaging Waste (T)	Recovered Incl. Exports And Stockpiles (T)	Recovery Rate
Total Packaging	4,422,845	2,491,278	56% ±17%
Glass	1,292,016	641,372	50% ±8%
Paper	2,052,052	1,470,186	72% ±13%
Unbleached	1,274,250	909,010	71% ±13%
Mixed	776,923	561,176	72% ±13%
Metal	**171,375**	**92,217**	**54% ±10%**
Aluminium	61,559	44,059	72% ±13%
Steel	109,816	48,158	44% ±8%
Plastic	**907,401**	**287,502**	**32% ±4%**
PET	138,585	40,764	29% ±5%
HDPE	328,727	96,883	29% ±4%
PVC	17,014	4,794	28% ±3%
LDPE	220,148	61,518	28% ±4%
PP	101,464	27,156	27% ±4%
PS	26,913	8,022	30% ±4%
Other	74,551	48,365	65% ±7%

***Figure I** Fate of packaging waste flows through the Australian waste system with current (aggregated) rates for collection, sorting and recovery.*



Traditionally waste exported overseas represents a significant proportion of the total waste recovered **(Figure I).** This points to the importance of growing local utilisation of secondary materials to achieve greater resilience in the Australian packaging system to fluctuations in global markets.

Figure II Estimated total packaging flows through the Australian waste management system (FY 2017/2018)

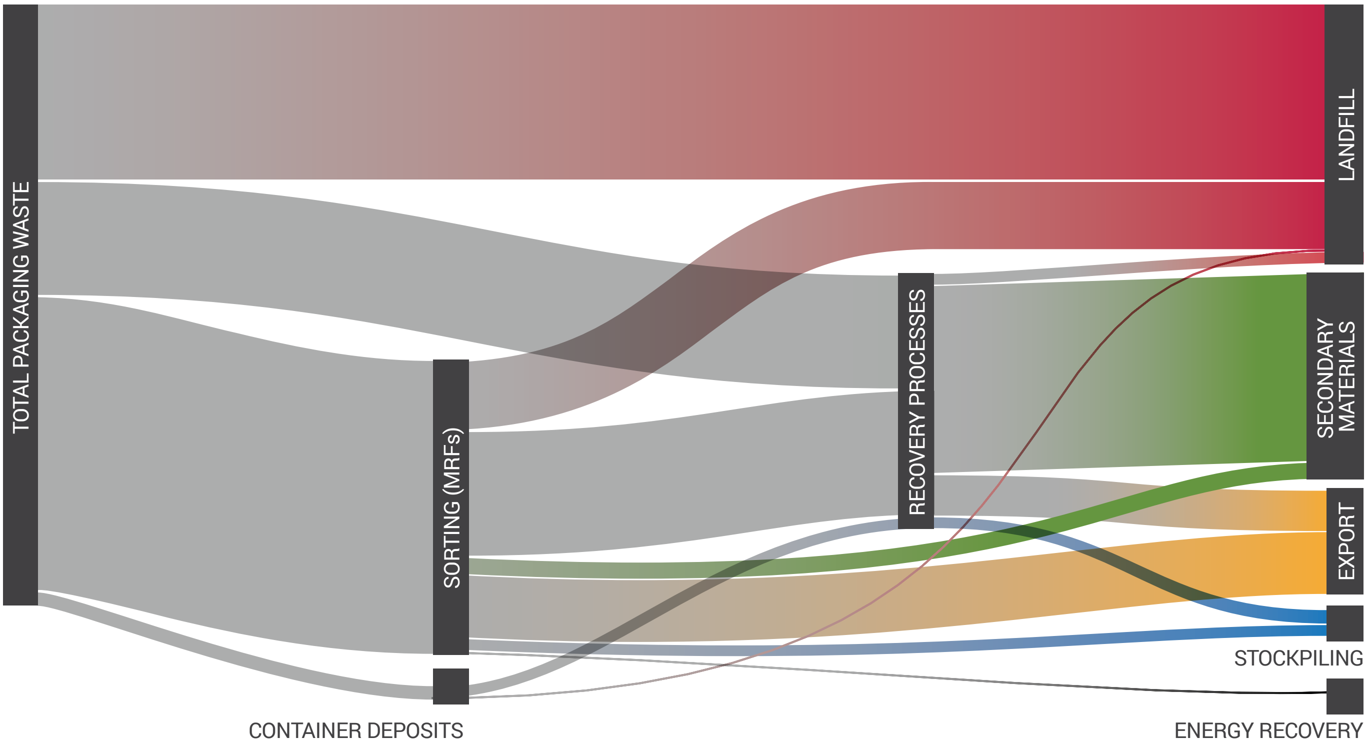


Figure II shows the major losses to landfill of recoverable materials occurring before waste is collected for sorting at material recycling facilities (MRFs), or container deposit scheme (CDS) collections. These losses can be attributed to incorrect disposal of packaging wastes by households and businesses. Better management of this waste at the source, through improved source separation, is important. Critically, consumer education and awareness raising around appropriate disposal and collection channels, as well as smarter design of packaging for recycling, are also key strategies. These are already supported by the new Australasian Recycling label (ARL) and the Packaging Recyclability Evaluation Portal (PREP). The removal of contaminants from the stream of collected materials through better source separation will improve sorting efficiency at the MRFs, along with investment in better sorting equipment. Additionally, this analysis shows the opportunity to increase overall sorting efficiency by diverting materials (especially glass) from kerbside to the expanding container deposit scheme collections.

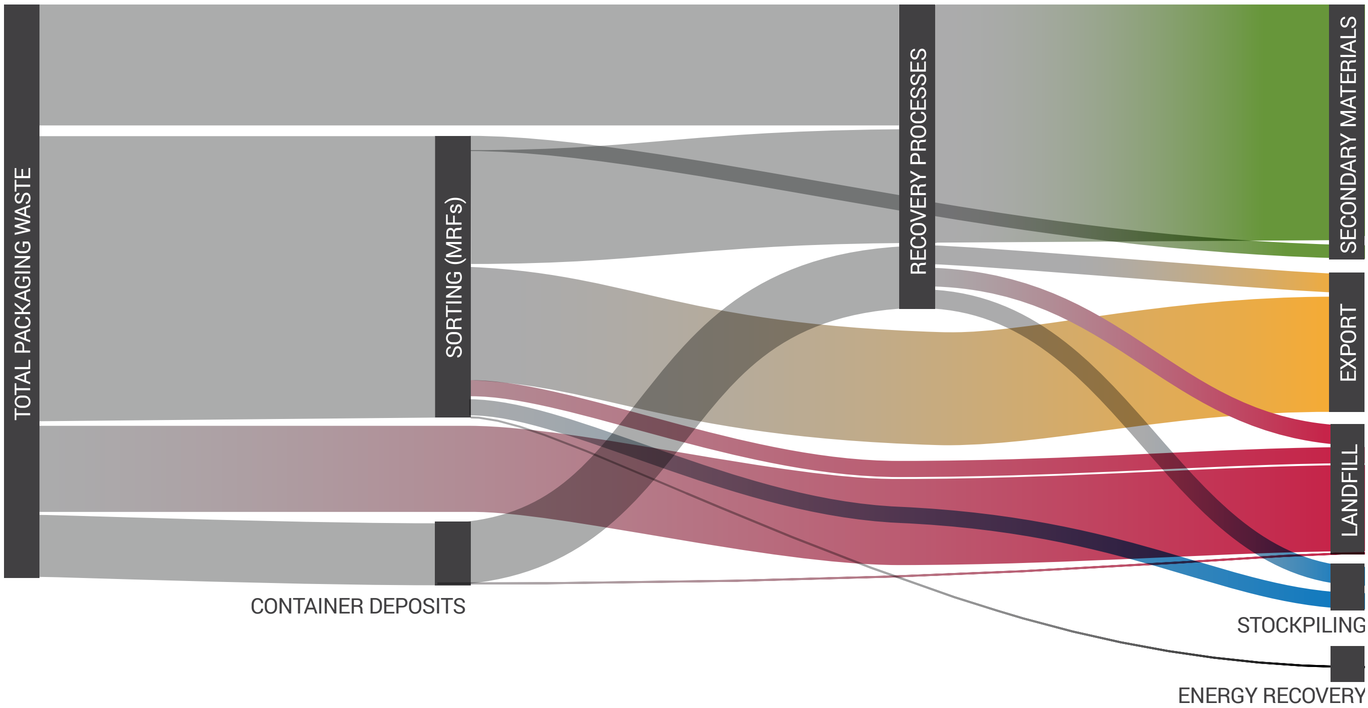
Future scenario modelling shows the potential to achieve an overall packaging waste recovery rate of 77%. This recovery rate is achievable with the assumed adoption of a range of strategies to address losses across the whole chain, from collection to reprocessing.

Figure III shows total flows through a future system assuming:

- A reduction in the disposal of recyclable packaging to the residual stream
- The deployment of CDS collections Australia-wide
- Adoption of best practice sorting at MRFs (e.g. optical sorting)
- Developing and implementing capacity for the composting of packaging.

These interventions are not exhaustive and may be complemented by other strategies to improve the performance of the waste packaging system.

Figure III *Modelled total packaging flows through a potential future Australian waste management system based on a future scenario analysis*



Performance measures

Four performance measures were used to highlight where the most significant losses are occurring, and where the main opportunities to improve recovery might exist for the individual streams.

Collection efficiency

Collection efficiency is the proportion of waste collected for sorting and/or recovery relative to total post-consumer packaging waste generated.

Sorting efficiency

Sorting efficiency is the proportion of waste destined for re-processing/downstream recovery and export to total post-consumer packaging waste generated.

Recovery rate

Recovery rate is the total waste recovered as a proportion of total post-consumer packaging waste generated (including local material utilisation, export, stockpiling, energy recovery).

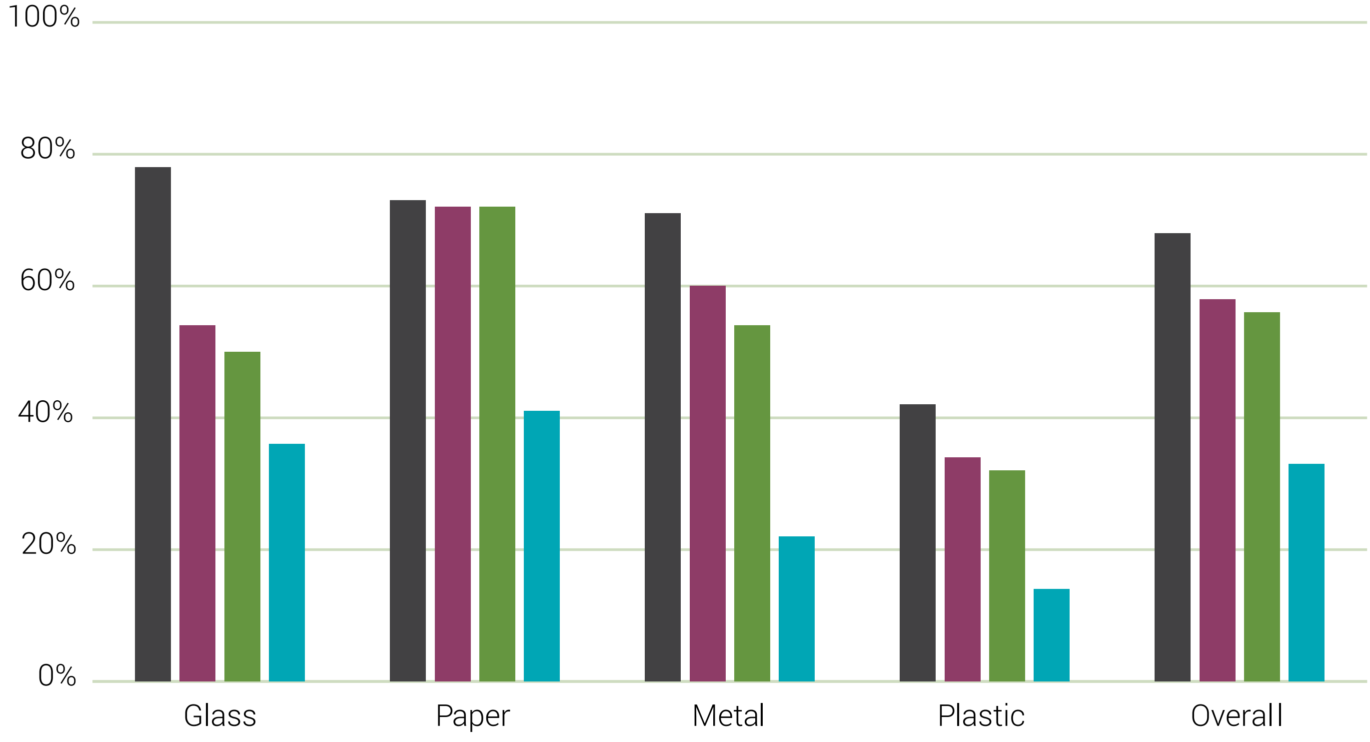
Local material utilisation rate

Local material utilisation rate highlights the proportion of materials that are recovered that are used for local manufacturing of new products.

Figure IV compares these performance metrics for each waste system. For example, highest collection efficiency is achieved for glass, yet a major decline is observed for glass sorting efficiency owing to significant losses at the MRF, e.g. due to breakages during transportation and handling, and during sorting into pieces too small for standard sorting equipment. This highlights the importance of reducing these losses that could be achieved with separate glass collections and/or by diverting collection from kerbside to CDS to avoid handling losses.

Tracing the drop-off in efficiency along the chain is useful to identify important intervention points. For example, for the paper system it is apparent that a reliance on export markets makes this system particularly vulnerable to fluctuations in global markets, as has been observed for the mixed paper stream with the curtailment of China as an export destination. The poor collection efficiency for plastic highlights the importance of better management of this stream at the source through greater source separation.

Figure IV *Comparison of key performance metrics for the different waste packaging material streams*



	GLASS	PAPER	METAL	PLASTIC	OVERALL
Collection efficiency	78%	73%	71%	42%	68%
Sorting efficiency	54%	72%	60%	34%	58%
Recovery rate	50%	72%	54%	32%	56%
Local material utilisation rate	36%	41%	22%	14%	33%

Recommendations

This study demonstrates the great potential to increase the recovery of packaging materials towards a circular packaging economy by adopting a range of strategies across the whole chain from collection to reprocessing. We note that not all strategies for achieving higher recovery have been examined in this study, including importantly the possibility of avoiding packaging, redesign of packaging to eliminate difficult to recycle materials (e.g. composites), reuse, and ramping up energy recovery (via biological or thermal processes). We have highlighted the significant paucity of data characterising the Australian packaging system that is needed to inform future strategies.

Packaging design, industry and consumer disposal practices, and sorting and processing capacity must all evolve in parallel to effectively bring about the system change required for a circular economy for packaging in Australia.

Specifically:

- Better data characterising the packaging waste stream that is not being collected (e.g. litter, leakage to the residual stream) is important to inform future strategies that might for example promote packaging redesign, or prioritise scaling up source separation of soft plastics.
- Equally, better data describing MRF operating efficiencies for individual material streams can inform a priority strategy for investment and/or clarify the extent to which diverting kerbside collections to CDS collections is beneficial.
- Data characterising compostable packaging is also limited. Greater clarity on what materials might be replaced with compostables, as well as the implications for downstream investment processing capacity is necessary to inform holistic strategies to improve packaging recovery.
- Better data on the number, throughput capacity and individual sorting capabilities of MRFs and throughput capacity of reprocessors currently in operation would improve future scenario assumptions. These data limitations make it difficult to accurately identify specific system constraints and/or opportunities to scale-up sorting and processing capacities.
- Finally, energy recovery (both biological and thermal processing) is likely to be a necessary final component to achieve very high recovery targets (i.e., > 77 %) particularly if the amount of materials exported is limited in the future. Deployment of these technologies at the right scale can support waste recovery and carbon mitigation objectives.

Australia's approach to managing packaging waste, supported by ambitious targets, is approaching an era of significant, fundamental change. For the first time, this report has identified the state-of-play with respect to characterising material flows for packaging waste in Australia. With limited data, it paints a compelling picture of the need to increase recovery rates and shows the potential of possible future interventions.

Importantly, this analysis identifies that currently available data is insufficient and concerted efforts by all stakeholders will be required to provide an accurate national picture. Some future directions for packaging waste management are clear, others are more complex, contested and require better data to inform decision making.

Contents

Glossary	Definitions
Beneficiation	Process for separating glass into different colour streams, cleaning and removing contaminants (e.g. Pyrex)
Collection efficiency	Materials collected for recycling divided by total packaging waste entering the collection system
Commercial and Industrial (C&I)	Materials arising from commercial and industrial sources
Compostable packaging	Packaging that, in an industrial system, is designed to degrade by biological processes to yield carbon dioxide, water, inorganic compounds and biomass
Container deposit scheme	Separate collection system for paper, plastic and metal containers
Cullet	Whole or crushed and glass ready to be remelted. We assume for this study an insignificant amount of contamination in cullet produced through beneficiation
Domestic	Materials from domestic (households) sources
EPS	Expanded polystyrene (PIC 6)
Flow	Material transfer through the system
HDPE	High density polyethylene (PIC 2)
Household	Materials from domestic (household) sources
Kerbside recycling	Materials collected at kerbside from municipal sources
LDPE	Low density polyethylene (PIC 4)
Local material utilisation	Materials recovered and reprocessed (recyclate) for use within Australia for the manufacture of new products
Local material utilisation rate	Materials recovered for local manufacturing of new product divided by total packaging waste entering the system
Material flow analysis (MFA)	Material flow analysis is an assessment of state and changes of material flows and stocks in a defined system
Material recovery facilities (MRF)	A facility for sorting of recyclables into product streams
Mixed paper	A general definition is post-consumer kerbside mix of fibre based packaging and non-packaging papers. Includes materials such as magazine, newspaper, marketing, some OCC. Typically has high levels of contamination, e.g. glass fragments. *Note: In this study we consider packaging papers only, and not other paper waste streams*
Mixed plastics	A general definition is post-consumer kerbside mix of plastics based packaging and non-packaging items. Includes materials such as bottles, containers, and other packaging formats consisting of all major polymers *Note: in this study we consider packaging only and assume mix plastics to be all remaining polymers after the separation of PET and HDPE at MRF*

Glossary	Definitions
OCC	Old corrugated cardboard (unbleached kraft)
Packaging	Material used for the containment, protection, marketing or handling of a product. Includes primary secondary and tertiary (freight) packaging for consumer and industrial applications
PET	Polyethylene terephthalate (PIC 1)
PIC	Plastic identification code
PP	Polypropylene (PIC 5)
Process	Activity involving a transformation, transportation or storage of materials
PS	Polystyrene (PIC 6)
PVC	Polyvinyl chloride (PIC 3)
Recovery rate	Total materials recovered (incl. materials for local manufacturing, energy recovery, export and stockpiling) divided by total packaging waste entering the system
Recyclate	Scrap material either before or after reprocessing
Recycling	A general term covering the chain of processes encompassing collection, sorting, reprocessing and the manufacture of new product
Reprocessing	Processes that convert materials collected at end of life for conversion into raw materials as input for the manufacture of new product
Residual stream	A general definition is post-consumer waste recovered at household (red bin)
Sorting efficiency	Material processed at MRF or CDS divided by total packaging waste entering the system
Stock	Quantity of material held within a process activity (e.g., stockpiling)
System	Set of material flows, processes and stocks with well-defined bounds (geographical, temporal)
System boundary	Geographical, 'virtual' (e.g. packaging waste), use systems (e.g. co-mingled kerbside collection) and temporal
Transfer coefficient	A derived factor that defines the partitioning of an input entering a process into a transformed material stream (e.g., the separation of PET from kerbside recycling materials at MRF)
Unbleached kraft	Old corrugated cardboard (OCC)
Un-utilised secondary materials	Recovered materials that are not used for local manufacture (stockpiled)

1 Introduction

Project context and scope

On 27 April 2018, the Meeting of Environment Ministers (MEM) committed to set a sustainable path for Australia's recyclable waste. The announcement saw the endorsement of key circular economy principles that drive waste reduction, improve local resource recovery and increase demand for products that contain recycled materials.

Developing a circular economy for used packaging in Australia requires a fundamental system change, involving coordinated action across the whole supply chain from manufacturers, brand owners, consumers, and the resource recovery sector. Shifting the management of used packaging is an important part of transitioning Australia to a circular economy. The recent challenges faced by our recycling sector in the wake of China's decision to halt the imports of large amounts of recyclable materials has helped focus the attention to our collective ability to recover greater value from used packaging materials.

Packaging waste is currently a poorly characterised waste stream in Australia and the materials from packaging – post-consumer glass, paper, metal and plastic – also have a very low rate of recovery for manufacturing new products, or for energy generation. A more detailed understanding of the material flows for packaging supports the development of appropriate management solutions and strategies to transition to a circular economy approach.

Research approach

This document summarises research conducted by the Institute for Sustainable Futures (ISF) for the Australian Packaging Covenant Organisation (APCO) characterising the material flows through the Australian waste packaging system, using material flow analysis (MFA).

The research involved four distinct phases:

- The initial phase of the research established the **inventory of available data** describing the packaging waste system. We collected and collated data from a number of government, industry and academic sources and assessed quality and reliability, to determine the impact of this data uncertainty on the MFA;
- **MFAs** were undertaken for the paper, glass, metals and plastic packaging systems.[1] The MFAs highlighted significant data gaps and uncertainties;
- We sought to address data gaps and uncertainties by conducting a number of **targeted expert interviews, peer review,** and through mathematical modelling;
- The final phase of work developed **future scenarios** to explore how to improve system performance.

[1] A description of the data inventory and the initial MFAs was provided to APCO in an interim report. This report highlighted a number of data gaps and uncertainties that further data collection and modelling could improve. The interim report was also provided to expert stakeholders for peer review. Further details of this process are provided in Section 2.2.

2 Research Methodology

2.1 Material flow analysis

Material flow analysis (MFA) is a methodology that involves a systematic assessment of the state and changes of material flows and stocks within a system defined in space and time (Brunner & Rechberger, 2017).

MFA is based on the principle of conservation of mass in a well-defined system, and by balancing material inputs and outputs, the material flows within the system become visible and can be analysed using quantitative methods.

The first step in establishing an MFA is the definition of the system under study, and its boundaries in space and time. A system is defined as a set of material flows, stocks and processes within the defined *system boundary* (Brunner & Rechberger, 2017). The system boundary can consist of geographical boundaries (e.g., Australia), and 'virtual' boundaries that could include specific product systems (e.g., packaging, or waste in general), and use systems (e.g. co-mingled recyclables kerbside collection, home composting systems). Temporal boundaries are also important, and selection of an appropriate temporal boundary is dependent on the system under investigation. For waste management systems, a temporal boundary of a single year is typical.

The elements of a system can be categorised as *flows, processes, and stocks*. A flow is the rate of material transfer through the system between processes, and can be considered an exchange of mass between two or more connected processes (e.g., packaging waste collected from kerbside and directed to material recycling facilities, MRFs). A *process* is defined as an activity that can involve transformation, transport, or storage of materials that enter the process (Baccini & Brunner, 1991). For example, a MRF is an example of a transformation process considering that the flow of mixed discarded packaging entering the MRF is sorted into varying outflows (recyclate, sorted material, contamination, etc.). Quantitatively, *transfer coefficients* are derived from the data, and describe the partitioning of a material in a transformation process, either for a single input, or for the sum of all inputs entering a process (Brunner & Rechberger, 2017).

A *stock* (or reservoir) is another process activity where once the material entering the process has been transformed, a proportion of the flow remains within the process as an accumulation (e.g., stockpiling).

For this study, we are considering the Australian packaging waste system for a single year in time (2017/18 financial year). The elements of the MFAs described herein are based on published data, information provided by APCO, expert stakeholder interviews, and peer review feedback. This data informed the system definitions and boundaries, and was used to estimate major flows through the system.

Box 1 describes the MFA system for glass packaging to illustrate the methodology. The glass packaging system and other material systems are described in detail in Section 3 and the Appendix.

Box 1: Description of the MFA system for glass packaging waste developed for this study

This box contains a detailed description of the MFA system for glass packaging waste under investigation. We provide this as an example to illustrate the key concepts of MFA applied in this work.

Figure 1 (a stock-and-flow diagram) characterises the Australian glass packaging waste system prepared for this project.

The **system boundary** for the glass packaging system encompasses the aggregated, national waste management system for glass. That is, all jurisdictional flows occurring within the system are combined. The temporal boundary has been set for the 2017/18 financial year, to align with other national and jurisdictional data sets.

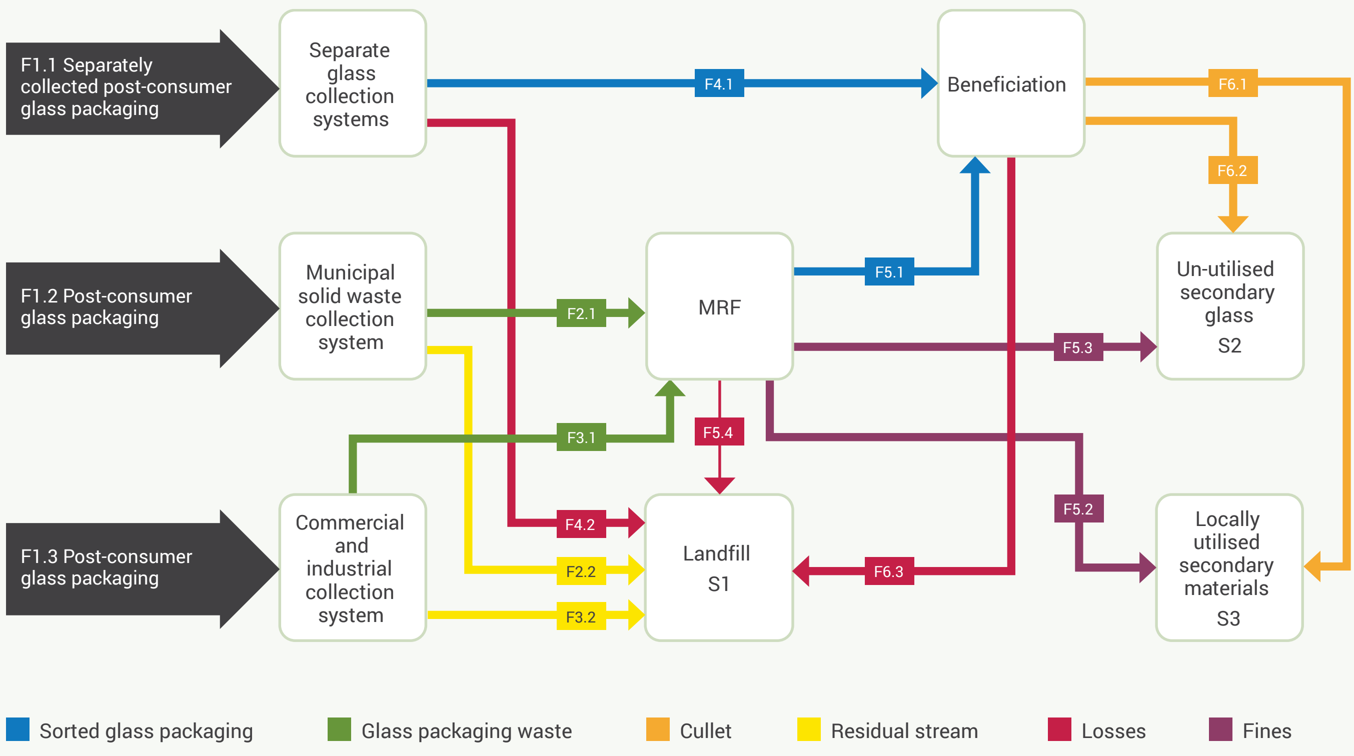
There are 5 **non-accumulating processes** within the glass MFA system:

- **Separate glass collection system,** corresponding with container deposit scheme (CDS) collection
- **Municipal solid waste collection system**, that is the kerbside waste collection
- **Commercial and industrial collection system,** which corresponds to the C&I waste collection system
- **MRF,** that represents all MRFs in Australia that take glass packaging waste
- **Beneficiation,** that represents all glass beneficiation plants in Australia

There are 3 **accumulating processes** within the glass MFA system, i.e., stocks:

- **Landfill,** which corresponds to all landfills in Australia, taking glass waste
- **Un-utilised secondary glass,** that is recovered cullet and fines that are stockpiled
- **Locally utilised secondary material,** that is recovered glass waste used locally for manufacturing new products

Figure 1: *Glass MFA system diagram*



There are 16 flows in the glass packaging waste system, corresponding to flows of glass waste through the system.

These are described as follows:

FLOW	DESCRIPTION
F1.1 – Separately collected post-consumer glass packaging	Post-consumer glass packaging destined for the container deposit collection system. This flow is derived from jurisdictional data for glass beverage containers directed to CD collection
F1.2 – Post-consumer glass packaging (MSW)	Post-consumer glass packaging destined for the municipal waste system. This flow is derived from both national estimates on glass waste generation, and from jurisdictional MSW/C&I splits
F1.3 – Post-consumer glass packaging (C&I)	Post-consumer glass packaging destined for the commercial and industrial waste system
F2.1 – Glass packaging waste	Glass packaging waste collected from MSW, and directed to MRFs for sorting. This flow is based on jurisdictional data on glass collection and destinations
F2.2 – Residual stream (MSW)	Glass packaging waste that has been disposed of into the residual stream from the kerbside
F3.1 – Glass packaging waste	Glass packaging waste collected from C&I, and directed to MRFs for sorting
F3.2 – Residual stream (C&I)	Glass packaging waste disposed of into the residual stream at the source of generation for C&I waste only
F4.1 – Sorted glass packaging	Container deposit collection to glass beneficiation. This figure is based on LCA data on waste sorting efficiencies, and verified through expert interview
F4.2 – Sorting losses	Efficiency losses at container deposit collection sorting, that is directed to landfill
F5.1 – Sorted glass packaging	Glass packaging waste that has been sorted at the MRF, and directed to the next stage of recovery. This figure is based on national, jurisdictional data, and LCA data on sorting process efficiencies
F5.2 – Fines	Glass fines that have been recovered at the MRF, and directed to secondary material supply. This flow is based on expert input
F5.3 – Fines	Glass fines that have been recovered at the MRF, but directed to un-utilised supply of glass. This figure is based on jurisdictional data describing glass stockpiles
F5.4 – Sorting losses	Efficiency losses during sorting at MRF that is directed to landfill
F6.1 – Cullet	Recovered cullet from beneficiation plants that is directed to the secondary material supply. This figure is based on jurisdictional data on the split of fines/cullet from recovered glass
F6.2 – Cullet	Recovered cullet directed to un-utilised secondary material supply
F6.3 – Recovery losses	Efficiency losses at beneficiation plants. This figure is derived from expert interviews, and LCA data on sorting and recovery process efficiencies

2.2 Data collection

The published data used for this study was collected from 15 sources, including data sets and reports provided by APCO, and other publicly available data. **Table 1** describes the data source and how it was used in this study.

Data derived from these sources were used to establish the inventory of available data, including: total packaging waste collected and consumed, waste packaging recovery, and exports of recovered waste packaging material. Often, assumptions and modelling were required to transform collected data into usable data for the MFA. For example, all data was adjusted to a baseline year of 2017/18 by estimating per-capita generation rates for a given reporting year. All assumptions are provided in later sections of this report.

While a wide range of sources have been used, there is a general paucity of high quality data for specific waste flows in Australia. Our analysis identifies inconsistencies and gaps, which include:

- Characterisation of the waste packaging stream directed to landfill from the use phase (i.e., the residual stream);
- Waste packaging flows from the MRF, i.e., owing to sorting efficiencies; and
- Characterisation of contamination in packaging waste streams.

Peer review and expert stakeholder interviews

To supplement the published data, and to address data gaps and uncertainties, further data was collected through targeted expert interviews and peer review. 17 expert reviewers from organisations across consulting, government, manufacturing and waste management sectors were engaged. Targeted semi-structured interviews were conducted with expert stakeholders to address inconsistencies, and validate assumptions. Reviewers provided feedback on the MFAs (Interim Report, August 2018), the assumed system boundaries and flows, data sources, and MFA results.

2.3 Managing data uncertainty

Assessing data uncertainty is a key step in the MFA methodology. It is important for two reasons: it provides a measure of data quality, and it informs how accurately the MFA results can be stated with reasonable confidence.

If direct measurements of a flow or process activity are not available, best estimates can be made by drawing on alternative sources whilst acknowledging the quality and appropriateness of the source, i.e. the 'uncertainty' (Laner et al., 2014). Uncertainties can be calculated, for example by drawing on literature data, or indirect measurements, to construct probability distributions for each data point, from which uncertainty bounds can be calculated. However, in the case when such data is not available, more qualitative methods can be employed, which was the approach taken in this study.

Our approach modified an established method developed by Laner et al. (2015). [2] Three indicators were used to describe the total uncertainty of a data point: **reliability** (of the data source and methodology); **completeness** (if the data includes all relevant information and flows); and **similarity** (how similar an underlying data point or source is relative to a direct measurement of a flow or process in our system). Each data point collected was evaluated according to these indicators, and scores between 1 or 2 (i.e. low or high uncertainty) were assigned. From this score, a coefficient of variation is modelled (the ratio of the standard deviation of the data to the mean), from which a quantitative assessment of uncertainty can be given in the form of confidence intervals, assuming that uncertainties are normally distributed.[3]

See **Appendix 1** for worked example of this uncertainty assessment approach.

[2] Laner et al (2015) employs figure indicators to describe the total uncertainty of a data point and a score of 1–4 is assigned. Our simplified methodology, that reduces the number of indicators and levels of appraisal, minimises possible bias in the uncertainty appraisal process.

[3] The approach assumes that all data is normally distributed. This generalisation simplifies the calculation of uncertainty, and has been shown to be a reasonable assumption based on a comparison of the uncertainty estimates from the Laner et al. (2015) method when compared to uncertainty estimates from other published MFAs.

***Table 1:** Key data sources used*

Data Source	Relevant Material Stream	Remarks
Assessment of Australian recycling infrastructure and 2016-17 exports to China – Paper and paperboard (IndustryEdge, 2018)	Paper and paperboard	Provides data on production, consumption, export of paper and cardboard. Includes description of local and exportable marketable products. Used for determining paper waste flows
Assessment of Australian recycling infrastructure and 2016-17 exports to China – Metals (REC, 2018)	Metals	Provides data on total metals exported to China. Includes description of recovery infrastructure, however is not a particularly useful data source
Assessment of Australian recycling infrastructure – Glass packaging (SRU, 2018)	Glass	Provides information on glass recycling infrastructure locally, and includes some national figures on total generation and recovery of glass packaging
Assessment of Australian recycling infrastructure and 2016-17 exports to China – Plastics (Envisage, 2018)	Plastic	Includes breakdown of plastics consumption by application (e.g., MSW packaging), and by individual polymers. Also includes breakdown of local reprocessing, reprocessed for export, and direct exports overseas
National Recycling and Recovery Surveys (NRRS) – Paper packaging, glass containers, steel cans and aluminium packaging (IndustryEdge, 2017)	Paper, glass, metals	Includes total consumption and recovered for the listed material categories for 2010/11 to 2014/15; used for calibration of other estimates
National Recycling and Recovery Survey (NRRS) 2015-16 for plastics packaging (Envisage, 2017)	Plastics	Includes data on plastic packaging recycling from 2000 to 2015/16, plastic packaging consumption, and recovery by polymer. Also includes destination of packaging recyclate by jurisdiction; Used in conjunction with other plastics data sets to determine plastic packaging flows
2016-17 Australian Plastics Recycling Survey – National Report (Envisage & SRU, 2017)	Plastics	Similar to the above data source. Used with other plastics data sets to determine plastic packaging flows
Stage 1 Final Report – Study on the South Australia Plastics Packaging Resource Recovery Sector (Rawtec, 2012)	Plastics	In depth description of the South Australian plastic packaging recovery sector. Includes data on recovery by polymer, mass balance of SA plastics recovery, and existing recovery infrastructure. Used for information on plastic recovery processes
Recycling Activity in Western Australia 2015-16 (ASK, 2017)	Paper, glass, metals and plastics	Includes data on packaging generation and recovery in general. Used to calibrate per-capita estimates
Victorian Recycling Industry Annual Report 2015-16 (Sustainability Victoria, 2017)	Paper, glass, metals and plastics	Includes data on packaging generation and recovery in general. Used to calibrate per-capita estimates
South Australia's Recycling Activity Survey 2016-17 Financial Year Report (Rawtec, 2017)	Paper, glass, metals and plastics	Includes data on packaging generation and recovery in general. Used to calibrate per-capita estimates; Contains data for container deposit flows, and packaging waste directed to energy recovery
Recycling and Waste in Queensland 2017 (Queensland Government, 2017)	Paper, glass, metals and plastics	Includes data on packaging generation and recovery in general. Used to calibrate per-capita estimates
Market Summary – Recycled Glass (Sustainability Victoria , 2014)	Glass	Estimates on glass packaging consumption, recovery, and exports in Victoria; Used to derive estimates on re-processing losses, and recovery efficiencies
NSW Glass Recycling – Issues and Options (CIE, 2017)	Glass	Study on glass recycling in NSW; Used to estimate stocks of cullet and fines
Analysis of material recovery facilities for use in life-cycle assessment (Pressley et al., 2015)	All streams	Academic source on MRF recovery and sorting rates, based on a life cycle assessment of MRFs across the United Kingdom
National Waste Report 2018 (Blue Environment, 2018)	All streams	Report prepared for the Australian Department of the Environment and Energy describing the entire Australian waste management system; The report was used to compare MFA estimates

2.4 System performance indicators

In order to evaluate the performance of the waste packaging systems, four system performance metrics were developed. These metrics allow comparison between packaging systems (e.g., comparing the recovery rate of paper versus plastic), and can highlight where in the system there are opportunities for improving performance.

Table 2: *Selected system performance metrics*

Performance Indicator	Definition	Significance
Collection efficiency	Waste **not** directed to landfill at collection, divided by total waste entering the system	This indicator describes the performance of the collection system. Low efficiency means a high proportion of the flow isn't separated from material flows at the household or business and is directed to landfill, e.g., owing to limited source separation and/or poor disposal practices
Sorting efficiency	Waste destined for re-processing/downstream recovery, divided by total waste entering the system	Low sorting efficiency highlights opportunities to reduce contamination of collected materials and/or improve sorting processes at MRF/sorters, e.g. by investing in automated sorting, increasing manual sorting, or reducing the rate of throughput at MRFs
Recovery rate	Total waste recovered, divided by total waste entering the system. Waste recovered includes: secondary material recovery, energy recovery, exports, and stockpiling. Note that we consider waste that has been sorted/treated at MRFs/reprocessors to be exported overseas as waste recovered	The performance of the whole system for recovering waste material for useful purposes, including as inputs to local/overseas manufacturing, and energy recovery
Local material utilisation rate	Secondary recyclate produced **(excluding stockpiled amounts)** to be utilised locally for manufacturing, divided by total waste entering the system	The performance of the local material utilisation system. Low material utilisation rates indicate that a high proportion of waste is not recovered, exported (directly or reprocessed), or stockpiled

3 Results & Discussion

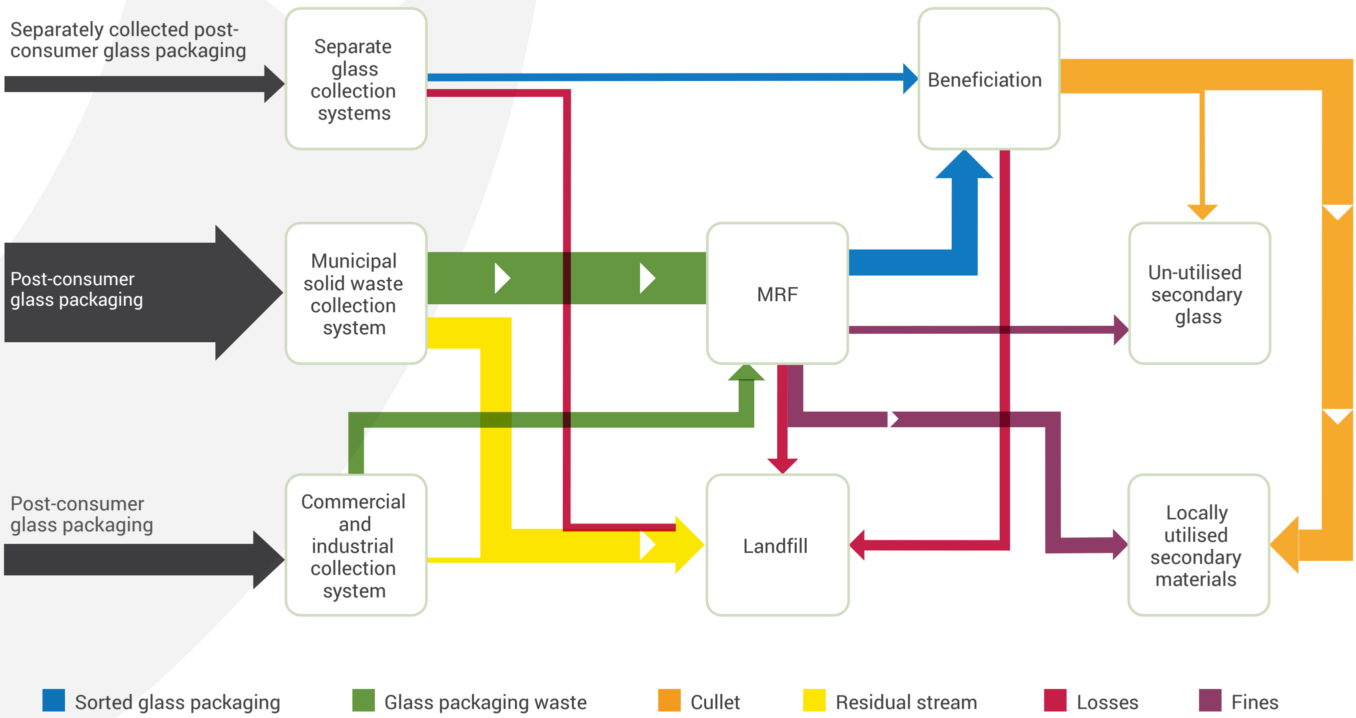
This section presents the key findings and discussions from our research. The results of the individual material streams are presented in sections 3.1 to 3.4. An overview of the entire waste packaging system is provided in section 3.5. Further details, including more detailed system descriptions, are provided in the Appendix.

3.1 Glass packaging

Highlights

- The municipal waste stream dominates the glass packaging waste system, accounting for almost 80% of total glass packaging waste flows
- Estimated recovery rate of the glass system is 50%±8%[4]
- Approximately 80,000 tonnes of glass packaging waste was collected and sorted through container deposit collection systems. This amount is anticipated to increase as container deposit schemes are further deployed across the country
- About 23% of glass waste is disposed directly to the residual stream, representing losses at the household through incorrect disposal practices. These losses are compounded by a substantial flow of sorting losses directed to landfill from MRFs after collection that is likely owing to rough handling (e.g. breakages owing to compaction in trucks and during sorting)
- There is significant potential to improve overall glass recovery performance by improving material handling and sorting where losses are high, or diverting glass from the kerbside sorting channel to container deposit scheme collections. This may have benefits for other material streams affected by glass contamination at MRFs (i.e., paper)
- Approximately 30% of glass recovered is from recovered fines, which represent an economic loss when considering the higher value of cullet for packaging manufacturing

Figure 2: *Glass packaging waste MFA diagram*



[4] *Uncertainty ranges reported are at the 95% confidence interval*

Main findings and discussion

Figure 2 contains the results from the MFA for the glass packaging system. A stock-and-flow diagram is provided in Appendix 6. (The glass packaging waste system is described in detail in Section 2, Box 1, and in Appendix 2.)

Uncertainty has also been estimated for each flow, which ranges from ~4% for estimates derived from well described and reliable data, to ~22% where uncertainties in the data have propagated through the system.

The municipal waste stream dominates the glass packaging waste system, accounting for almost 80% of total glass packaging waste flows. A substantial amount (approximately 23%) of glass waste is disposed directly to the residual stream. This represents losses at the household through incorrect disposal practices (e.g., recyclable glass placed in the residual bin instead of dry recycling bin), and to a lesser degree contamination. Additionally, there is a substantial flow of sorting losses going to landfill from MRFs. This flow is likely to represent both process efficiency losses at the MRF (e.g., through mishandling of waste throughput, operational inefficiencies, etc.), and contamination in the waste stream being removed from recyclable glass at the MRF. However, data at the facility level is not available to verify the root cause of these losses.

Figure 3 presents the source of glass packaging waste disposed to landfill, showing that waste disposed to landfill is largely derived from kerbside collection (~43%) and MRF sorting losses (~49%). The largest fraction disposed to landfill is from the MRF and this may be largely owing to compaction in trucks during kerbside collections that results in fracturing of glass into pieces that are too small for the MRF sorting equipment. A reasonable amount of waste is also disposed of to landfill from recovery operations, equaling approximately 50,000t or ~5% of the total waste stream. For our analysis, we've assumed these losses to be occurring at the beneficiation process as a result of operational inefficiencies (e.g., mishandling, breakages, etc.).

Figure 3: *Source of landfill disposal of non-recovered glass packaging along the waste recovery infrastructure*

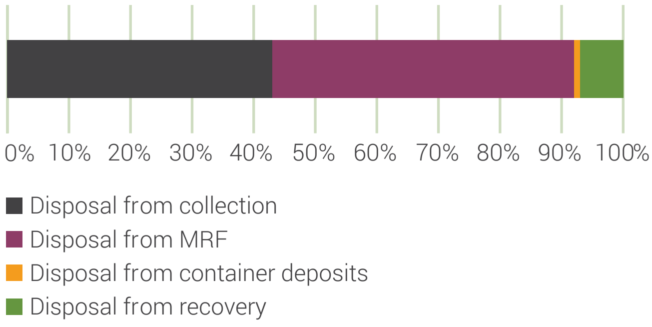


Table 3: *Glass system performance indicators*

Performance metric	Value	Remarks
Collection efficiency	78%±11%	A considerable proportion of glass packaging is directed to landfill, primarily owing to incorrect disposal at the kerbside. Whilst collection efficiency is relatively high, there remains room for improvement
Sorting efficiency	54%±9%	Sorting efficiency is poor, primarily owing to contamination in the glass stream (e.g., borosilicate glass and ceramics), breakages during transportation (compaction and trucks) and sorting.
Recovery rate	50%±8%	Total recovery rate is poor. Recovered cullet for local utilisation contributes approximately 50% of overall recovery, indicating that the potential of circular materials use is underutilised for the glass stream owing to generation of fines along the recovery chain
Material utilisation rate	36%±6%	Material utilisation is poor. Note that this figure does not include stocks of un-utilised recyclate, which are not re-directed back into manufacturing. There is significant potential to use the un-utilised cullet for glass manufacturing and fines as inputs for industrial processes.

Of the total glass packaging waste recovered, approximately 30% is estimated to be recovered fines. While fines are useful secondary materials for inputs into industrial processes (e.g., abrasives, road base), they do not contribute to reducing virgin glass demand for glass packaging. Fines represent an economic loss considering the higher value of cullet for packaging manufacturing.

Table 3 contains calculated performance metrics for the glass packaging system (refer to **Table 2** for how these metrics are calculated). Total glass recovery has been estimated at 50%±8%. Considering the drop in efficiency between collection and the MRF (collection and sorting efficiency of 78%±11% and 54%±9%, respectively), there is considerable potential to increase recovery by improving material sorting. The nature of the co-mingled waste stream means that glass packaging waste is subject to breakages, which not only limit the recyclability of the glass stream, however it can also lead to losses and contamination for other streams. Improving sorting efficiency would potentially incur a large increase in waste processing costs associated with investment in new equipment for automated sorting, or additional manual sorters (MRA, 2018). An alternative solution is to achieve better separation of glass waste at the point of collection, e.g. by collecting glass separate from co-mingled recyclables, or diverting containers collected at the kerbside to CDS.

Glass recycling capacity

Figure 4 shows the estimated proportion and amounts of glass packaging sent to MRFs, container deposit collection, and to beneficiation (derived from our MFA results). Most glass is collected in co-mingled recycling from households and business which is then directed to MRFs for sorting (~1 million tonnes of glass in 2017/18). Demand for glass packaging has fallen in recent years (CIE, 2017; SRU, 2018), which may reduce pressure on recovery infrastructure to treat this waste stream in the future.

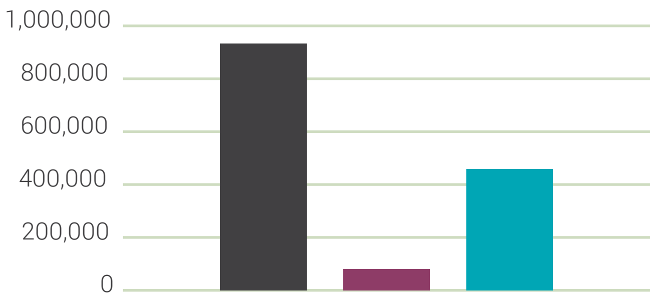
It is estimated that approximately 80,000 tonnes of glass packaging waste was collected and sorted through container deposit collection systems. This amount is anticipated to increase as container deposit schemes are deployed across the country. The Queensland CDS is expected to commence in November 2018 and the Western Australian CDS is expected to commence in 2020. Increasing the proportion of glass packaging waste collected via container deposit schemes is expected to improve the quality of the stream and significantly increase the quantity available for bottle-to-bottle recycling. This collection channel avoids the significant losses associated with kerbside collection because the handling is gentler (including in some cases manual sorting into colour streams) and losses at the MRF owing to fracturing are minimised. There are also benefits for other material streams, especially paper.

Approximately 460,000 tonnes of glass packaging waste was directed to beneficiation in 2017/18. With the scale-up of CDS collection, it is likely that the quantity and quality of glass received by beneficiation facilities will be greater. There are reportedly six glass beneficiation plants in Australia (SRU, 2018): three located in Victoria, and one located each in NSW, SA and Queensland. Glass processed at beneficiators are directed to glass packaging manufacturers located in Brisbane, Sydney, Melbourne and Adelaide (SRU, 2018). The demand for specific coloured cullet is partly based on location and impacts the cullet supply chain. For example, green glass is in oversupply in Sydney and Melbourne and therefore is directed to Adelaide to supply green cullet for the local winemaking industry there.

Scrap glass collected through container deposit systems is of a much greater quality than glass derived from co-mingled sources, and is in demand from glass manufacturers as an alternative to primary sources of glass.

Overall, cullet represents less than ~50 % of total manufactured volumes (Pers. Comm. 2018) suggesting that, in theory, there is capacity to double this input if the quality is good enough to displace virgin inputs.

Figure 4: *Glass packaging to recovery infrastructure*



GLASS PACKAGING 2017/18 TONNES	
Glass to MRFs	933,510
Glass to CD collection	79,665
Glass to reprocessors	458,421

3.2 Paper and paperboard packaging

Highlights

- C&I dominates the generation of paper packaging, accounting for about 75% of total scrap paper packaging generation. Unbleached kraft makes up approximately 60% of total paper packaging
- Estimated recovery rate of the paper packaging system is 72%±13%, and is the best performing packaging system across the performance metrics
- Unbleached kraft in the MSW stream makes up less than 5% of total unbleached kraft flow but this stream is expected to grow with an anticipated increase in Australian online shopping leading to greater amounts of cardboard in the MSW stream
- Recyclable losses to the residual stream is substantial owing to incorrect disposal practices, accounting for approximately 27% of total paper packaging generation for 2017/18
- To improve the total paper packaging recovery rate, effort should be placed in ensuring that unbleached kraft and mixed paper are disposed of correctly and that source contamination is reduced (glass fines) in an effort to increase collection and sorting rates.

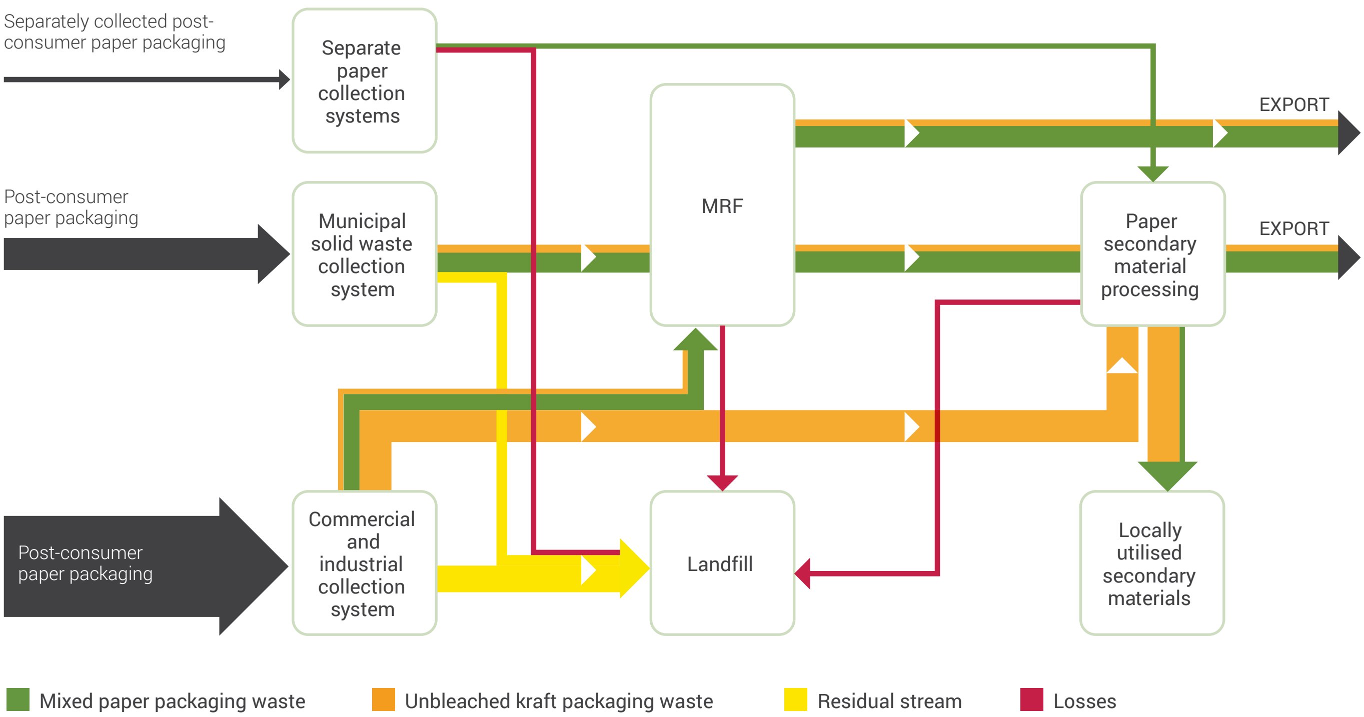
Main findings and discussion

Figure 5 shows the MFA diagram for the paper packaging waste system. A stock-and-flow diagram of the paper MFA can be found in Appendix 7. This MFA splits the flow of paper packaging into flows of unbleached kraft and mixed paper. Multiple exports of paper from this system are shown including exports overseas direct from the MRF, and from paper recovery facilities. A detailed description of the paper packaging waste system can be found in Appendix 3.

Uncertainty has been estimated for each flow, which ranges from ~4% for estimates derived from well described and reliable data, to ~36% where uncertainties in the data have propagated through the system. There is high uncertainty in the assumed split between unbleached kraft and mixed paper.

The commercial & industrial waste streams dominate the generation of paper packaging, accounting for about 75% of total scrap paper packaging generation. Unbleached kraft makes up approximately 60% of total paper packaging across MSW and C&I waste streams, with the majority of the flow occurring in the C&I stream. A small amount (less than 1,000 tonnes) of liquid paperboard packaging is also collected through container deposit schemes. Of note is the flow of unbleached kraft in the MSW stream. Although this flow makes up less than 5% of total unbleached kraft flow, it is expected to grow with an anticipated increase in Australian online shopping leading to greater amounts of cardboard in the MSW stream.

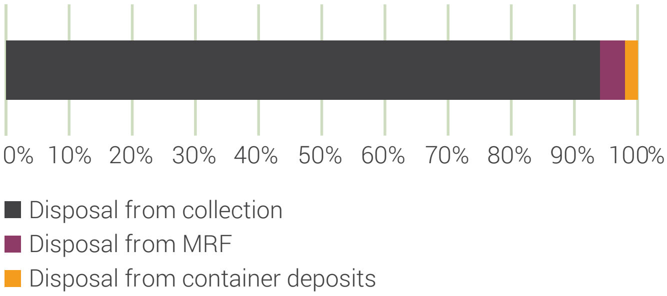
Figure 5: *Paper packaging waste MFA diagram*



A substantial amount of paper packaging is estimated to be lost in the residual stream owing to inefficient disposal practices, accounting for approximately 27% of total paper packaging generation for 2017/18.

Figure 6 shows the source of paper packaging waste disposed to landfill, indicating that waste disposed to landfill is mainly derived from the residual stream at collection. Data on residual stream disposal is very poor, and these losses can only be attributed to poor disposal practices without more granular data on this flow.

Figure 6: *Source of landfill disposal of non-recovered paper packaging along the waste recovery infrastructure*



Of the total paper packaging waste recovered, approximately 60% is estimated to be recovered unbleached kraft. This stream of paper has the highest value for secondary material use in packaging manufacturing, and is also not subject to the restrictions on import to China, as is the case for mixed paper (APCO, 2018).

Subsequent to the curtailment of the Chinese market as a destination for mixed paper, these volumes are likely being exported to new markets, or being diverted to secondary material processing (if demand for recovered mixed paper fibre is high), stockpiled, or disposed to landfill. Ensuring that this flow of mixed paper is still recovered and not disposed is important for ensuring the recovery rate of the paper stream remains relatively high, considering that this flow contributes ~20% to the total stream recovery rate.

Table 4 contains calculated performance metrics for the paper packaging system. Total paper packaging recovery has been estimated at 72%±13% (unbleached kraft 71%±13%, and mixed paper 72%±14%). Considering upstream collection and sorting efficiencies, the recovery efficiency of the paper system is very high, with only ~2% efficiency loss occurring between collection and final recovery. This indicates that to improve the total paper packaging recovery rate, effort should be placed in ensuring that unbleached kraft and mixed paper are disposed of correctly and that source contamination is reduced. This high rate of recovery however is under threat given the Chinese import restrictions on mixed paper imports. While it is assumed that exports would continue to other export markets in 2017/18, mixed paper has a highly uncertain future. If export demand does not continue at levels previous to the importation restrictions, then mixed paper needs to be diverted to local materials recovery to ensure recovery rates remain high. A perverse outcome may be the stockpiling of recovered mixed paper, that while considered 'recovered' in this analysis as landfilling is avoided, no economic benefit is captured.

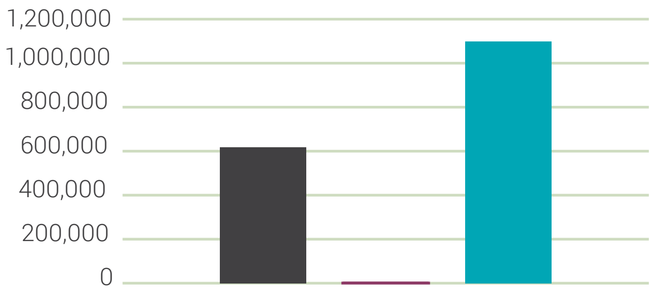
Table 4: *Paper and paperboard packaging system performance metrics*

Performance metric	Value	Remarks
Collection efficiency	Total: 73%±13% Unbleached kraft: 72%±12% Mixed paper: 75%±14%	Reducing packaging complexities (i.e., polymer coated cardboard) may be a pathway to promoting better source separation
Sorting efficiency	Total: 72%±13% Unbleached kraft: 72%±12% Mixed paper: 73%±13%	Improvements to sorting could include reducing contamination in the paper stream (e.g., glass fines which are a problem contaminant for paper streams), and improving MRF sorting operations
Recovery rate	Total: 72%±13% Unbleached kraft: 71%±13% Mixed paper: 72%±14%	Recovery rate is good, however this metric is sensitive to export demand, as in the case of the curtailment of China as an export destination for mixed paper waste imports
Local material utilisation rate	Total: 41%±7% Unbleached kraft: 54%±9% Mixed paper: 20%±5%	Material utilisation is dominated by recovered unbleached kraft used in local manufacturing of paper packaging. Improving local material utilisation will not have a significant impact on the current recovery rate, however may provide the driver to improve upstream efficiencies, and to offset diminishing export markets for mixed paper

Paper recycling capacity

Figure 7 shows the estimated proportion and amounts of paper packaging sent to MRFs, container deposit collection, and to paper recovery processes from the MFA results. Approximately 620,000 tonnes of paper packaging waste (unbleached kraft, and mixed paper) is directed to MRFs. Paper deposited through CDS collections is minimal, and constitutes a small proportion of total container deposit collections.

***Figure 7:** Paper packaging to recovery infrastructure*



PAPER PACKAGING 2017/18 TONNES	
Paper to MRFs	618,282
Paper to CD collection	879
Paper to reprocessors	1,099,288

Just over 1 million tonnes of paper packaging waste was directed to secondary paper processing in Australia in 2017/18, with the majority of the waste being unbleached kraft. In 2016/17, total use of raw fibre for paper/paperboard manufacturing was over 3 million tonnes (IndustryEdge, 2018) from all paper/paperboard waste sources, with approximately 47% of this fibre derived from local and exported secondary sources. Of note are single-stream sorting facilities, which receive unbleached kraft predominately from the commercial stream, which is subsequently directed to major reprocessors.

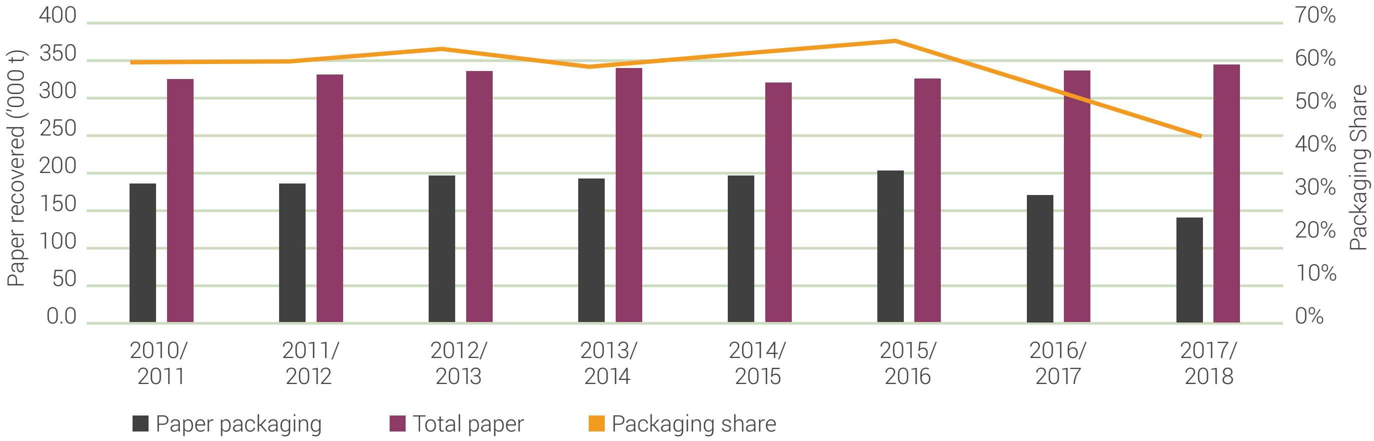
From the MFA, it was estimated that approximately 800,000 tonnes of paper packaging was directed to reprocessors via single-sorting facilities. There are reportedly 16 of these facilities located across Australia (IndustryEdge, 2018).

Sorted materials from MRFs/single stream sorting supply 10 paper reprocessing plants operated at 8 facilities by 4 companies. These facilities are located in NSW, Queensland, Victoria and Tasmania. About 1 million tonnes of paper packaging waste was directed to these plants in 2017/18, with the majority being unbleached kraft.

Figure 8 shows historical paper packaging recovery and total paper recovered from 2010/11 to 2017/18, derived from MFA estimates, National Recycling and Recovery Survey (IndustryEdge & Equilibrium, 2017), and from National Waste Report data (Blue Environment, 2017). According to our analysis, total paper recovery from 2010–2018 period ranged from about 3.2–3.4-million tonnes per annum (including material for export), of which recovered packaging paper made up at most 65%. This suggests that total paper recovery infrastructure has an annual throughput capacity of at least ~3.4 million tonnes per annum. Given the relative fraction of paper packaging recovery, there is possibly some ability in the existing recovery system to accommodate higher packaging flows. This is possibly true for unbleached kraft which is the primary form of paper packaging recovered due to the business-to-business nature of C&I paper collections (IndustryEdge, 2018). For the specific case of mixed paper, which is primarily derived from co-mingled municipal waste collection, the capacity of the primary processing facilities to increase throughput is uncertain. Equally, the potential for MRFs to improve the quality of this stream is unclear. Because a major contaminant of this stream is embedded glass, the future is contingent on possible changes in glass waste management.

Production of alternate paper-based products would require additional MRF sorting to required specifications but this market is relatively small.

***Figure 8:** Historical paper and paper packaging recovery in Australia*



3.3 Metals

Highlights

- The municipal stream dominates generation of metal packaging (87% of total metal packaging generation). Steel packaging makes up approximately 65% of total metal packaging
- Metal packaging recovery is estimated at 54%±10%. The recovery rate of metal packaging is low, considering high upstream collection efficiency. Reasons for this could be owing to contamination in the metal stream from the source, and poor recovery operations
- Approximately 28% of total scrap metal packaging generation for 2017/18 was disposed to landfill from collection. Over 60% of total metal packaging landfill disposal occurs before MRF sorting. Disposal of sorting losses at the MRF is also a significant flow, contributing ~20% of total landfill disposal in the system
- While there is presently strong local and international markets for scrap metal, with the increasing trend towards exporting scrap metal, the Australian system may be vulnerable when export markets are weak. This is particularly relevant for aluminium, where low demand for recycled aluminium has led to export of aluminium scrap to be the dominant recovery pathway

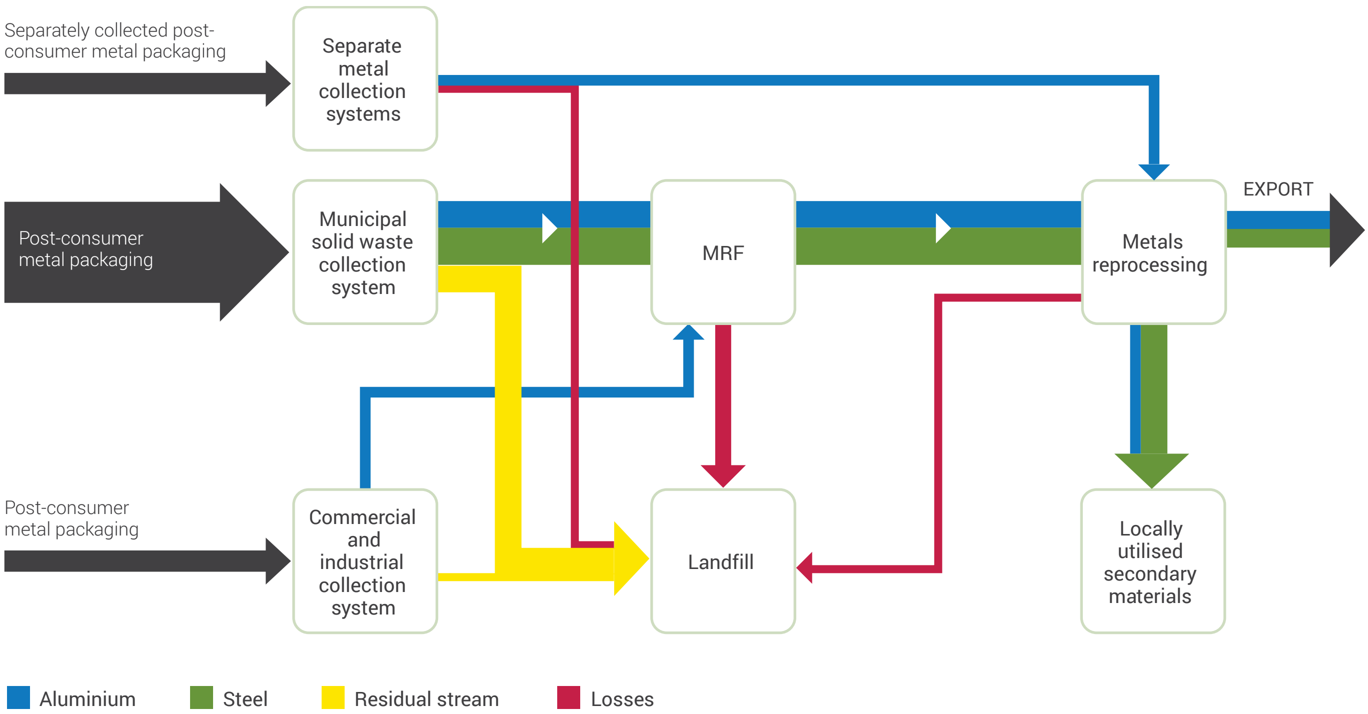
Main findings and discussion

Figure 9 shows the flow of metal packaging through the system and between processes. The thickness of the line corresponds with the size of the flow. A stock-and-flow diagram for this system is provided in Appendix 8. This MFA splits the flow of metal packaging into flows of aluminium and steel packaging. There are two exports in this system of recovered aluminium and steel from the metals recovery process. Due to data limitations describing export flows from the MRF, there is assumed to be no exports of baled aluminium/steel packaging from sorting, as is the case for the paper and plastic systems. A detailed description of the metals system can be found in Appendix 4.

Uncertainty has been estimated for each flow, which ranges from ~4% for estimates derived from well described and reliable data, to ~24% where uncertainties in the data have propagated through the system. High levels of uncertainty are most associated with the flow of potentially recyclable metal packaging to the residual stream at the source.

The municipal waste stream dominates the generation of metal packaging, accounting for approximately 87% of total metal packaging generation. Steel packaging makes up approximately 65% of total metal packaging by mass across MSW and C&I waste streams, with all of this flow occurring in the municipal waste stream. This is supported by the literature and data collected describing metal packaging waste in Australia indicating that steel packaging in the C&I stream is insignificant. This assumption was supported by expert stakeholder interview.

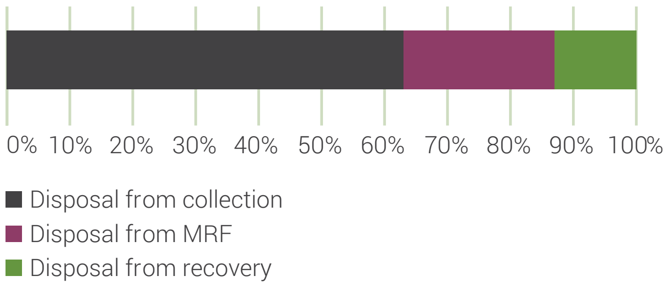
Figure 9: *Metal packaging waste MFA diagram (tonnes)*



A substantial amount of metal packaging is estimated to be lost in the residual stream owing to incorrect disposal practices, accounting for approximately 28% of the total scrap metal packaging generation for 2017/18.

Figure 10 shows the source of metal packaging waste disposed to landfill, showing that waste disposed to landfill is mostly from waste disposal to the residual stream at collection. Data on residual stream disposal is lacking, and these losses can only be attributed to poor disposal practices (without better data that could be obtained through comprehensive bin audits). Disposal of sorting losses at the MRF is also a significant flow, contributing ~20% of total landfill disposal in the system.

Figure 10: *Source of landfill disposal of non-recovered metal packaging along the waste recovery infrastructure*



Metal packaging recovery is relatively evenly split between recovered aluminium and recovered steel, with steel constituting ~52% of total metal recovery by mass (as previously noted, steel is heavier than aluminium).

Of the total ~92,200 tonnes of metal waste recovered, approximately 60% of this secondary material is exported to overseas markets. Data is unavailable on the rates of contamination in the export flows of aluminium and steel derived from waste packaging.

It is estimated that approximately 36,890 tonnes of metal packaging is recovered for local utilisation. There is a paucity of data on the fate of recovered metals, and it is unclear how much of this recovered metal returns to metal packaging manufacturing.

Table 5 contains calculated performance metrics for the metal packaging system. Total metal packaging recovery has been estimated at 54%±10%, with aluminium packaging 72%±13%, and steel 44%±8. The recovery rate of metal packaging in general is quite low, considering upstream collection efficiency, and published MRF and recovery efficiencies for metal waste overseas. For example, Pressley et al. (2015) performed a life cycle analysis of MRFs in the United Kingdom, finding that metal sorting rates of up to 97-98% can be achieved. Reasons for poorer local efficiencies could be due to contamination in the metal stream from the source, and poor recovery operations. Data on contamination and specific mass balances from metals recovery facilities were not available for this project, but may assist in better identifying reasons for these losses.

Table 5: *Metal packaging performance indicators*

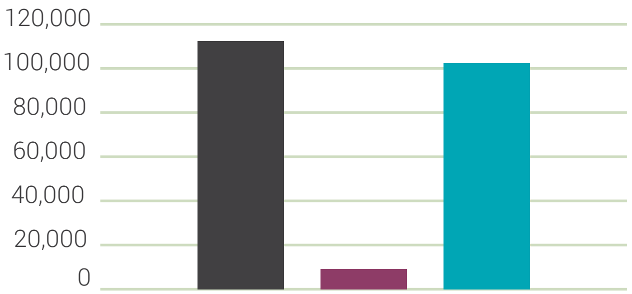
Performance metric	Value	Remarks
Collection efficiency	Total: 71%±13% Aluminium: 88%±15% Steel: 61%±12%	There is an opportunity to improve kerbside disposal practices especially targeting steel packaging waste;
Sorting efficiency	Total: 60%±10% Aluminium: 79%±13% Steel: 49%±9%	There is a loss of over 10 %-points from source separation to sorting. Improvements here could include reducing contamination in the metal stream, and ensuring that MRFs are operating at best practice[4] (e.g., high levels of process efficiency, best available technology, etc.) ;
Recovery rate	Total: 54%±10% Aluminium: 72%±3% Steel: 44%±8%	Export is the dominant pathway for secondary metals, with approximately 60% of recovered metal exported. Local demand for secondary metals is strong, however is sensitive to fluctuations in the scrap metal market;
Local material utilisation rate	Total: 22%±4% Aluminium: 15%±3% Steel: 25%±5%	Local material utilisation is dominated by recovered steel (on a mass basis), demand for which is strong. Improving local material utilisation may not have a significant impact on the current recovery rate, however may provide a driver to improve upstream efficiencies

Metal recycling capacity

Figure 11 shows how metal packaging diverted to waste recovery infrastructure (derived from MFA results). Approximately 112,000 tonnes of scrap aluminium and steel packaging was directed to MRFs in 2017/18 for sorting. Considering that metal packaging processed through MRFs makes up a small proportion of total packaging MRF throughput (approximately 5% in 2017/18), it is unlikely that MRF capacity will constrain future metals recovery. However, the impacts of the Chinese import restrictions affecting MRF revenues may threaten the financial viability of MRFs that could have indirect implications on metals recovery capacity.

[5] Here, we define best practice to be MRFs that operate with low process losses relative to incoming waste. This might be achieved through use of best available technology, with additional manual sorting

***Figure 11:** Metal packaging to recovery infrastructure*



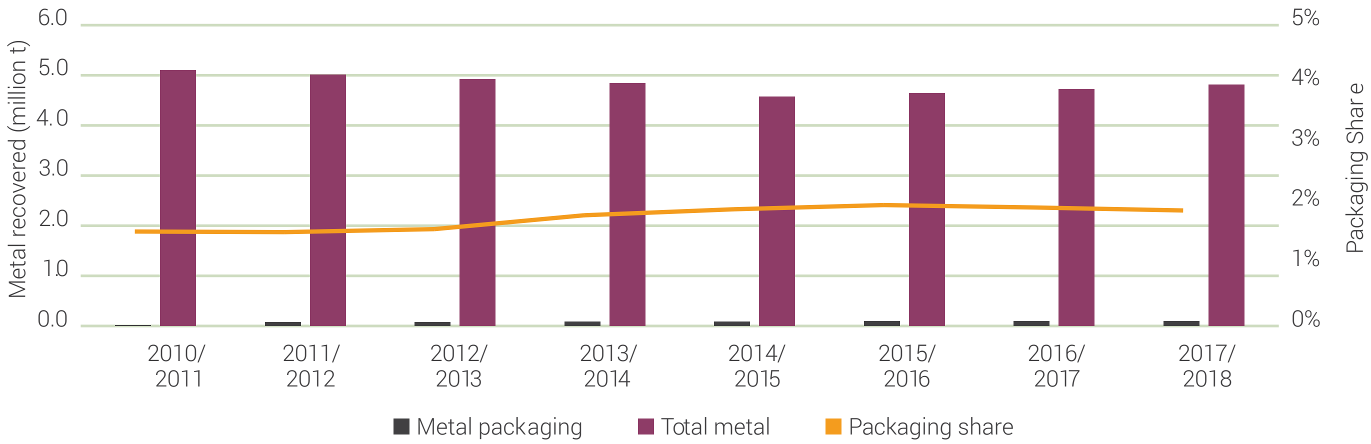
METAL PACKAGING 2017/18 TONNES	
Metal to MRFs	112,490
Metal to CD collection	9,189
Metal to recovery processes	102,464

Figure 12 shows historic metal recovery over time, derived from MFA estimates (for 2017/18), National Waste Report data (Blue Environment, 2017) and NRRS data (IndustryEdge & Equilibrium, 2017). Metal packaging recovery makes up a very small proportion (~2%) of total metal recycling in Australia. Note that total metals recovery in this figure includes other metals not predominately used in packaging (e.g., copper).

Recycled scrap metals including from packaging have a high commodity value relative to other recycling streams (REC, 2018), however this does fluctuate which at times has put financial pressure on metals recovery (Blue Environment, 2017). This may have an impact on future metal processing. While there is presently strong local and international markets for scrap metal, with the increasing trend in the export of scrap, the Australian system may be vulnerable when export markets are weak. This is particularly relevant for aluminium, where low demand for recycled aluminium has led to export of aluminium scrap to be the dominant recovery pathway (Blue Environment, 2017; REC, 2018).

There are reportedly six key metal reprocessors in Australia that take metal scrap. These include two blast furnaces located in Port Kembla and one in Whyalla. However it is unknown how much packaging scrap is processed by these operators – the main input to these plants is iron ore. Three electric arc furnaces also produce steel from scrap, including two furnaces located in Sydney and Melbourne and one in Newcastle. Boyne Smelters Ltd located in Gladstone operate Australia's largest reprocessing plant for aluminium scrap recovery, including from aluminium beverage packaging. It is reported that this smelter receives approximately 2,400 tonnes of packaging aluminium per year (REC, 2018). The actual capacity of these facilities to process metal packaging waste is unknown, however considering packaging metal makes up such a small proportion of total metal waste generated, it is unlikely that reprocessing capacity will constrain metal packaging recovery.

***Figure 12:** Historical metal and metal packaging recovery in Australia*



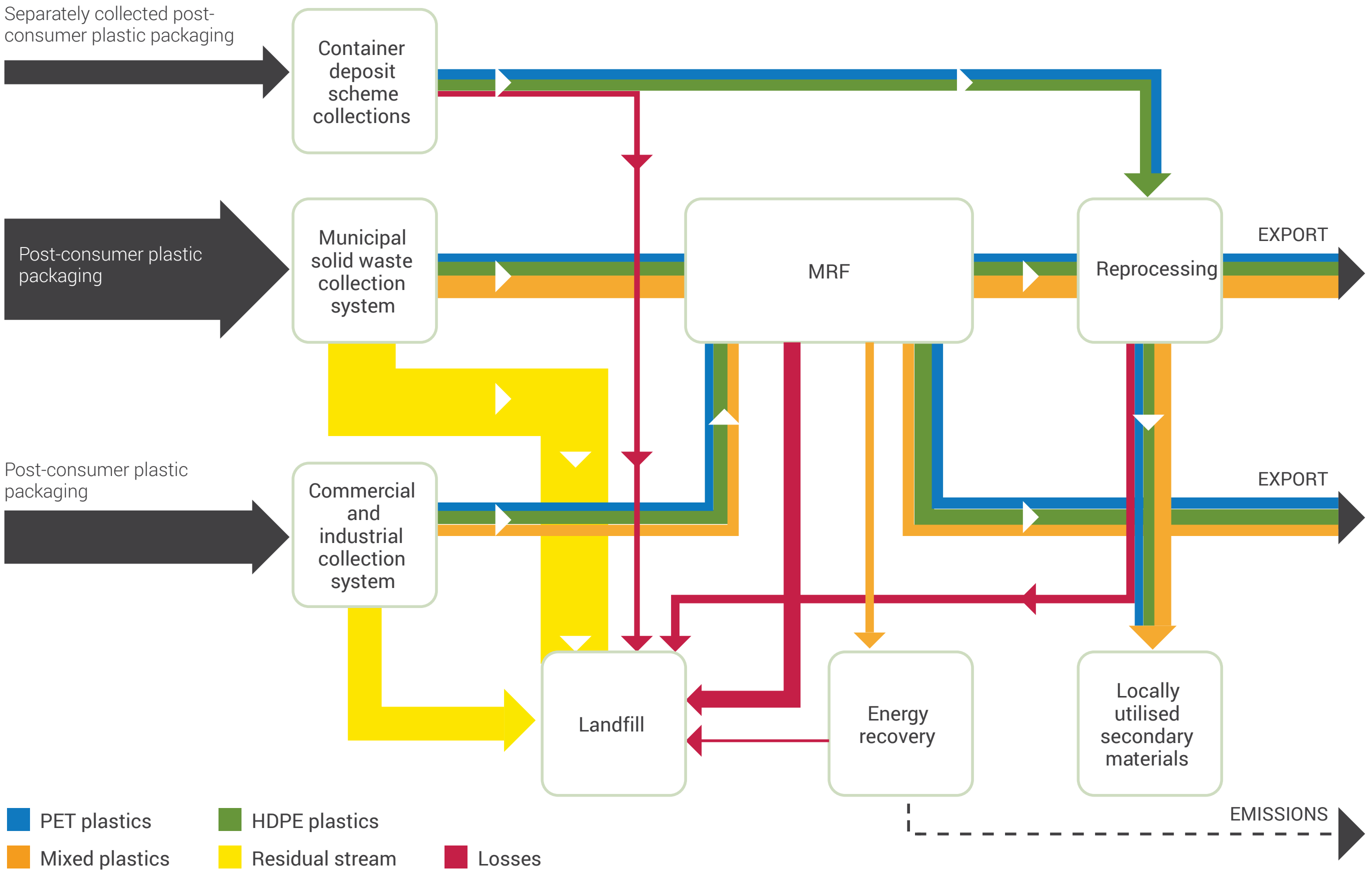
[4] Here, we define best practice to be MRFs that operate with low process losses relative to incoming waste. This might be achieved through use of best available technology, with additional manual sorting

3.4 Plastics

Highlights

- The municipal waste stream accounts for approximately 75% of total plastic packaging generation. Mixed plastic packaging makes up approximately 50% of total plastic packaging by mass across MSW and C&I waste streams
- Total plastic packaging recovery has been estimated at 32%±4%, with PET recovery at 29%±5%, HDPE recovery at 29%±4%, and mixed plastics recovery at 34%±4%
- Mixed plastic makes up the bulk of plastic packaging recovered. With the present limitation on imports of mixed plastic bales to China, this will likely lead to a reduction in demand for plastics recovery until new or additional recovery pathways and/or local end markets for mixed plastic recyclate are established
- Around 58% of total plastic packaging generation is disposed of to landfill from collection. This represents a major inefficiency in the system, and a significant opportunity to improve source separation.

Figure 13: *Plastic packaging waste MFA diagram*



Main findings and discussion

Figure 13 shows the flow of plastic packaging through the system and between processes. A stock-and-flow diagram is provided in Appendix 9. This MFA splits the flow of plastic packaging into flows of PET, HDPE, and mixed plastic packaging after collection. For our estimates, 'mixed plastic' refers to non-PET and non-HDPE polymers combined.[5] There are multiple exports in this system of recovered plastic packaging occurring at both the MRF (sorted and baled plastic packaging) and the plastic recovery process (recovered secondary polymers). The plastic system includes energy recovery from waste.[6] A detailed description of the plastic system can be found in Appendix 5.

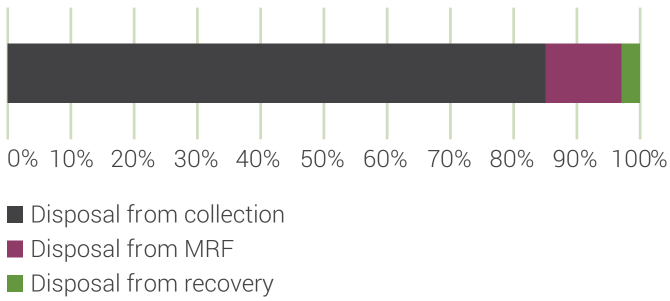
Uncertainty has been estimated for each flow, which ranges from ~4% for estimates derived from well described and reliable data, to ~23% where uncertainties in the data have propagated through the system. The highest levels of uncertainty are associated with the outflows from the MRF process, and from energy recovery.

The municipal waste stream dominates the generation of post-consumer plastic packaging, accounting for approximately 75% of total plastic packaging generation. Mixed plastic packaging makes up approximately 50% of total plastic packaging by mass across MSW and C&I waste streams. This stream consists of PVC, LDPE, PP, PS, EPS with LDPE accounting for about 50% by mass.

A significant amount of plastic packaging is estimated to be lost to the residual stream owing to incorrect disposal practices, accounting for approximately 58% of total plastic packaging generation for 2017/18. This represents a critical inefficiency in the system, and a significant opportunity to improve source separation.

Figure 14 shows the source of plastic packaging waste disposed to landfill, showing that waste disposed to landfill is mostly derived from waste diverted to the residual stream at collection, accounting for 85% of all scrap disposed to landfill. Data on residual stream disposal is lacking, and these losses can only be attributed to poor disposal practices. Disposal of sorting losses at the MRF constitutes the second largest source of plastic waste disposal to landfill, equalling ~12% of total landfill disposal in the system.

Figure 14: *Source of landfill disposal of non-recovered plastic packaging along the waste recovery infrastructure*



[5] Note that actual 'mixed plastic' bales produced at the MRF may also contain quantities of PET and HDPE. Flows of PET and HDPE that are contained within mixed plastic bales are captured in the PET and HDPE flows in our system

[6] For our estimates, we have assumed a medium sized incineration facility operating at high levels of thermal efficiency. It must be noted that the energy recovery process features a single export of emissions into the environment, which is accounted for in our analysis in order to maintain the mass balance

Figure 15 shows the proportion of total plastic recovery by recovery source, showing that the bulk of recovery occurs first at the MRF through direct export, and local utilisation of recovered plastic as a secondary material. Approximately 10% of plastic recovered is exported as reprocessed secondary materials. Local material utilisation represents a significant proportion of total recovered plastics (44%) while energy recovery only contributes a small amount.

Figure 15: *Sources of plastic packaging recovery*

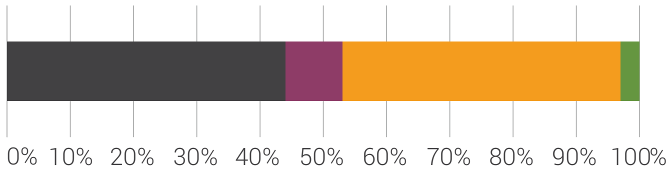


Table 6 contains calculated performance metrics for the plastic packaging system. Total plastic packaging recovery has been estimated at 32%±4%, with recovered PET recovery at 29%±5%, HDPE recovery at 29%±4%, and mixed plastics recovery at 34%±4%. The recovery rate of plastic packaging in general is very low, in addition to poor source separation and sorting efficiencies, meaning the plastic waste packaging system is very inefficient across all performance metrics.

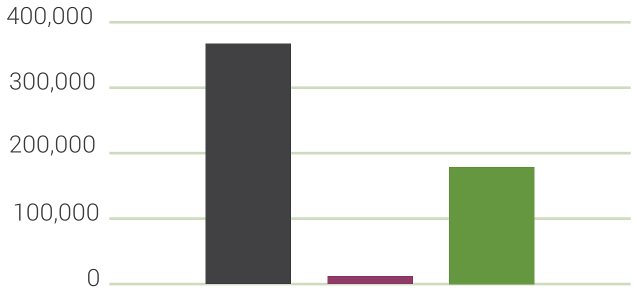
Table 6: *Plastic packaging performance indicators*

Performance metric	Value	Remarks
Collection efficiency	Total: 42%±3% PET: 35%±2% HDPE: 38%±3% Mixed: 47%±3%	The low collection efficiency highlights the opportunity to improve source separation. Improving source separation can be done through better disposal practices to reduce leakage, expanding collection of soft plastics through existing stewardship schemes (e.g. REDcycle), or interventions such as container deposits that bypass kerbside collection systems
Sorting efficiency	Total: 34%±5% PET: 29%±4% HDPE: 32%±5% Mixed: 35%±4%	Sorting rates are very low, owing largely to poor upstream collection efficiency. There is a noticeable drop in efficiency between collection and sorting, estimated to be owing to contamination in waste stream received at the MRF, and sorting losses at the MRF. Opportunities for improvement include investment in better sorting equipment, and improved packaging design to facilitate better sorting
Recovery rate	Total: 32%±4% PET: 29%±5% HDPE: 29%±4% Mixed: 34%±4%	Recovery rates are very low, with mixed plastic packaging constituting the majority of recovered plastic (52% of total recovered plastic), despite being a lower valued stream compared to PET/HDPE. This is owing to the greater exports of baled mixed plastic from the MRF, higher material utilisation rate, and energy recovery. Note here we define mixed plastic as all non-PET and non-HDPE polymers combined
Local material utilisation rate	Total: 14%±2% PET: 10%±1% HDPE: 10%±2% Mixed: 18%±2%	Material utilisation rates are very low. For PET and HDPE packaging there are strong local and export markets

Plastic recycling capacity

Figure 16 contains results from the MFA for plastic packaging diverted to waste recovery infrastructure. This figure shows that approximately 367,000 tonnes of plastic packaging waste was directed to MRFs in 2017/18 for sorting. As recovered plastic (particularly PET and HDPE) have currently high market value, it is not likely that MRF throughput capacity would be a limiting factor on plastics recovery, rather economic viability linked to the market price of secondary plastics would be a key constraining factor. As with CDS collection expands across the country, the amount of plastic directed to MRF may diminish, if plastic containers are taken out of the dry recyclable stream for CDS collection. However it is unknown the proportion of CDS collection in the future that would be derived from the litter stream rather than the household dry recyclable stream. As CDS systems expand, plastic reprocessors will have access to a higher quality of high-value PET and HDPE scrap.

Figure 16: *Plastic packaging to recovery infrastructure*

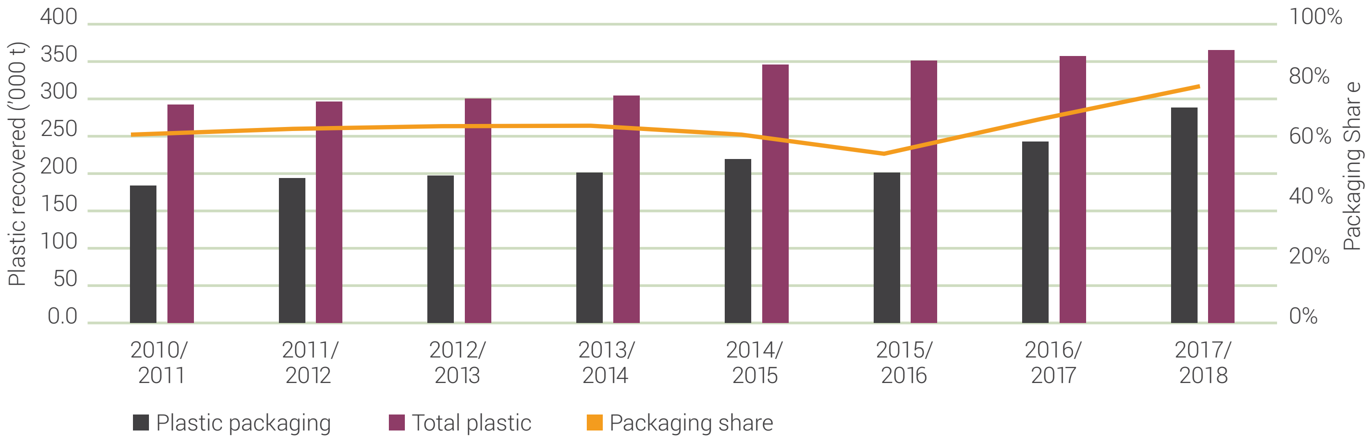


PLASTIC PACKAGING 2017/18 TONNES	
Plastic to MRFs	367,142
Plastic to CD collection	11,934
Plastic to recovery processes	178,972

Figure 17 shows historic plastic recovery over time, derived from MFA estimates (for 2017/18), National Waste Report data (Blue Environment, 2017) and Envisage's report on the assessment of Australian plastic recycling (Envisage, 2018). Recovered plastic packaging makes up a significant proportion of total plastics recovery, rising to ~70% in 2017/18.

There are approximately 64 plastic reprocessors operating in Australia (Envisage, 2018), many treating multiple polymer types. Local material utilisation represents 44% of total plastics recovery. Local material utilisation rates by polymer relative to recovery per-polymer are: PET 34%, HDPE 35%, and mixed plastics 53%. Mixed plastic makes up the bulk of plastic packaging recovered, however with the limitation on imports of mixed plastic bales to China, the driver for recovering these materials is undermined. New or additional end of life pathways are required, e.g., advanced MRF sorting to meet Chinese quality standards for import), and/or support to establish local end markets for mixed plastic recyclate and/ or energy recovery. In the case of improved MRF sorting, capacity to sort scrap plastic to higher quality specifications may be limited assuming that not all MRFs will be able to invest in sorting equipment upgrades or additional labour.

Figure 17: *Historical plastic and plastic packaging recovery in Australia*



3.5 Overall assessment of the packaging waste system performance

Table 7 shows estimated packaging waste generated, recovered, and a recovery rate for each material stream and sub-stream investigated in this study. The estimated overall recovery rate of packaging waste in Australia for 2017/18 was 56%±17%. Of the material streams investigated, the best performing stream in terms of total recovery was paper, with a recovery rate of ~72%. The worst performing stream was the plastic stream with recovery rate of ~32%. Common across all the systems is a significant amount of recyclable waste disposed to landfill through incorrect disposal practices. For systems with poor collection efficiencies, this loss is compounded when waste reaches the MRF for sorting. This is most evident in the case of glass.

Figure 18 provides a Sankey diagram of the aggregated packaging waste flows through the Australian waste management system, estimated from the MFA. In this diagram, the width of the flow lines are proportional to the size of the flow. The figure shows that a large proportion of waste is directed to landfill before going through any sorting or recovery process.

Our investigation shows how general stream contamination, and glass breakages, can have significant negative impacts on MRF sorting efficiency. By alternatively diverting packaging waste through a CDS collection system, the stream is not subject to these inefficiencies at the MRF, and can be directed straight to secondary material recovery. Similarly a large proportion of total packaging waste (derived from commercial and industrial paper packaging) is directed to recovery from use. This higher quality stream consists of used C&I cardboard packaging that has been collected separately and transported direct to recovery.

Export of recovered waste overseas is also shown **(Figure 18);** this occurs as either sorted and baled waste exported from MRFs, or the export of recovered secondary material. Exports overseas represent approximately a third of total waste packaging recovered in 2017/18.

Table 7: *Summary of waste system performance by material type*

Waste packaging stream	Generated packaging waste (t)	Recovered incl. exports and stockpiles (t)	Recovery rate
Glass	1,292,016	641,372	50% ±8%
Paper	2,052,052	1,470,186	72% ±13%
Unbleached	1,274,250	909,010	71% ±13%
Mixed	776,923	561,176	72% ±13%
Metal	171,375	**92,217**	**54% ±10%**
Aluminium	61,559	44,059	72% ±13%
Steel	109,816	48,158	44% ±8%
Plastic	907,401	**287,502**	**32% ±4%**
PET	**138,585**	**40,764**	**29% ±5%**
HDPE	**328,727**	**96,883**	**29% ±4%**
PVC	**17,014**	**4,794**	**28% ±3%**
LDPE	**220,148**	**61,518**	**28% ±4%**
PP	**101,464**	**27,156**	**27% ±4%**
PS	**26,913**	**8,022**	**30% ±4%**
Other	**74,551**	**48,365**	**65% ±7%**
Total Packaging	4,422,845	2,491,278	56% ±17%

[7] This is the estimated national recovery rate. State waste recovery rates may vary by more than the ± indicated

__Figure 18:__ Sankey diagram of estimated total packaging flows through the Australian waste management system in 2017/18

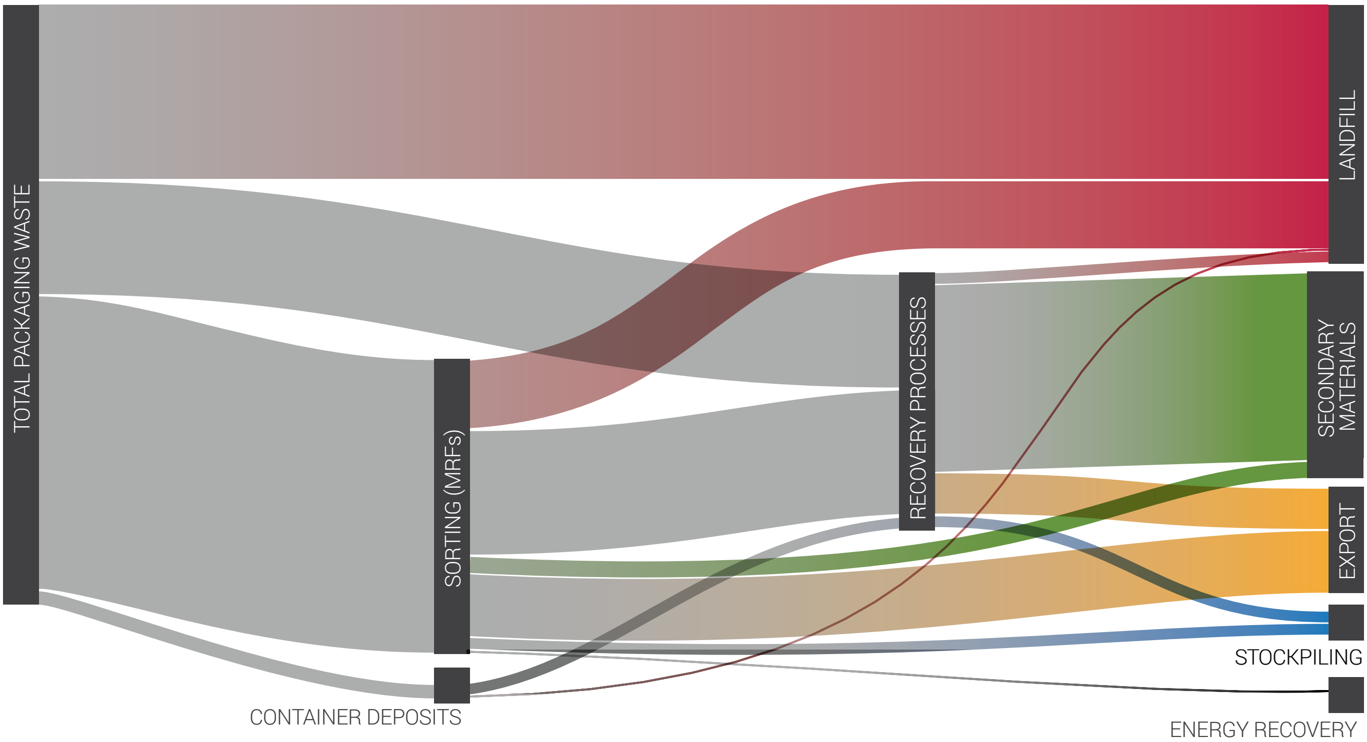
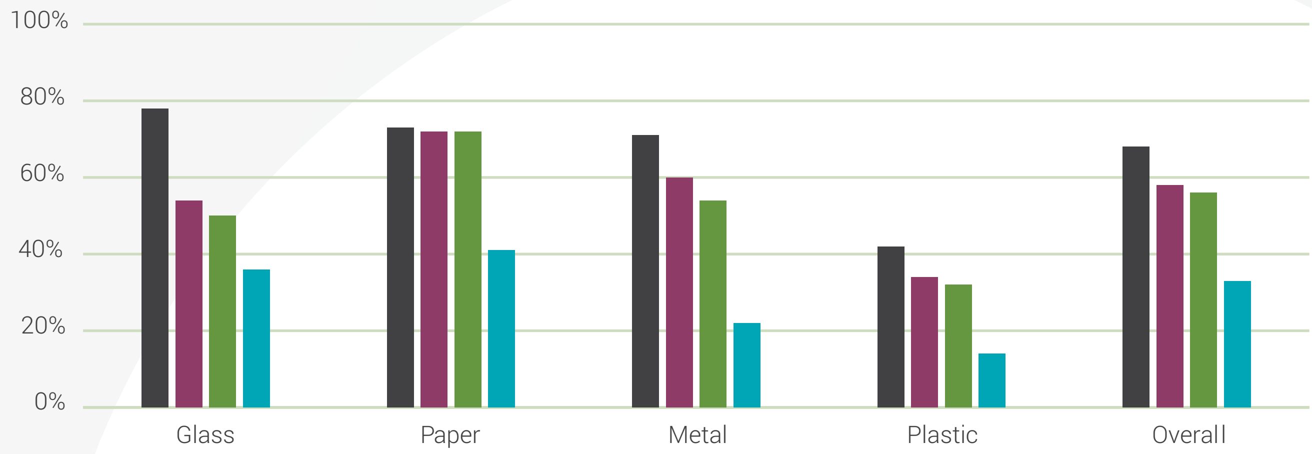


Figure 19 compares the calculated performance metrics for the waste packaging systems. There are different opportunities for improving the overall performance for the different material streams. For example, glass collection efficiency is relatively high, however system performance diminishes when the glass waste is sorted at the MRF with sorting efficiency dropping to 54%. This indicates that MRF sorting is inefficient for glass packaging, and efforts should be taken to either improve collection and MRF sorting of glass, or diverting recyclable glass away from MRF to the CDS channel. Similar system performance is evident across the other systems with the exception of paper, which sees only a 1-2% drop in efficiency from collection, to sorting, to recovery. This indicates that paper sorting and recovery are very efficient, and efforts should be focussed on the collection efficiency. Similar conclusions can be made when comparing where in the system the major losses are occurring. For glass, the major losses are observed during sorting, while major losses in the paper system occur at the point of collection (i.e. the household).

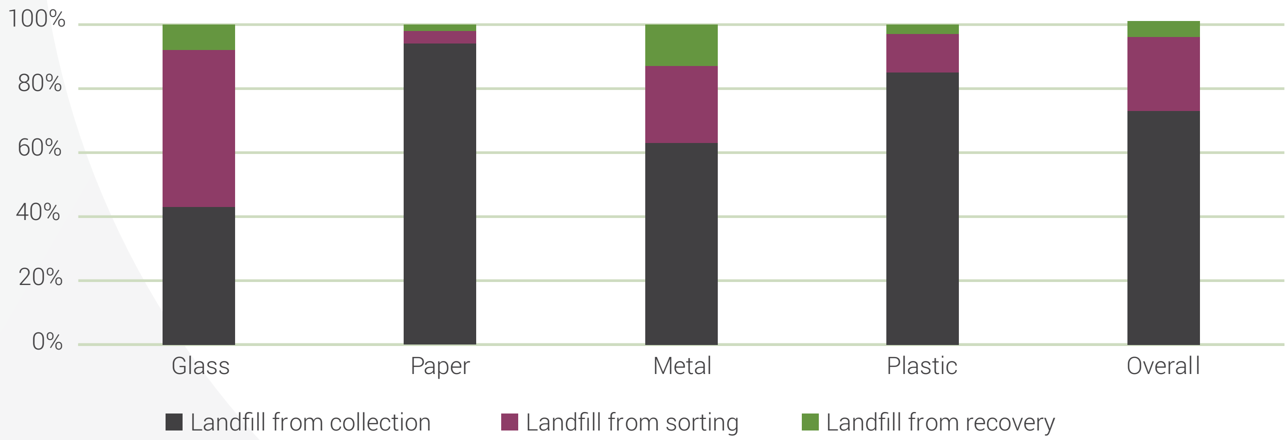
Figure 20 shows the proportion of total packaging disposed to landfill from collection, sorting and recovery processes.

Figure 19: Comparison of performance metrics for the different waste streams



	GLASS	PAPER	METAL	PLASTIC	OVERALL
■ Collection efficiency	78%	73%	71%	42%	68%
■ Sorting efficiency	54%	72%	60%	34%	58%
■ Recovery rate	50%	72%	54%	32%	56%
■ Local material utilisation rate	36%	41%	22%	14%	33%

Figure 20: Source of landfill-destined waste



4 Recycling Infrastructure Capacity

4.1 Overview of existing local recycling capacity

Highlights

- There is a lack of reliable data on the number, throughput capacity and individual sorting capabilities of MRFs and throughput capacity of reprocessors currently in operation. These data limitations make it difficult to accurately identify specific system constraints and/or opportunities to scale-up sorting and processing capacities
- The sustained economic viability of MRFs, linked to accessibility of local and export markets for sorted materials, is crucial for a sustainable future recycling system
- Improved collection efficiency and improved sorting efficiency at the MRF would likely increase the amount of waste available for material reprocessing, it is uncertain if sufficient capacity for this exists
- Significant growth in CDS collection is anticipated, and demand for this waste stream from reprocessors, particularly in the case of glass and PET/HDPE, will increase given the high quality of the CDS stream
- Local recovery capacity will need to grow to transfer recovery of waste ordinarily exported to China to local secondary material processing in the case of mixed plastics and mixed paper. Advanced sorting and processing and alternate manufacturing processes would open new local and export markets (or re-establish exports to China if quality specifications are met)
- Costs may be a factor in establishing additional processing capability. Local mixed plastic processing can be augmented with small facilities that can wash, flake and pelletise plastic waste cost-effectively for example, however additional capacity augmentation can be costly, as is the case for capital intensive paper reprocessing

Material recovery facilities

There are about 100 MRFs currently in operation across Australia. MRF throughput capacities range from 5,000 to 250,000 tonnes per annum, and there are a range of sorting capabilities, with the most advanced facilities capable of separating co-mingled recyclables into 13 separate streams (generally separating all material streams and sub-streams, e.g., amber glass, PET plastic, etc.) (MRA, 2018). Specific data on the operational characteristics by facility type and location is not publicly available.

Table 8 shows the amount of waste by material type that is directed to MRFs, CDS collection, and secondary material recovery facilities for 2017/18. Around 45% of the total waste packaging stream for 2017/18 gets directed to MRFs. This is a significant amount of waste, equal to approximately 30% of total Australian municipal solid waste generation for 2014/15 (Blue Environment, 2017). The capabilities of MRFs for efficiently sorting co-mingled and highly contaminated municipal waste is a major factor limiting packaging sorting efficiency in Australia (DoEE, 2018). Upgrading existing MRF capabilities is difficult and expensive owing to market uncertainties (e.g., caused by Chinese waste import restrictions), making the case for improving up-stream source separation and collection stronger. The amount of packaging waste currently destined for MRFs could potentially decrease, as collections through CDS increase, along with the implementation of other measures to divert recyclable materials to materials processing (e.g., increased compostable packaging). Improving source separation and disposal practices may result in additional pressure on MRF capacity (as waste ordinarily disposed of to landfill is diverted to the appropriate dry recycling stream); or improve MRF sorting capability as MRF efficiency will benefit from higher quality with decreased contamination. A detailed analysis of the potential implications for MRF operations on increased volumes versus reduced contamination is beyond the scope of this research.

It is noted that across the waste streams investigated, a dramatic increases in waste generation in the future beyond what would be expected from population growth, may result in capacity being an important constraint. The economic viability of MRFs has been highlighted as a major issue in the context of the new limitations on waste imports to China. However exports of waste, especially paper and plastic, to other export markets (i.e., Indonesia, Vietnam, Malaysia, India and Thailand) have increased in 2017/18 (DoEE, 2018). Local demand for secondary materials and accessibility to markets may have a very strong impact on the viability of local collection and sorting activities.

Data on the total amount of waste from the general waste stream (i.e., not packaging) directed to MRFs is uncertain. Any robust analysis into the existing and expected processing capacities of the MRFs will require data on the amount of waste that MRFs receive from all sources (not just from packaging), ideally at the facility level.

Container deposit scheme collection

Significant growth in waste collected through CDS is likely given the rollout of CDS in Queensland and Western Australia. This stream, particularly in the case of glass and plastic, is of a very high quality, and in demand by secondary material processors.

Data is not available characterising what occurs at the point of CDS collection, including the extent of sorting required of packaging deposited at CDS collection points and the subsequent quantities of residuals. Furthermore, the capacity of the CDS systems to scale-up is uncertain, and a better understanding of the likely proportion of CDS inputs derived from kerbside vs litter is required to appraise future capacities.

Table 8: *Overview of waste flows across recovery infrastructure*

	Waste sent to MRF (t)	Waste collected through CDS (t)	Waste sent to secondary material recovery (t)
Glass	933,510±15%	79,665±4%	458,421±14%
Paper	618,282±19%	879±4%	1,099,288±18%
Metal	112,490±20%	9,189±4%	102,464±17%
Plastic	367,142±7%	11,934±4%	178,972±13%
Total	2,031,424±15%	101,667±4%	1,839,144±16%

Secondary materials recovery

Approximately 1.8 million tonnes of packaging waste was sent either directly, or via MRFs/CDS, to secondary material recovery in 2017/18. Of this, ~1million tonnes was paper (predominately unbleached kraft) packaging.

Table 9 includes the number of reprocessing facilities known from available data, and the estimated amount of packaging waste processed by material stream for 2017/18.

In the case of glass, six beneficiation plants located across Australia send cullet to four local glass packaging manufactures that are located in Adelaide, Brisbane, Melbourne and Sydney. A portion of this cullet produced (~16%) at the beneficiation stage is stockpiled owing to lack of demand for cullet at the time of beneficiation. Findings from this study suggest that there is sufficient processing capacity for cullet that only represents about 50% of the total processing capacity (Pers. Comm. 2018). Greater quality recovered glass from CDS collection is expected to increase the supply of cullet available for glass packaging manufacturing and the main constraint for increasing this input will likely be the transportation costs affected by the proximity of beneficiation facilities to the manufacturers.

Table 9: *Summary of national material reprocessing facilities*

Packaging material	Number of reprocessing facilities nationally	Packaging waste reprocessed (2017/18)
Glass	6	458,421 tonnes
Paper [10]	16	1,099,288 tonnes
Metal	6	102,464 tonnes
Plastics	58	178,972 tonnes

[9] *Based on estimates from Envisage (2018), IndustryEdge (2018), REC (2018), SRU (2018), and NetBalance(2012)*

[10] *Includes single-stream sorting facilities (IndustryEdge, 2018)*

For paper packaging, approximately 1million tonnes of waste was recovered at secondary material reprocessors (with an additional ~400,000 tonnes recovered through export at MRFs). It is unclear from the available data how many paper waste reprocessing facilities are in operation in Australia. Of the total amount recovered at the reprocessing stage, approximately 20% was exported as recovered fibre and recovered mixed paper, with recovered mixed paper making up 20% of these exports. Unbleached kraft has a strong export and local market. About 700,000 tonnes of secondary unbleached kraft fibre was recovered for local utilisation in 2017/18. Considering the impact of the curtailment of mixed paper exports to China, local processing rather than exporting this waste has been proposed by stakeholders as a solution to maintain total paper packaging recovery rates, possibly requiring sorting to a higher quality specifications. The high capital intensity of paper processing has been noted as a possible barrier to increasing on-shore capacity that might favour the scaling up of existing paper mills rather than investment in new facilities (MRA,2018).

Considering metals processing, there are strong local and export markets for scrap metal, although these markets fluctuate due to global economic forces. Additionally, metal from packaging makes up a tiny fraction (~2%) of total metals smelting and refining from metal waste locally. The financial viability of MRFs to sort metal packaging streams in addition to smelting capacity availability would likely be key constraining factors in the future recovery of metals locally.

For plastics, of the ~160,000 tonnes of waste received by plastic reprocessors in 2017/18, approximately 80% was recovered and utilised locally for secondary materials (~14,000 tonnes of PET, ~34,000 tonnes of HDPE, and ~79,000 tonnes of mixed plastic). Of the ~30,000 tonnes of plastic exported from reprocessors, 50% of this was mixed plastic. Note that an additional ~48,000 tonnes of mixed plastic is exported from the MRF before the reprocessing stage of recovery. Since the curtailment of exports to China, the market value for mixed plastic has declined significantly and is not expected to recover in the short term (DoEE, 2018). Compared to mixed baled plastic, plastic materials sorted separately into polymer types at the MRF and exported directly are of greater value, and have greater market access. Enabling more efficient separation into different polymer types for export or for local markets might improve MRF economic viability in response to declining recyclate values. On the other hand, local reprocessing, and manufacturing utilising the mixed plastic stream, might be expanded to ensure recovery rates for plastics do not fall. In 2017/18, approximately 79,000 tonnes of mixed plastic was recovered locally as secondary materials, however the potential to scale-up this local mixed plastic processing capacity is unknown. Investment in small facilities that wash, flake and pelletise waste, possibly co-located with MRFs to achieve cost-efficiencies, has been proposed as a solution by providing a higher value stream for local and export markets (MRA, 2018).

In the case of PET and HDPE, 80% of the recyclate stream is utilised locally and the remainder is directed to strong export markets. Growth in CDS collection will mean plastic reprocessors will likely have access to a greater quantity of higher quality PET and HDPE containers for processing from this stream. The magnitude of this increase and the capacity of local plastic processors are uncertain, and may be impacted by market variability of virgin and secondary plastics.

National Packaging Targets for recycled content in packaging [11] will have an important, additional impact in providing demand for driving increases in local packaging recovery.

[11] *For example, Unilever will introduce at least 25% recycled plastic into bottles for key brands from as early as 2019 (https://www.unilever.com.au/news/press-releases/2018/Unilever-announces-landmark-packaging-move.html)*

4.2 Establishing the baseline and future recycling capacities

Establishing a baseline for current recycling capacity is important for waste management planning. It is also important for appraising possible pathways and future scenarios for the increased recovery of Australian packaging waste streams.

Our assessment of the available data has highlighted the following data gaps that need to be addressed to accurately estimate current recycling capacity:

- Total flows of waste/materials to individual MRFs and to reprocessors (and the fraction that is packaging)
- Reliable number and sorting/processing capabilities of MRFs and reprocessors, and their locations
- Specific MRF and reprocessing efficiency rates by material type/sub-type
- Annual facility throughput for MRFs and reprocessors

No estimate of recovery capacity for packaging waste can be made without considering the broader waste stream, as recovery infrastructure is shared. The flows of waste to MRFs and to reprocessors is known for the packaging waste stream based on findings from the MFA conducted for this report. However, MFAs or other similar accounting methods need to be performed for the entire waste stream to better understand total waste flows to and from MRFs and reprocessors. To the best of the authors' knowledge, such detailed data on the flows of the waste stream as a whole does not exist for Australia.

The number of MRFs and reprocessors located across Australia is publicly available from a number of datasets, including some of these noted in **Table 1.** Other key sources exist which give the number of MRFs or reprocessors, but there is significant disagreement between the sources, and the necessary level of detail to accurately estimate capacity (e.g., throughput capacity of individual facilities) is not available.

These additional datasets are as follows:

- **Analysis of Australia's Municipal Recycling Infrastructure Capacity, Department of Environment and Energy (2018)**—this report provides an appraisal of the capacity for the Australian waste management system to collect and process municipal waste, and does not provide new data on infrastructure capacity to process collected packaging or waste streams in general. Although packaging is a major component of the municipal waste stream, it is not the focus of the analysis. The report relies on a dataset of waste management facilities produced by Geoscience Australia, data on available waste collection services for local government areas across the country, and industry consultation reports on paper and paperboard, plastic, metal and glass packaging waste management (previously described in **Table 1**)
- **Waste Management Facilities, Geoscience Australia (2017)**—this dataset is produced by the Federal Government, and is stated to include Australia's known landfills, MRFs and transfer stations, and a large number of known waste reprocessing facilities. This data includes 229 operating MRFs/transfer stations and reprocessing facilities across Australia. However, this data does not discern between facility types in the case of MRFs, material types processed in the case of reprocessors, nor does it include characteristics about individual facilities beyond its geospatial location. As such, this dataset has limited application for estimation of recovery capacity
- **National Waste Report, Department of Environment and Energy (2013)**—the 2013 National Waste Report includes the number of MRFs and 'recovery facilities' for each jurisdiction in Australia. The report estimates 114 MRFs in operation in the reporting year, which generally agrees with other sources for the number of Australian MRFs (around 100). The definition of a 'recovery facility' is also ambiguous, including any type of facility that 'shreds, dismantles and sorts' (DoEE, 2013) materials suitable for reprocessing. From this definition, there is little differentiation between a 'recovery facility' and a MRF. The report estimates that there are 520 of these facilities operating across Australia in the reporting year. This number is inconsistent with other estimates of the number for MRFs or reprocessors that are operating in Australia currently. In addition, the report does not give details on operating characteristics for MRFs or reprocessors, nor their specific locations
- **The Australian Recycling Sector, NetBalance (2012)**—this report details the number of reprocessing sites by material across Australian jurisdictions, derived from a number of government data sources. The report lists the assumed number of processing facilities, however is inconsistent with other datasets collated for this study. Inconsistencies are relatively small when compared to those identified in the Geoscience Australia data set. These inconsistencies may be owing to the fact that the NetBalance study is 6 years out of date (for example, 73 plastics and 23 paper reprocessors in the NetBalance dataset compared to 64 plastics and 16 paper reprocessors from reviewed up-to-date literature). Additionally, the report does not detail operational characteristics of reprocessors, nor specific locations of reprocessing facilities.

To know the capacity to sort and process waste, the throughput capacity of individual MRFs and reprocessors is required. Capacity varies widely between facilities and is dependent on a variety of factors, including technology type, and what kind of sorting is done (e.g., 'dirty' MRF sorting vs. '13-sort MRFs').

Data on facility processing capacity is difficult to find, and inconsistent. Data sources used in this study estimate MRF throughput capacity between 5,000 and 250,000 tonnes per annum (Green Industries SA, 2018; MRA, 2018). Reprocessing throughput capacity is less well known. Green Industries SA (2018) notes medium tech-reprocessing facilities with throughput capacity between 10,000 and 20,000 tonnes per annum. The authors are unaware of other data specifying reprocessing capacity throughput by facility and material type.

It is important to note, it has been found that economic viability and the value of the sorted waste stream that leaves the MRF for further processing to be the greatest constraint on future viability of the recycling system. This case is largely the same for reprocessors.

5 Future Scenario Analysis

5.1 Introducing future scenarios

Five future scenarios that characterise different system improvements have been modelled. These scenarios were informed by review of the literature, expert stakeholder interviews, and the findings from the MFAs. These future scenarios are by no means exhaustive, however they are useful to examine potential future pathways for improving the waste packaging system in Australia. Descriptions of the future scenarios are given in **Table 10.**

Table 10: *Description of scenarios*

Scenario	Description	Relevant system(s)	Changes made to base case
Business-as-usual	The current waste packaging management system	All systems	NA
Scenario 1: Expanded container deposit collection	CDS collection covers all Australian jurisdictions, diverting waste from kerbside collection.	All systems, but relevant to glass, mixed paper, aluminium, PET and HDPE packaging types only	CDS collection per-capita is applied across the entire Australian population for 2017/18. Additional glass and PET/HDPE collections equal to 20% of the input to municipal glass and PET/HDPE streams is diverted from kerbside collection
Scenario 2: Improved disposal practices	Contamination, and disposal of recyclables in the residual stream (leakage) are reduced	All systems	Contamination rates and residual rates modelled from the data are reduced by 50%
Scenario 3: Improved MRF operation	MRFs are operating at best practice operational efficiencies	All systems	Average MRF efficiencies set to equal best practice MRF efficiency levels for each material category. These efficiency levels are derived from (ref: Pressley et al. (2015)
Scenario 4: Compostable packaging processing	The amount of compostable packaging in the stream is increased and directed to organics processing[12]	Paper (mixed paper), plastic (mixed plastic)	Compostable packaging material is estimated as 20%[13] of the total mixed paper and mixed plastic streams.
Scenario 5: Combined scenario	The above scenarios are combined	All systems	The above changes are incorporated into a combined scenario

[12] Organics recycling is not technology specific, and can include industrial composting or anaerobic digestion

[13] The likely amount of compostable packaging to enter the waste stream was unclear from our data analysis. An assumption of 20% of total mixed paper was used as an extreme example

5.2 Future scenario analysis

Scenario analysis results across the entire waste packaging system are found in **Figure 21** and **Figure 22,** and **Table 11** contains results for each material system.

From **Figure 21**, scenario 2 is shown to have the greatest impact alone on the recovery rate. This is consistent with general findings from our investigation whereby losses to the residual stream at collection represent a significant loss of potentially recyclable material from the recycling system. By reducing contamination and residual stream disposal by 50%, a system wide recovery rate of just under 70% may be achieved.

Also of note is the improvement in the performance from expanding the scope of the container deposit schemes (scenario 1) and increases in compostable packaging directed to organics processing (scenario 4). These two scenarios both divert quantities of waste ordinarily disposed of into dry recycling streams away from MRF sorting, thereby avoiding major losses owing to MRF sorting inefficiencies. This is evident in **Figure 22,** where the magnitude of the flow from use direct to recovery is a lot larger compared to the base case in **Figure 18.** (The scenario visualised in **Figure 22** is for the combined scenario.) It should be acknowledged that present levels of compostable packaging in the waste stream are small, and introducing an additional collection channel to direct this material to appropriate industrial organics processes may not reach maturity in the short term.

Scenario 3 models the improvement of MRF sorting by increasing the assumed average process efficiency to best-practice (assuming use of best available technology, additional manual sorting, etc. would have a significant impact on improving overall sorting efficiency). While scenario 3 has no impact on collection efficiency, the improvement in both sorting efficiency and recovery rate compared to the base case is meaningful, and aligns with the findings from our analysis highlighting that losses at the MRF are a significant barrier to achieving higher rates of downstream packaging recovery. Our assumption of using an average MRF sorting rate has implications for these results, recognising that not all MRFs across the country will have the ability to upgrade sorting technology, or augment existing sorting with greater manual sorting.

Scenario 5 is a combination of all future strategies explored in scenarios 1 through 4, i.e. it represents a theoretical maximum performance under our assumed future operating conditions. A significant increase in recovery rate from ~56% to ~77% can be achieved in this scenario. An additional improvement to performance under this scenario is the significant increase in local material utilisation, achieving almost 50% of all packaging waste recovered utilised locally. Note for these modelled scenarios we have assumed that local capacity for material utilisation and export markets' accessibility grow in proportion to recovery.

Figure 21: *System wide performance metrics for modelled scenarios*

Figure 22: Combined scenario (Scenario 5)

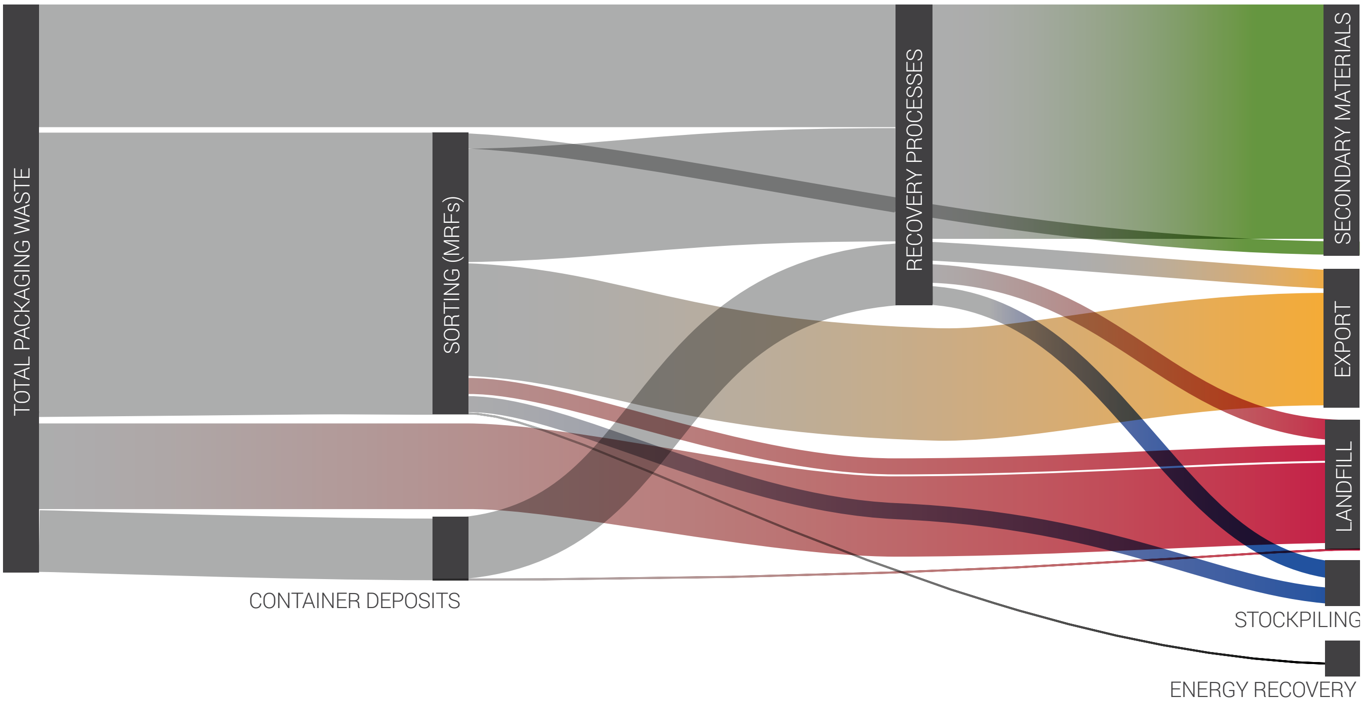


Table 11: Scenario analysis results

	BAU	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
COLLECTION EFFICIENCY						
Overall	68%	72%	83%	68%	77%	86%
Glass	78%	85%	88%	78%	78%	92%
Paper	73%	73%	87%	73%	88%	89%
Metal	71%	73%	84%	71%	71%	86%
Plastic	42%	47%	69%	41%	50%	73%
SORTING EFFICIENCY						
Overall	58%	63%	72%	65%	64%	82%
Glass	54%	67%	59%	71%	54%	85%
Paper	72%	72%	86%	73%	79%	89%
Metal	60%	62%	78%	59%	60%	79%
Plastic	34%	39%	55%	39%	48%	65%
RECOVERY RATE						
Overall	56%	61%	69%	63%	60%	77%
Glass	50%	60%	55%	66%	50%	77%
Paper	72%	72%	85%	73%	78%	88%
Metal	54%	56%	70%	54%	54%	72%
Plastic	32%	37%	52%	37%	37%	53%

6 Conclusions & Recommendations

Main findings from MFAs

The overall performance of the Australian packaging waste system was evaluated using material flow analysis on a waste material stream basis. The results indicate that around 4,423,000 tonnes of packaging waste was generated in 2017/18, of which 56%±17% was recovered with the remainder going to landfill.

Recovery rates are generally low across all the waste streams analysed. Paper and paperboard packaging has the greatest performance in terms of collection, sorting, recovery and material utilisation. The recycling system for waste plastic packaging is the lowest performing system, with an estimated recovery rate of 32%±4%, owing to high rates of disposal at collection, and inefficient sorting at MRFs.

Considering the range of available interventions to improve overall system performance at the kerbside (including diverting material to CDS) and at MRFs (automated sorting technology, increased manual sorting and/or slowing the throughput), this study provides targeted guidance on a limited range of strategies that could improve recovery rates across the different material streams. Specifically, this investigation has highlighted the importance of:

(i) improving source separation particularly for plastics to address the significant amount of losses to the residual stream;

(ii) a priority for paper in reducing contamination (embedded glass fines) that could be achieved with separate paper or glass separation;

(iii) the diversion of glass to CDS, that would significantly improve the quality of this stream to be suitable for bottle-to-bottle recycling and avoid contamination of paper and plastic.

Limitations and data uncertainties and recommendations for eliminating data gaps

Our study has identified a number of data gaps that not only impact the accuracy of this MFA but also have implications for developing a robust strategy to improve the performance of Australian packaging waste systems.

Key data uncertainties that were identified are:

- Inability to accurately assess the infrastructure capability, capacity and availability nationally
- Rates of MSW and C&I plastics diverted to landfill at the point of collection
- Steel packaging waste in the C&I stream, and sub-types of steel packaging
- Rates of contamination in the waste input at the MRF
- Material specific MRF operating parameters (e.g. sorting rate per polymer)
- Rates of contamination, if any, in waste sorted at the MRF
- Residual rates and efficiencies of re-processing per material type
- Non-packaging utilisation of recovered packaging waste
- Packaging waste diverted to alternate waste treatment technologies (e.g., energy recovery, anaerobic digestion/composting for biodegradables, AWT)
- Compostable packaging
- Litter[14]

[14] Despite the scope of this project being post-consumer packaging waste, litter is still an important part of the system especially when considering container deposit schemes which have been designed to have positive impacts on litter rates

Future research

This research is limited by data quality and availability, and the breadth of the analysis is constrained by the assumed system boundaries. We have identified a number of opportunities to extend this research to further support the development of strategies to improve packaging recovery and advance progress towards the 2025 National Packaging Targets:

- **Detailed characterisation of packaging losses at the source:** Better separation of packaging waste at the source was identified as an intervention point for improving recovery. Having a greater understanding of what packaging wastes are generated at the source, levels of contamination, and packaging disposal practices will guide future packaging waste management planning
- **Detailed characterisation of MRF sorting performance:** MRF sorting has been identified as an intervention point in the investigated systems, where losses and inefficiencies are high. Better understanding of the parameters influencing MRF performance will aid in packaging waste management decision making
- **Detailed characterisation of reprocessor performance:** Losses also occur at material reprocessors which needs greater clarity to better understand why these are occurring. For example, contamination levels of recovered secondary material inputs are unknown.
- **Expansion of system boundaries to cover packaging use rather than restricting to post-consumer waste.** This would allow the incorporation of litter as a waste flow, and the assessment of packaging re-use scenarios, however higher resolution data is required.

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