Final report

WHOLE OF MEAT SUPPLY CHAIN FOOD LOSS AND WASTE MAPPING AND INTERVENTIONS - PHASE 1 – FINAL REPORT

Project code: V.MFS.0457

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Abstract

This report details the findings of a research project into meat loss and waste in Australian beef supply chains, between receipt of livestock and the retail door. The aim was to generate a clearer picture of beef meat losses and waste than currently available. This included hotspot sources, causes and potential solutions, and approximation of the quantities and cost of losses.

Case studies of individual supply chain stages were conducted to identify sources and causes for each of the assessed supply chain stage. A whole of supply chain view was also taken in workshops to propose potential solutions, and, in particular, to examine losses that are co-created, requiring collaborative solutions. A framework for mapping and quantifying meat losses and waste in the beef meat supply chain was developed, and used to compile approximations of the scale of losses, based on available data, to help target future loss reduction planning efforts.

The most significant value from this research is the compilation of the key sources and causes of meat loss and waste. A key finding was that the most significant loss reductions will likely come from collaborative supply chain solutions that target loss reduction in refrigerated transport and distribution. This hinges on greater supply chain harmonisation, transparency, communication, and collaboration between supply chain stages and actors.

Executive summary

Background

The project responds to the growing need to address food loss and waste (FLW) from a whole industry sector perspective. Knowledge and data about food losses in Australian meat supply chains, in line with the international FLW Standard, has been patchy to date. This makes it difficult to plan the meat sector's meat loss reduction efforts under Australia's Food Waste Reduction Strategy.

This Phase 1 project – part of a broader research initiative of the Fight Food Waste Cooperative Research Centre (CRC) – focused on upstream production stages of the beef supply chain (meat processing and distribution through to retail door). The audience for this work is beef supply chain actors, including primary and secondar processors of beef, food processors for whom beef as an ingredient, and distributors of beef products.

Objectives

The aim of the project was to generate a clearer picture of beef meat losses and waste, with three main objectives:

- Identify the main sources of losses for each individual supply chain stage (primary, secondary, tertiary processing, and refrigerated transport and distribution) and fractions that go to food waste destinations.
- Engage with supply chain actors to identify potential causes and solutions of losses.
- Approximate the amounts and potential costs of losses.

Methodology

The method was based on Waste Resource Action Program's (WRAP) "whole of supply chain waste mapping and resource efficiency" process. The aim of this approach was to consider not only losses generated at each individual supply chain stage, but also those co-created across multiple supply chain actors and requiring collaborative solutions. Emphasis in this project was placed on exploring collaborative mechanisms of waste creation and potential solutions.

Information and data for this project was obtained via case study analyses of individual supply chain stages to identify sources and destinations for losses, waste mapping to approximate amounts of losses, supply chain workshops to explore root causes and possible solutions, and use of the Dynamic Industry Resource Efficiency Calculator Tool (DIRECT) to estimate the costs of losses. While there were limitations of what the data represents due to the small sample of case studies observed, the broader engagement and workshops with experts and supply chain actors meant the findings have a wider application than the datapoints from the limited case studies.

Results/key findings

This research defined food loss and waste in the context of meat. Losses are the fractions of edible meat and edible offal, meant for human consumption, which are difficult to harvest, and which are directed to non-food destinations as a cost-effective means of value recovery. Animal parts not destined for human consumption are not considered losses. Only losses of edible meat and edible offal that go to waste destinations (landfill, composting, digestion, combustion, wastewater) are considered food waste. The research examined all losses, as well as those considered food waste.

The research generated a compilation of the key sources and causes of meat loss and waste for beef supply between receipt of livestock to the retail door. A preliminary catalogue of loss reduction solutions has been co-designed through engagement with industry, which may be useful in the development of a Sector Action Plan as part of Australia's Food Waste Reduction Strategy.

An approximation of the amount of beef meat losses suggests that around 6% of beef meat intended for human consumption may potentially be lost between livestock receipt and the retail door. This is indicative only, due to acknowledged limitations and data gaps (see below). In primary and secondary processing, most losses can be recovered if there is access to rendering facilities or pet food manufacturing, resulting in no or low food waste. For tertiary processing, opportunities for loss recovery are more limited, resulting in food waste generation, but the total amount is expected to be low due to relatively low inclusion of beef ingredients in prepared foods. Potential for food waste generation is expected to be most significant in distribution (particularly product rejected at retail door due to packaging or temperature maintenance failures). This is because the rate of product loss is likely to be substantial - at least 1.5% and supported by findings from another study (Brodribb and McCann, 2020)) – and with a greater chance of it going to a waste destination. However how much of this becomes food waste is still a data gap due to lack of information about destinations.

Therefore, it appears that reducing product rejects at retail receipt provides the greatest opportunities for reducing food waste. As such rejects are co-created by multiple actors along the supply chain due to multiple root causes, solutions hinge on greater supply chain harmonisation, transparency, communication, and collaboration between supply chain stages and actors.

The project also trialled the use of the DIRECT tool for estimating the cost of meat losses in the processing stages, which may help the sector understand the potential cost savings from reducing beef meat losses.

Benefits to industry

The benefit for the meat supply chain actors is information to enable i) future planning of meat loss reduction initiatives and the financial saving that will accrue for supply chain actors, and ii) participation in the National Food Waste Reduction Strategy bringing increased social licence. It also provides impetus for increased collaboration and transparency along the supply chain to unlock innovation.

Consideration of environmental benefits from beef loss reduction were outside the scope of this project, but some commentary on the links between meat loss reduction and reduced greenhouse gas emissions is also provided.

Limitations

The sample of supply chain operations that could be observed was a key limitation of this project. The small sample size of operations observed means that the estimates of amounts and costs of losses and waste are not representative of the sector. However, the data does indicate relative amounts to inform further planning and data collection.

Future research and recommendations

The information generated by this project will likely be useful for the development of Sector Action Plan (SAP) under Australia's Food Waste Reduction Strategy, particularly the findings generated from the supply chain workshops regarding causes of meat loss and waste and potential solutions.

Data gaps remain due to limited information and data about the amounts and destinations of losses, despite best efforts. A better understanding of the amounts and destinations of beef product rejected by retailers will require engagement with retailers, and the cooperation of multiple industry actors, including transport carriers who did not respond to requests to participate in the project's workshops. Further to this, the use of the DIRECT tool by other organisations within the industry will help create a more accurate picture of the cost of meat loss and waste, and may be useful for future planning efforts, either for individual organisations, or the industry as a whole.

Given the findings of this study point to the need for collaboration, it is recommended that in-depth root cause analysis workshops be adopted as an industry approach to loss and/or waste analysis. The collaborative discovery of waste creation processes appears to facilitate the design and implementation of effective collaborative solutions across supply chain actors.

While the limitations of this project are recognised, the research methodology and findings do provide a foundation for the next phases of the Fight Food Waste Cooperative Research Centre (FFW CRC) research program examining other meat types and downstream supply chain stages.

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1. Background

1.1 Project details

This report describes the Fight Food Waste Cooperative Research Centre (FFW CRC) Project 1.1.4 Whole of meat supply chain waste mapping and interventions – Phase 1.

The project responds to the growing need for a considered effort to address food loss and waste. This aligns with the ambitions of the United Nations (UN) Sustainable Development Goals (SDG), specifically, UN SDG 12.3 to halve per capita global food waste at the retail and consumer levels by 2030, and to reduce food losses along production and supply chains.

Knowledge about food loss and waste in Australian meat supply chains has been patchy to date. Some data and insights can be drawn from Australia's National Food Waste Baseline (FIAL, 2021), from an industry study focused on the refrigerated transport and distribution (Brodribb and McCann, 2020), and from work on red meat supply in the UK (WRAP, 2020b). However, Australia does not currently have a comprehensive picture of the scale, causes and destinations of meat losses along the supply chain, particularly for production processes upstream of retail.

This lack of information makes it difficult to plan and prioritise the meat sector's food loss reduction efforts under Australia's Food Waste Reduction Strategy (Commonwealth of Australia, 2017). We know that the volumes of meat losses are lower than other food types, but that the financial value and greenhouse gas implications of the losses are potentially high. This is an incentive to identify potential loss reduction opportunities, which can accrue value for the sector economically and socially. This is the key research challenge addressed by this project.

There is also an increasing recognition of the 'economic and societal case' for food loss reduction that is broader than the traditional 'business case' of cost savings for individual supply chain businesses. By adopting this 'economic and social case' lens, a shift is needed in order to consider interventions that require the collaboration of multiple actors through the supply chain to not only tackle food loss and waste, but also deliver benefits to whole industry sectors and the wider public at large. This project provided the opportunity to also examine losses with a whole of supply chain perspective and pilot a transferable methodology for other industry sectors.

The project represents Phase 1 of a broader 3-phased research initiative (see Figure 3) aimed at filling gaps in information about meat loss and waste across the Australian meat supply chain, to inform the co-development of loss reduction solutions with industry and government partners.

This Phase 1 project focused on one meat product (beef), and the upstream production stages of the beef supply chain (meat processing and distribution up to the retail door). It is anticipated that subsequent research phases will expand into other meat types (lamb, pork, chicken) and the downstream consumption stages (see Figure 3).

The aim of this current project was to generate a clearer picture of beef meat losses and waste in the upstream processing and distribution stages, including i) sources of losses and waste, ii) causes and potential solutions, and iii) approximation of the relative amounts and cost of losses. The project was only able to partially addresses the last of these objectives due to limitations the project team encountered with data collection. Therefore, the emphasis of the report is on sources, causes and potential solutions for beef meat loss and waste.

The outputs from this project are:

1. A framework for mapping losses and waste in the beef meat supply chain, and approximations of amounts to help target future loss reduction planning efforts.
2. Identification of sources and causes of losses and waste in beef processing and distribution.
3. Estimation of the potential scale of financial cost of meat waste losses, for individual businesses and extrapolated for the meat processing and distribution section.
4. A catalogue of solutions for reducing beef losses and waste, co-developed with industry partners in collaborative and documented workshops.
5. Initiation of a collaborative forum for bringing together key actors in red meat processing and distribution, for ongoing co-development of food loss and waste mitigation strategies.

The desired outcomes from this will inform future food loss and waste reduction initiatives which seek to:

1. Reduce meat losses in targeted value chains by 15-25%.
2. Enable economic savings.
3. Reduce environmental impacts associated with meat loss.
4. Unlock cost-effective solutions that are possible if supply chain partners were working alone.
5. Increase capabilities in the industry in resource efficiency.
6. Provide industry with an evidence base for effective reduction/ valorisation measures.

<u>Researchers</u>

The project was led by Queensland University of Technology (QUT) Centre for Agriculture and the Bioeconomy, with contributions from Royal Melbourne Institute of Technology (RMIT) and Lifecycles. The researchers also acknowledge the services of Currie Communications who facilitated the industry engagement workshops.

<u>Research Partners</u>

Partners supporting the research, who are participants of the Fight Food Waste Cooperative Research Centre (FFW CRC), are Meat and Livestock Australia (MLA), Queensland Government Department of Environment and Science (QDES), Australian Country Choice (ACC), Australian Food Cold Chain Council (AFCCC) and Royal Melbourne Institute of Technology (RMIT) School of Design. Partners contributed to the project by participating in the project steering committee, sharing leads to existing data and documentation, and sharing industry contacts for consultation and workshop recruitment.

<u>Project Steering Committee</u>

The project was guided by a steering group comprised of representatives from the above project partners, meat processing and cold chain industry bodies, the food packaging industry, organisation involved in national food loss and waste strategies, and supply chain specialists. The membership of the committee is detailed in Appendix Section 8.2. Terms of reference for the committee are provided in Appendix Section 8.3. The authors acknowledge the valuable contributions of steering committee members to this research and wish to thank them for their involvement.

1.2 Project scope

1.2.1 Supply chain scope

The supply chain scope includes processes occurring in upstream stages of Australia's meat supply chain (see Figure 1):

- for **domestic markets**, from receipt of livestock at abattoirs up to the delivery of beef meat products to retail outlets or supermarket door; and
- for **export markets**, from receipt of livestock at abattoirs up to the point where processed beef meat products are shipped abroad (i.e., the port).

Meat processing for both the domestic and export markets were considered since both are accounted for in the National Food Waste Baseline irrespective of product destination (a territory-based approach). The study focused on processing that occurs in Australia (for both domestic and export bound products) and downstream supply chains that occur in Australia (domestic bound product only).

It assumed that most beef destined for export is transported directly from primary processor to export port with no further processing, and that losses are not detected until they are received by the overseas customer and are not returned to Australia. Therefore, supply chains from the port across national borders into global export markets were not considered. Beef products imported into Australia were not considered, as they were not part of the scope for this project.

The following terms were used to describe the supply chain stages included in the scope:

- **Primary meat processing**, referring to slaughter and boning occurring at abattoirs to produce primal cuts.
- **Secondary meat processing**, referring to the further processing of primal cuts into retail cuts (also called 'value-adding' in the industry).
- **Tertiary food processing**, referring to the production of prepared food products that contain beef as a dominant ingredient. Examples are small goods, prepared pasta products, meat pies and sausage rolls.
- **Refrigerated transport and distribution** of beef products from the processors to domestic marketplaces.

The primary, secondary, tertiary processing terminology is used to be consistent with three-stage model of agri-food processing used in the National Food Waste baseline method (FIAL, 2021).

Meat processing operations within the supply chain are not uniform, with processing and end-products varying widely across processing plants. Traditional abattoirs focus on primary meat processing to primal cuts, whereas integrated complexes conduct both primary and secondary meat processing all the way through to retail-ready cuts.

Rendering and pet food manufacture are ancillary operations closely associated with meat processing, and their products are important revenue streams for the sector. Less than half of meat processing plants have their own rendering operation, and the remainder will send rendering material to a specialist renderer.

Australian beef supply chains are networks of businesses and actors with differing roles and practices. Two types of supply chains structures were described by workshop participants, which have implications for meat losses:

- **Single-leg/integrated supply chain**: all material planning and movements and critical supply chain settings are under the control of a single (vertically) integrated organisation. They are more suited to command-and-control style management.
- **Multi-leg/consolidated supply chain**: material movements involving more than one controlling organisation including proprietors, custodians, and agents whose collaboration is governed by a set of rules and practices that implicitly and explicitly determine the commercial and physical movement of goods from source to destination. These supply chains require more collaborative approaches to ensure efficient material flows.

Linear flow diagrams depicting supply chain flows, such as that in Figure 1, suggest clearly separated channels in a linear sequential order. However, in reality, meat supply chains are complex combinations of pathways and non-linear movements leading from source via intermediate stages to their final destination, such as shown Figure 2, based on work by Escavox (2020). This shows how multiple processors and multiple distribution centres may be connected in Australian meat supply chains, relying on a set of heterogenous actors, modes of transport, packaging formats, and practices of documentation and information exchange. To illustrate this point, Escavox (2020) estimate that the journey of chilled red meat in the domestic supply chain in Australia from abattoir to a retail store is generally between nine and 90 days and there can be two to five changes of ownership and actors. This point not only illustrates the complexity of the supply chain, but it also suggests the need for collaboration amongst actors to manage losses.

Figure 1. Linear representation of beef supply chains, showing the scope of this project

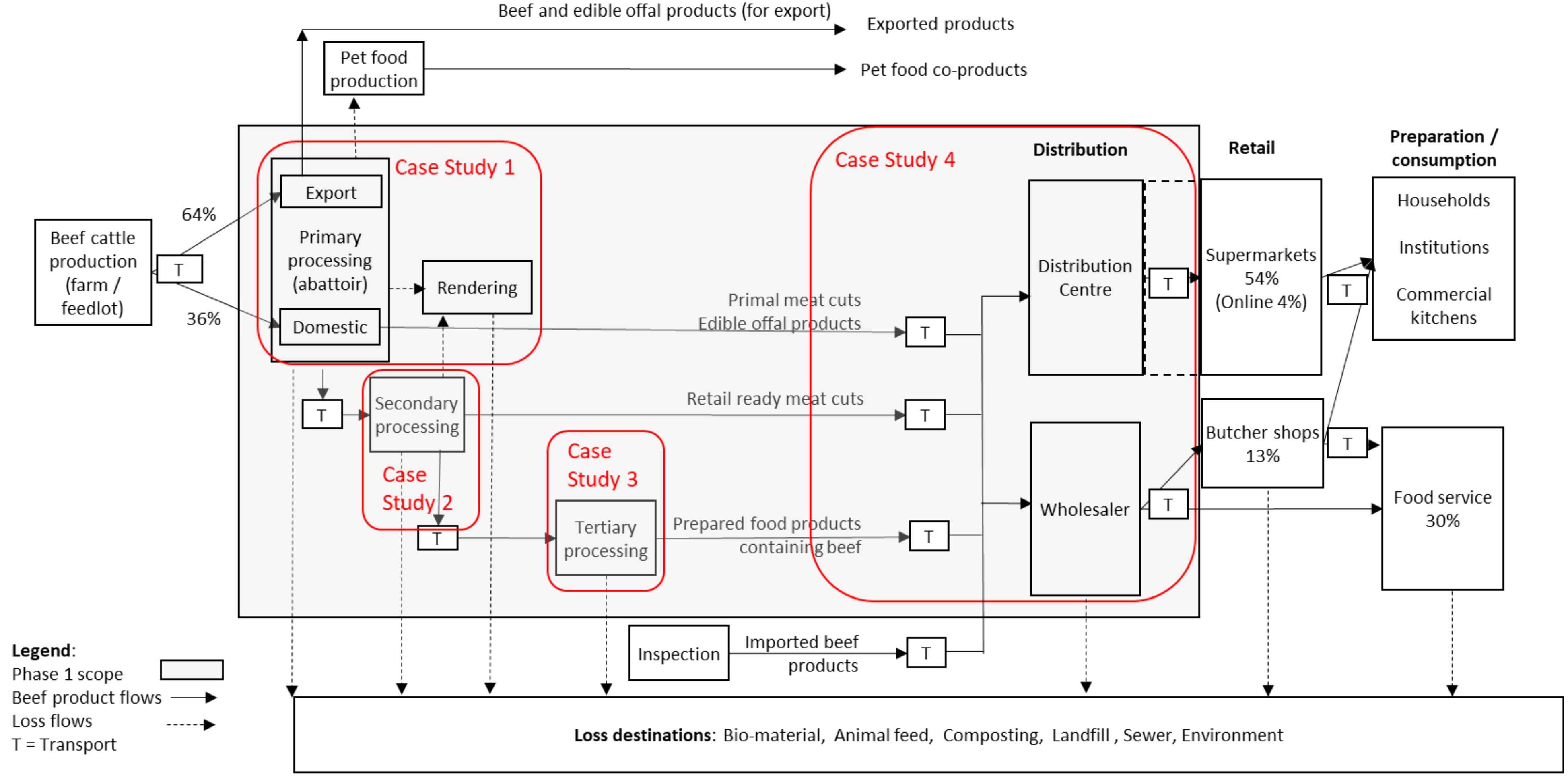
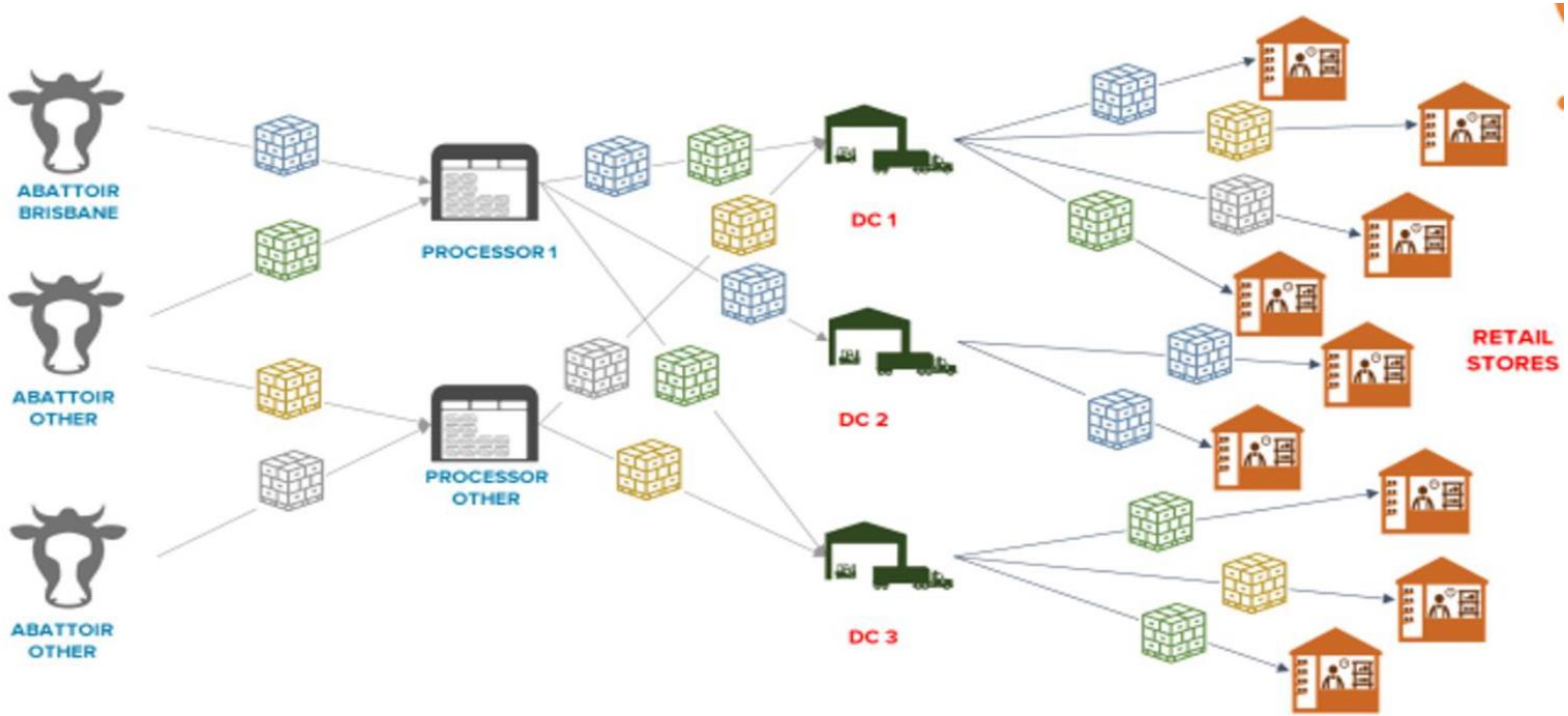


Figure 2. Network representation of beef supply chains (Escavox, 2020)

DC= Distribution Centre



1.2.2 Assessment scope

The project was guided by the "whole of supply chain waste mapping and resource efficiency" methodology of the UK's Waste Resource Action Program (WRAP, 2020a), the steps of which are summarised in Table 1. Steps 5-8 of this process fall outside the scope of this study but should be considered in subsequent phases of the research. These in-scope tasks are described in Section 3.

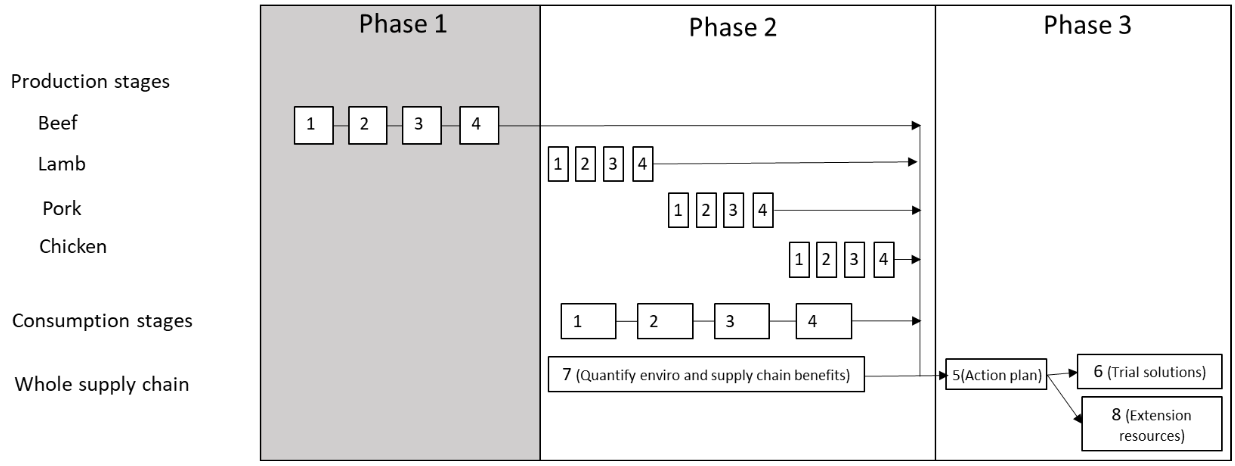
Table 1. Steps in 'Whole of supply chain waste mapping and resource efficiency process'

Steps performed in this project	1. Defining the project plan (establishing team, define supply chains, identify case study sites, clarify meat loss accounting method, literature review); 2. High-level accounting of beef meat loss along the supply chain; 3. Identifying, collecting and verifying data from case study sites / operations regarding the composition of beef meat losses and the costs to the generator; and 4. Conducting industry workshops to identify root causes of beef losses and identifying solutions.
Steps to be perform in subsequent phases	5. Formulating an action plan; 6. Trialling and evaluating solutions; 7. Quantifying environmental and supply chain benefits; and 8. Developing resources to support implementation, staff training.

A longer term objective is to conduct this process for different meat types (beef, lamb, pork, chicken) across the whole supply chain (farm to plate), but it was considered impractical to include all those components in the one project. Therefore, this overall research aspiration was broken into three separate phases (Figure 3).

Phase 1 of the study, reported here, focuses on upstream production stages of the beef supply chain only (meat processing, and refrigerated transport and distribution to the retail door) and performs steps 1-4 of the WRAP process (Table 1). Step 5-7 will be conducted as part of the Sector Action Planning process of Stop Food Waste Australia and in future phases of the research initiative.

Figure 3. Scope of Phase 1 within the overall research initiative



1.3 Literature review

1.3.1 Defining the scope of food loss and waste in the context of meat

The Food Loss and Waste (FLW) Standard, developed by the World Resources Institute (WRI, 2016) defines 'food loss and waste' (FLW) as materials that have been diverted from the food supply chain. It can originate from all phases of supply chains, with the exception of on-farm pre-harvest losses, which are not considered within the adopted methodology (see Figure 4). Inedible materials as well as edible materials are considered in the FLW Standard to recognise cultural differences in what may be regarded as edible in different parts of the world.

Based on the FLW Standard, food waste is characterised according to the end destinations rather than the type of material (Figure 5). In the Australian National Food Waste Baseline, lost materials sent for redistribution to people, animal feed or to biomaterial processing to convert them into other products are excluded as waste destinations and not considered food waste (see Figure 4).

For the 'biomaterial processing' destination, there have been various interpretations over the years, as shown in Figure 5. This has relevance for primary meat processing as the many components of slaughtered livestock fall into this category. Figure 5 shows that bioprocessing was included as a waste destinations for Australia's first National Food Waste Baseline (Arcadis, 2019), was excluded for Australia's most recent updated National Food Waste Baseline (FIAL, 2021), and in the WRAP reporting guidelines for meat processing (WRAP, 2018) there is differentiation between different types of biomaterial processing.

This project took guidance from the WRAP reporting guidelines for meat processing (WRAP, 2018) and also the following definition from a UK meat industry study (WRAP, 2020b):

> *"Any meat product, or animal-derived material sent to a waste destination, including anaerobic digestion, incineration /controlled combustion, rendering with minimal valorisation, land application, sewer/wastewater treatment. For the purpose of this ambition, we are focused on material that, if managed differently, could have remained in the food chain. Of lower priority is material classified as 'inedible parts' of food, including feathers, hides, hair, bones, skin, that typically would not be eaten. In most cases this material cannot be avoided, and so cannot typically be a target for waste reduction.*

Although it is important to quantify these 'inedible parts', take steps to get maximum value from them, and minimise the impact of their use / disposal on the environment."

The WRAP (2018) guidelines include losses directed to pet food under the banner of 'animal feed' as a non-waste destination. This approach was adopted by the National Food Waste Baseline (Arcadis, 2019) and by this project.

On-farm livestock losses were excluded due to the 'food system boundary' being determined to start at harvest and slaughter (Arcadis, 2019, p.44). The reporting guidelines for meat processing note that approval by the inspector could be taken as the point at which 'ownership' is transferred from farm to processor, so animals that are dead on arrival (DOA) are not considered (WRAP, 2018).

For meat supply chain stages downstream of the abattoir (secondary and tertiary processing, distribution, retail, home consumption) the determination of food waste is more straight-forward. It includes meat losses that are diverted to the following waste destinations: landfill, sewer, composting, land application and anaerobic digestion for methane production. It does not include materials diverted to food rescue and animal feed.

In summary, this project defined food loss and waste in the context of meat as follows, and aimed to identify both meat losses and meat waste:

- **Meat losses**. Animal parts not destined for human consumption are not considered food losses (hides, hoofs, bones, inedible and condemned offal). They are directed to rendering for processing into non-food products (meat and bone meal, tallow, pet food), which are important revenue streams for the industry. Some fractions of edible meat and edible offal, which would otherwise be destined for human food, and which are hard to harvest, may be directed to these non-food destinations as a cost-effective means of value recovery. These have been categorised as **food losses**, but not food waste.
- **Food waste** are losses of edible meat and edible offal that go to landfill, wastewater, composting, digestion, combustion.

1.3.2 Quantities of meat losses and waste

Past studies suggest that while the amounts of meat losses are lower than other food types, the financial value is high. Australia's first National Food Waste Baseline (Arcadis, 2019) accounted for meat losses (all meats) only from abattoirs (123,000 t/yr in 2016/17), and as it included materials going to 'biomaterial processing' destination (as discussed above), it is considered to be an over-estimate. The recent update of the baseline (FIAL, 2021) provided a more comprehensive account of losses including distribution and retail, but did not include any losses from abattoirs, due to it not having the resources to explore the complexities of this supply chain stage. Another study (Brodribb and McCann, 2020) also provided estimates of meat losses attributed to deficiencies in the refrigerated transport and distribution of 155,000 t/yr for all meats and 76,000 t/yr for beef meat.

While there can be seen to be growing data sets of meat loss characterisation and quantification, there is a lack of consistent and comprehensive mapping of meat losses, with significant data gaps and no integration of data along supply chains. Furthermore, there is little understanding of the reasons for loss generation, making it difficult to currently identify and prioritise loss reduction solutions.

Figure 4. Summary of meat loss components considered food waste

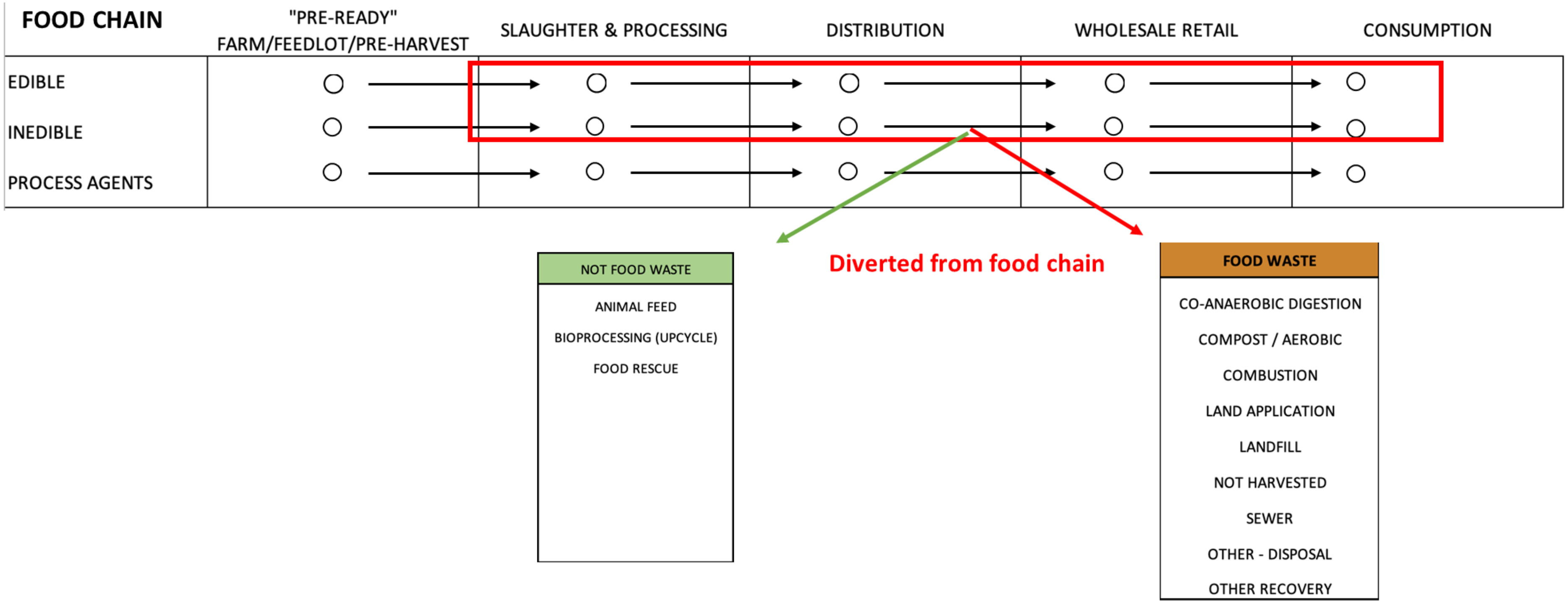
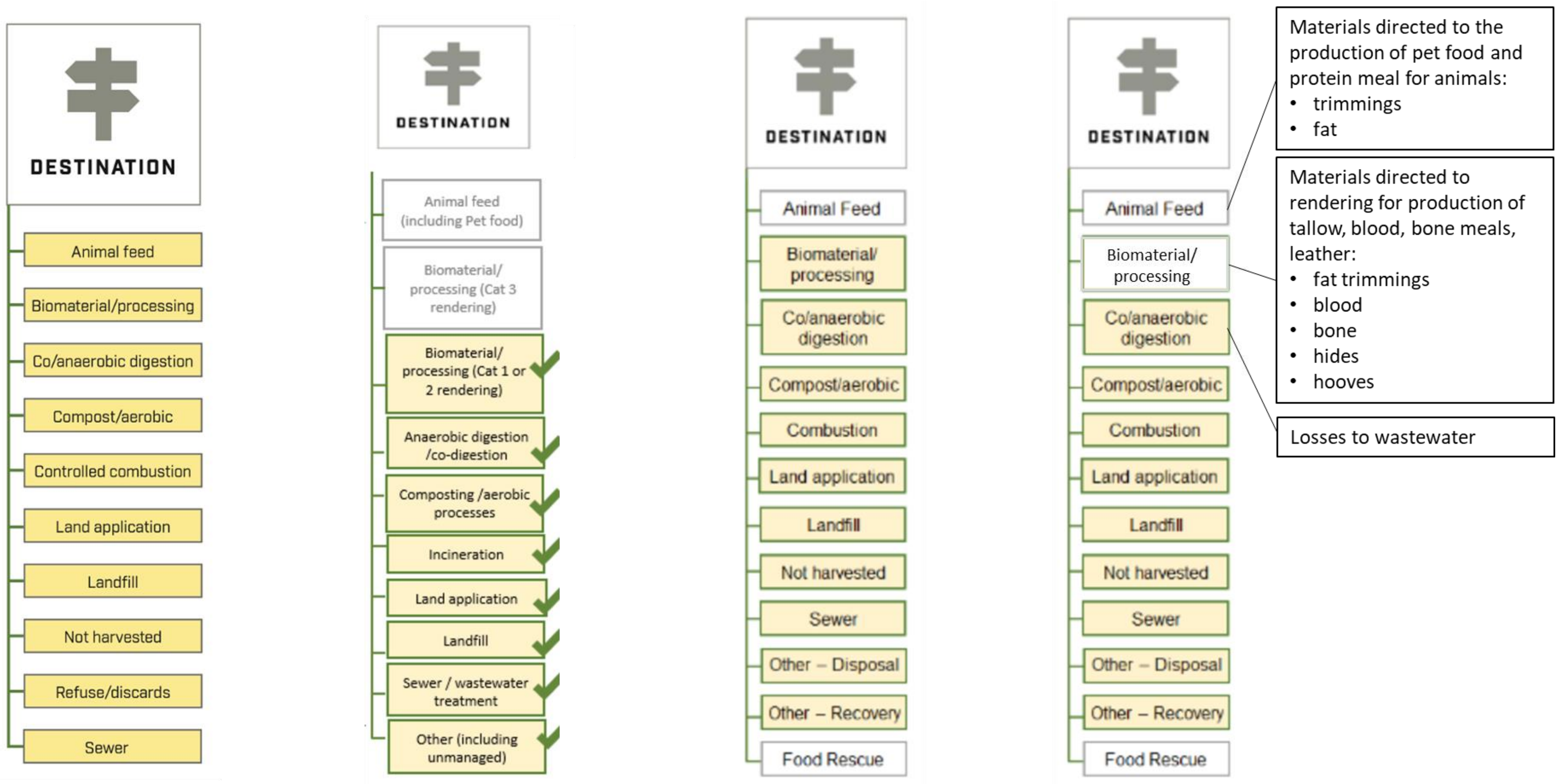


Figure 5. Waste destinations for various interpretations of the Food Loss and Waste (FLW) standard

(extracts from source documents showing in yellow shading destinations considered to be food waste destinations)



Food Loss and Waste (FLW) Standard WRI (2016)

WRAP Guideline for meat processing WRAP (2018)

National Food Waste Baseline 2016-17 (Arcadis 2019)

National Food Waste Baseline 2018-19 (FIAL 2021)

1.3.3 Collaborative solutions for co-created meat losses

Research and practice of FLW prevention in industrial supply chains have been predominantly focused on concepts of eco-efficiency that view losses and waste as an inefficiency or aberration of production and resource use. As such, eco-efficiency targets measures to reduce material and financial losses while at the same time enhancing the environmental sustainability of production and consumption. Accordingly, efficiency improvements deliver a promise of operational and financial benefits as an important incentive for industry to commit investments to projects targeting a reduction of FLW. This prevailing view of achieving environmental and economic win-wins through food waste reduction and prevention have been termed the “business case” of FLW reduction (Hanson and Mitchell, 2017).

More recently, food loss and waste research has increasingly considered systemic characteristics of supply chains, including conflicting interests, overlaps and redundancies, competition related practices and behaviour and commercial contradictions and trade-offs as potential causes for intended and unintended creation of FLW at the production stage. The systemic view proposes that FLW does not only originate from single firms or distinct supply chain stages but reflects broader settings of supply chains that result in a form of “co-creation” of food waste. As such, systemic losses created through joint participation and interaction of various supply chain actors in complex and dynamic supply chains are accepted as part (and a cost) of running efficient businesses at industrial scale (Canali et al., 2013).

This brief review introduces some background of the concept of “collaborative loss creation”, which FLW research has been increasingly adopting in recent years as a relevant and fruitful perspective for research, policy development and practice. FLW as a research area has only started to receive wider attention during the last two decades, including increased presence in public media, which created growing awareness of up to 30-50% of global food production being discarded as waste. In response, key academic and institutional publications and initiatives emerged, targeting the scope and scale of the problem, developing definitions, and identifying interventions and solutions. Early efforts to compile and categorise causes for food waste were focused on consumer and household waste as a highly visible and tangible form of food waste (WRAP, 2011). Inventories of food waste causes soon progressed beyond individual wasteful behaviour towards a more comprehensive view of FLW that includes proximate causes related to resourcing, production, distribution and marketing throughout whole supply chains (Göbel et al., 2015).

A milestone report by World Resource Institute (Lipinski et al., 2013) highlighted the importance of a ‘collaborative integrated supply chain approach’ that also considers indirect causes of FLW creation. This call for collaborative approaches was echoed in a recent publication by the United Nations Food and Agriculture Organisation (FAO, 2019, p.14) proposing an analytical framework of ‘direct and indirect drivers of food loss and waste’. Indirect drivers include market prices, public services, infrastructure, informational or other social services, legal frameworks, and cultural factors. The concept of indirect and systemic causes recognises that practices by producers, suppliers and consumers are often influenced by the behaviour of other actors in the food supply chain, whose actions may result in food loss. For example, food may be lost at one stage in the food supply chain because of actions at another stage, such as mishandling during processing or transportation or overordering and rejection at retail. This emerging concept of systemic and indirect causes of FLW was proposed to identify effective entry points for interventions and policies addressing root causes that are not obvious, proximate, or entirely under the control of individual supply chain actors.

Subsequently, the EU FUSION framework (Canali et al., 2013) presented an elaborate framework of direct and indirect food loss drivers based on the categories of technology, business & market, legislation & policies, and social behaviours & lifestyles. Similarly, the United Nations Higher Level Panel of Experts (HLPE, 2014) proposed a framework of three levels of causes for food loss. These are a) causes within individual enterprises, b) causes attributed to the food chain as a whole and, c) causes related to broader food systems and beyond. This framework offers intuitive and suitable concepts for analysing modern industrial supply chains and has largely been adopted within the methodology of this report, particularly in the consideration of causes of, and solutions to reduce, waste.

Many key reports and frameworks have cited the lack of coordination among different actors as a key reason for the occurrence of FLW in supply chains. This issue is especially relevant for the context of highly developed economies, including the US, EU and Australia, and as a fundamentally systemic problem the issue of lacking cooperation and coordination requires 'whole food chain approaches' (HLPE, 2014, p.64) to account for all directly and indirectly generated FLW.

In line with the evolving understanding of FLW as a systems issue, a UN Food and Agriculture review (FAO, 2019, p.48) of the state of global food waste prevention in agrifood systems recently recognised the limitations of the 'business case' of FLW, which views food loss reduction predominantly from a perspective of a firm's eco-efficiency and targets FLW interventions for the commercial benefit of individual actors. Rather, the FAO proposed a broader 'economic case' of FLW that encompasses a more comprehensive scope of interventions that may offer the opportunity to tackle FLW problems at a scale beyond the limited capabilities of individual firms and deliver benefits to whole industry sectors and the wider public at large.

FLW research and practice are increasingly promoting whole of industry approaches and collaborative solutions to FLW creation, with the Australian Food Pact and its 'industry sector plan approach' (SFWA, 2023) providing an important template. Following this shift in perception, research studies are called upon to present in-depth practical evidence of systemic loss creation, to capture root causes of whole supply chain FLW, to develop a tangible and practical methodology of analysis, and an appropriate scope of collaborative actionable solutions.

2. Objectives

The aim of this research was to generate a clearer picture of beef meat losses and waste in the upstream processing and distribution stages, including (1) sources of losses, (2) causes and potential solutions, and (3) approximation of the amounts and costs of losses.

In order to address these aims, the questions guiding this research were:

1. What are the main sources and causes of beef losses and waste in the upstream processing and distribution stages of Australian beef supply chains?
2. What are the causes and potential solutions for reducing beef losses at individual supply chain stages but also across supply chain actors?
3. What are the approximate amounts of losses and waste in the assessed supply chain stages?
4. What are the economic costs of these losses and wastes?

Question 1 was answered through observations of production practices during site visits to case study operations, drawing on the expertise of the supply chain specialists serving the industry, and feedback received at supply chain workshops.

Question 2 was answered by conducting workshops attended by supply chain actors, at which solutions for reducing meat losses were co-developed.

Question 3 was answered by collating any available information about rates of meat losses for key sources (loss factors) from literature, the case study assessments and consultation at the workshops, and compiling these into a material flow analysis for the sector (waste mapping).

Question 4 was answered by using the Dynamic Industry Resource Efficiency Calculator Tool (DIRECT) calculate the approximate cost of beef losses, using the compiled loss factors and the published business costs.

3. Methodology

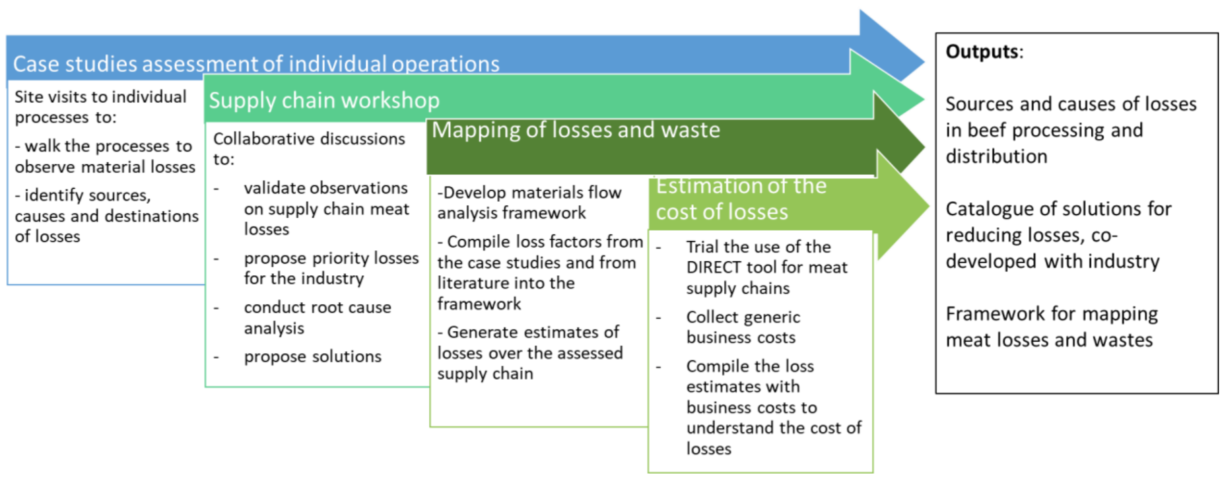
3.1 Method overview

The project aimed to follow the "whole of supply chain waste mapping and resource efficiency" (WRAP, 2020a), which considers losses for the individual stages of the supply chain. However, a more holistic view of beef supply chains was taken to consider not just losses managed in each individual stage, but also those co-created across multiple supply chain actors and requiring collaborative solutions. The project has the following four elements (Figure 6):

1. Case studies of each supply chain stage
2. Supply chain workshops
3. Mapping of losses and waste
4. Estimation of the cost of beef losses, using the DIRECT tool

Since the project involved participation by people in case study site visits and workshops, it was necessary to apply for ethical approval via the lead research organisation, QUT. The application was reviewed as low-risk and approved by the delegated review body of QUT's University Human Research Ethics Committee (UHREC) as meeting the requirements of the National Statement on Ethical Conduct in Human Research (2007, updated 2018). See Appendix 8.4 for a copy of the approval confirmation.

Figure 6. Overview of the project method and outputs



3.2 Case study assessment of each supply chain stage

The case studies enabled detailed examination of each of the key supply chain stages. The objectives of the case study assessments were to:

- Collect information about sources and causes of losses based on observations at site walk-throughs and discussions with case study participants.
- Create a picture of key loss issues to inform subsequent workshops discussions.

The initial intention was to recruit four businesses that would, collectively, represent a typical beef product supply chain in Australia: 1 for primary processing (abattoir), 1 for secondary processing, 1 for tertiary processing, and 1 for transport and distribution of beef products. Recruitment involved consideration of the following criteria:

- a focus on beef only products – this was preferable but not essential (operations handling mixed products was deemed acceptable)
- potential to generate learnings that can be transferrable to many operators, i.e.:
    - represent operations present in both urban- or regional-based settings,
    - represent operations present in most states,
    - represent a context that is relevant to different scales of production (small as well as large),
    - represent a resource efficiency performance typical for the industry,
- be prepared to allocate staff time and data within the case study timeframe.

To assist with recruitment, contact with potential case study organisations was initially done via the industry organisations on the project's steering committee, i.e., Meat and Livestock Australia (MLA) and the Australian Meat Processor Council (AMPC). MLA and AMPC were provided with the Contact Letters and the Participant Information and Consent Form to send out to their members. Interested businesses were advised to contact the researchers directly, so that participating businesses could remain de-identified if required. Once the researchers received expressions of interest, they contacted the interested businesses.

Despite support from the industry associations and multiple attempts to recruit case study organisations, it proved difficult to find businesses interested in participating. The timing of the recruitment efforts was at the end of the COVID pandemic restrictions when meat businesses were struggling to rebuild staff and staff skills. As a result, it was difficult for them to participate when they needed to prioritise production during a difficult period. Consequently, the research team had to loosen the selection criteria and engage with any business that was willing to participate.

In the end, two companies agreed to participate in the research. Company 1 represented both primary processing (to primal cuts) and secondary processing (to retail cuts), and Company 2 represented tertiary processing. Identifying operations that represented refrigerated transport and distribution was difficult, as this is mostly a transport activity that is difficult to observe in practice. Instead, the research team drew on the valuable experience of two specialist businesses (companies 3 and 4) servicing meat product distribution. The resultant case studies were:

Case study #1 Primary processing operations (observed at Company 1)

Case study #2 Secondary processing operations (observed at Company 1)

Case study #3 Tertiary processing operations (observed at Company 2)

Case study #4 Refrigerated transport and distribution (drawing on expertise of Companies 3 and 4)

For the primary and secondary processing study (Case studies 1 and 2), a generic process flow diagram (Pagan et al., 2002) and generic mass balance of material flows (Wiedemann and Yan, 2014) was first used build a framework for mapping flows of beef meat through the process (Figure 7). Multiple site visits and process walk-throughs of the co-located Case study 1 and 2 processes were then conducted by the researchers, accompanied by company personnel, to observe and collect information about the points of loss in this process, their causes and destinations. The generic mass balance of materials flows in meat processes (Wiedemann and Yan, 2014) was the main source for estimating quantities of losses, but this was verified against the company's own mass balance (confidential) and information about destinations for losses.

For the tertiary processing study, a site visit and walk-through of the Case study 3 process was conducted by the researchers, accompanied by company personnel. Information and data about the types and quantities of ingredient inputs was collected, along with data about material and product losses (confidential) collected as part of their quality management system.

For the transport and distribution study (Case study 4) physical observation of transport/distribution processes was prohibitive. Therefore researchers consulted with industry specialists in meat product distribution, especially packaging and temperature maintenance.

The small sample of case studies was a limitation for this project, particularly in relation to understanding quantities of loss and the associated costs. However, the purpose of the case studies was largely exploratory in that the aim was to build a picture of how and where losses and wastes are generated. The information was subsequently used to inform the supply chain workshops (Section 3.3), whereby the focus was on the root causes of losses and waste generation and potential solutions.

3.3 Supply chain workshops

Two workshops were designed to bring together experts and practitioners employed, engaged, knowledgeable, and experienced in Australian meat supply chains. The objectives were to:

- identify root causes of loss and develop solutions, and
- build transparency and collaboration across supply chain actors to facilitate whole of supply chain solutions.

The intent was for workshop participants represent actors from each of the supply chain stages (i.e., primary meat processing, secondary meat processing, tertiary processing, refrigerated transport and distribution), but also actors that contribute to or influence the supply chain, including retail, regulators, and expert consultants.

The recruitment process for the workshops relied on:

- initial recommendation by the project's steering committee and by the funding organisations (MLA, AMPC),
- existing contacts of QUT, RMIT or the Fight Food Waste CRC from the Australian meat industry; and,
- recommendations by experts already recruited as participants.

All potential participants were contacted directly by the research team and asked to be involved in the workshops. The recruitment process was successful in engaging the following organisational representation at the workshops: primary meat processing companies (2), secondary processing companies (2), tertiary processing (2), meat processing industry peak bodies (3), supply chain data management specialists (1), cold chain temperature management specialists (1), packaging suppliers (1), government policy agencies (1). In total, 28 people participated in the workshops, 18 representing supply chain actors and 10 representing the project team and the FFW CRC.

The recruitment process was not successful in recruiting participation by transport carriers (i.e., transport companies). Invitations extended to three companies were not accepted. This was a key limitation of the supply chain representation and meant that voices of the key actors involved in refrigerated transport and distribution of meat products were not heard.

Workshop 1 was held on December 1, 2022, attended by 16 industry participants, and focused on "whole of supply chain" FLW generation, particularly that related to co-created packaging and temperature maintenance failures requiring collaborative solutions. Workshop 2 was held on December 15, 2022, attended by 17 industry participants, and focused on FLW generation for the meat processing stages (primary, secondary, and tertiary). Both workshops were held online (Zoom) over 3 hours each.

All participants gave informed consent for information and data discussed during the workshop to be aggregated and de-identified. Participants also acknowledged a competition statement read out to establish a "pre-competitive" platform of discussion and ensure participants are aware of potential conflicts of interest. The workshop was facilitated by Currie Communications as a project advisor and service provider.

At the workshops, participants were briefed on the compiled information about beef loss and waste and then participated in discussions aimed at verifying the main aspects of beef losses, nominating priority aspects, and discussing the causes of losses and potential solutions. The output from the workshops were collective suggestions for meat loss reduction opportunities.

The introduction and dissemination of current knowledge on meat supply chain losses from existing publications and the industry engagement process gave workshop participants the opportunity to consider and validate proposed findings. The workshop attendees discussed five hotspots of loss creation in meat supply chains, which were put to a vote to identify the three most important causes. Each of the three root causes became the topic for a break-out session with purposefully selected and allocated participants.

Each break-out session was individually guided by a moderator and recorded by a scribe. Key points compiled at the end presented and discussed to a plenary forum. The plenary sessions were recorded by Zoom to capture the authentic and original voice of research participants.

3.4 Waste mapping

Waste mapping involved developing an account of beef meat flows to approximate the scale of potential losses and waste over the in-scope supply chain.

The first step was to review if any existing frameworks could be applied to do this at the whole of supply chain scale. The following identified frameworks were reviewed, which all use a material flow analysis (MFA) approach:

- **Australian Food Waste Baseline database** (Arcadis, 2019, FIAL, 2021). This database provides the baseline for Australia's National Food Waste Strategy (Commonwealth of Australia, 2017), and is the most relevant and up-to-date data on food waste across all stages of the value chain, including meat, and disaggregated by meat type, supply chain stages and destination. The online dashboard enables access to some of the data related to meat. The database behind the baseline data is a spreadsheet that performs an MFA for all food categories at a national scale. It uses publicly available data for the starting agricultural commodity and known or estimated loss fractions at each stage to derive amounts of losses directed to FLW destinations. However, as the database aims to cover all food commodities and at a large scale, it does not allow the disaggregation and higher resolution required for this industry specific study.
- **Queensland Government Material Flow Analysis for Organics** (Organics MFA) database (Ricardo, 2020), developed for Department of Environment and Science (QDES). This is a useful framework because it has been developed for consistent accounting of all organic material flows through the economy (including raw material and product flows as well as waste flows), not just food waste, to support government policy. It was not considered as a computation tool for the project, due to it being too high-level for the purpose of this project. However, in future there would be value in aligning the meat loss and waste data compiled in this project with the material flow taxonomies, assumptions and regional disaggregation processes used in the Queensland Department of Environment and Science Organics MFA to facilitate data comparison and exchange.
- the **Dynamic Industry Resource Efficiency Calculator Tool (DIRECT)** was also considered as a potential framework. DIRECT can be used to characterise, and cost quantify food loss and waste over a whole supply chain as well as for individual, linear supply chains, depending on how the model is set up. However, for this project there was not enough information to populate all the data required for a whole of supply chain analysis. However, it was used to estimate the costs beef losses for the processing stages once a more comprehensive MFA was conducted (see Section 3.5).
- **Food Surplus and Waste Data Capture Sheets** developed by WRAP for recording and reporting data describing food loss and waste. These data capture sheets provide a similar function to the DIRECT tool by providing a consistent format for characterising and quantifying food loss and waste in line with the FLW Standard. They are useful for individual businesses for recording and tracking food losses, but not suited to a sector scale account.

As the existing frameworks were not entirely fit for purpose, a simple MFA framework was developed for this project. Like the latest Food Waste Baseline database (FIAL, 2021), it traces the flows of the material components from total beef cattle numbers slaughtered in Australia, and accounts for losses at each stage to achieve a mass balance over the supply chain. The data the was populated in the MFA framework is shown in Figures 8 and 9.

Quantities of losses at each stage in the supply chain were estimated based on the loss factors identified from literature and the case studies. These loss factors and their sources are described in Sections 4.1, 4.2, 4.3, 4.4.

3.5 Calculating the cost of beef losses using the DIRECT tool

The Dynamic Industry Resource Efficiency Calculator Tool (DIRECT) was used to generate an approximate picture of the costs of meat losses, to inform the consideration of potential savings in future planning of loss reduction initiatives.

DIRECT operationalises the Food Loss and Waste (FLW) Accounting and Reporting Standard developed by the FLW Protocol (WRI, 2016) and has been peer-reviewed by the World Resources Institute (WRI) and Australian National University (ANU). It also estimates the monetary cost of the material flows of FLW, in line with aspects of the International Standard ISO 14051, which is a general framework for material flow cost accounting (MFCA). It was initially developed by an RMIT-led consortium (Verghese et al., 2018), and then commercialised with co-investment from the Fight Food Waste Cooperative Research Centre (fightfoodwastecrc.com.au/project/direct/) and industry partner Empauer. It is now available as a cloud-based software product (https://empauer.com/solutions/direct/). Researchers from RMIT were engaged to assist with the use of DIRECT.

DIRECT assessments were performed for the primary, secondary, and tertiary processing stages, for which data could be collected. For the refrigerated transport and distribution stage, information was not available to perform a DIRECT analysis, hence the research drew on the prior work of Brodribb and McCann (2020).

The data entered into DIRECT was based on loss factors compiled as part of the case studies (see Section 3.2), and business operating costs for meat processing derived from a published industry study of processing costs commissioned by AMPC (2019). Inputs and assumptions for the DIRECT analysis are summarised in Appendix 8.5.

In line with ISO 14051, DIRECT apportions costs to material losses as a proportion of the mass of material inputs that flow into material losses and non-product outputs, which is used to calculate the indirect business costs related to material losses. These indirect 'hidden' costs of losses are absorbed expenditure on infrastructure, labour, transportation, energy, and other business costs.

DIRECT also uses non-product material destination income to offset the costs of material losses, relative to product income. This means that it accounts for the lost margin of not turning material inputs into products, which could be considered a lost-margin offsets (Empauer, 2022).

Therefore, DIRECT accounts for indirect costs and lost-margin offsets to generate the 'true cost' of loss and waste, which has been adopted by WRAP (Waste & Resources Action Programme) in the UK (WRAP, 2013). The term 'true cost' is not the 'full cost' accounting notion which includes a wider range of hidden costs and externalities – such as upfront, back-end, environmental and social costs.

4. Results

The results reported in this section summarise the key findings of the project. It firstly outlines for each stage of the supply chain, the sources, quantities, destinations, causes, and potential solutions for losses and waste. Following on from this, a categorised catalogue of potential solutions is provided to take forward into future loss reduction strategies. Lastly, the waste mapping and DIRECT analysis outcomes are presented to show the approximate scale and cost of meat losses for the sector as a whole, to help inform prioritisation of future loss reduction strategies.

4.1 Primary processing meat losses

Activities occurring at primary processing include receipt of beef cattle, slaughter, boning, and trimming to product primal cuts. Many plants have a co-located rendering plant, which receives materials not destined for food for processing into co-products (meat and bone meals, tallow, etc.).

Sources, loss factors, and destinations

Meat processes can recover value for all components of the cattle carcass via associated rendering processes. The meat industry recognises livestock as a source of multiple non-food products, in additional to meat products. Parts of the animal that do not have markets as food (hides, bones, blood, fat, hooves, inedible offal, etc.) are processed into non-food products (protein meals for animal feed, blood and bone meals for fertilisers, tallow for fuels, leather, pet food etc.) (see Figure 7). Directing these non-food materials to pet food manufacture or rendering for converting them into non-food products is not considered to be a food loss (see Section 1.3.1 for further details).

Some meat from the carcass suitable for human consumption does find its way to rendering (for value recovery as meat and bone meal and tallow) or to pet food, which does represent a food loss:

- Meat left on the bone,
- Meat left on trimmed fat,
- Meat dropped during boning, and
- Edible offal with no market access for human food.

Losses of beef meat occur during boning where meat is cut away from bone, and during trimming where fat is trimmed from meat portions. Small amount of meat can remain on the bones or be attached to fat that is trimmed off. These typically go to rendering.

These losses are carefully monitored through quality assurance (QA) systems due to the high value of the meat. However, the amount is difficult to measure and, as a result, is not regularly quantified. The 'boning yield' metric (weight of primal cuts/weight of carcass as a %) may be used by abattoirs as a general gauge of how much meat product is recovered from a dressed carcass. Inversely, it can be a gauge of how much material is not recovered as product, including the bone and fat that is purposefully removed, but also meat that is left on the bone or lost as small scraps. Good boning yields for beef cattle (i.e., low losses) vary depending on the breed, age, and size of animal. Lower than optimal boning yields is an indication that meat is being lost from the product stream.

As these small amounts of meat and edible offal become part of larger material loads flowing to rendering, it is difficult to disaggregate them and estimate quantities. Consequently, the most recent National Food Waste Baseline (FIAL, 2021a) reported food losses and waste from meat processing as zero for this reason. A UK study also estimated losses from abattoirs to be very small (WRAP, 2020b); about 2% of the edible component of the carcass.

A study by Partners in Performance (2019) undertook trials to measure the amount of beef left on bone, beef left on trim and beef straps dropped to the floor. From their data the amount of meat left on bone and fat was derived to be 1.4% of the beef meat on the carcass. Their trials also found that with further careful trimming 0.9% is recoverable. Therefore, only the recoverable amount of 0.9% was taken to be the loss factor and used in the waste mapping (Section 4.6).

Small quantities of meat dropped to the floor and washed to wastewater during cleaning are captured in primary screening and sent with other rendering material to be processed into non-food products. The contaminants in wastewater are soluble materials, and not considered losses.

The amount of edible offal directed away from human consumption depends on access to markets for offal. For those primary processors with established supply chains for edible offal, particularly into Asia and the Middle East, most edible offal can be directed to human food. However, many processors do not have this access, and in those cases, edible offal is directed to rendering or pet food manufacture; this would be considered a loss but not a food waste. Data was not available for the amounts of edible offal directed to various destinations, hence it was not included in the waste mapping (Figure 9). However, losses and destinations for edible offal were included in the economic cost of beef losses for a hypothetical individual operation (Section 4.7).

Causes and solutions - Primary Meat Processing Losses

From the cases studies and subsequent workshops with industry, the following underlying causes of losses generated at primary processing plants were identified. Each is discussed in the relevant sub-section with related suggested solutions following:

1. Speed of the process (chain speed).
2. Human skill and fatigue.
3. Edible offal with no market.
4. Lack of skilled staff for offal harvesting.

Speed of the process

Each business has a chain speed that they operate at to ensure economic viability. There is no average industry speed, and, in principle, each plant's business case must be considered separately (i.e., dependent on species, throughput per day, markets supplied). Cases were described for integrated primary and secondary meat processing plants where the chain speed of primary processing is higher than the secondary processing which causes potential backlogs of product. This can be due to the higher wages cost for boning, which necessitates a higher chain speed to reduce throughput time for each batch processed.

Human skill and fatigue

Boning, trimming, and cutting are highly skilled and physically demanding tasks and managing of operator skills and fatigue are very important. It can influence the efficiency of meat recovery and conversely losses of meat that are left on bone etc.

Edible offal with no human food market

There is limited interest from Australian consumers for edible offal, however, Middle East and Asian markets have more demand for edible offal as human food. Processors with access to export markets can direct edible offal to human food. However, for processors without access to export markets, edible offal is directed to rendering (along with meat trim) for conversion into meat meal for animal feed or directed to pet food manufacturers.

Lack of skilled staff for offal harvesting

Another reason for processors not harvesting edible offal for food product can be lack of required staff. This was observed at the time of the research when processors were struggling to have enough skilled staff after the COVID pandemic restrictions.

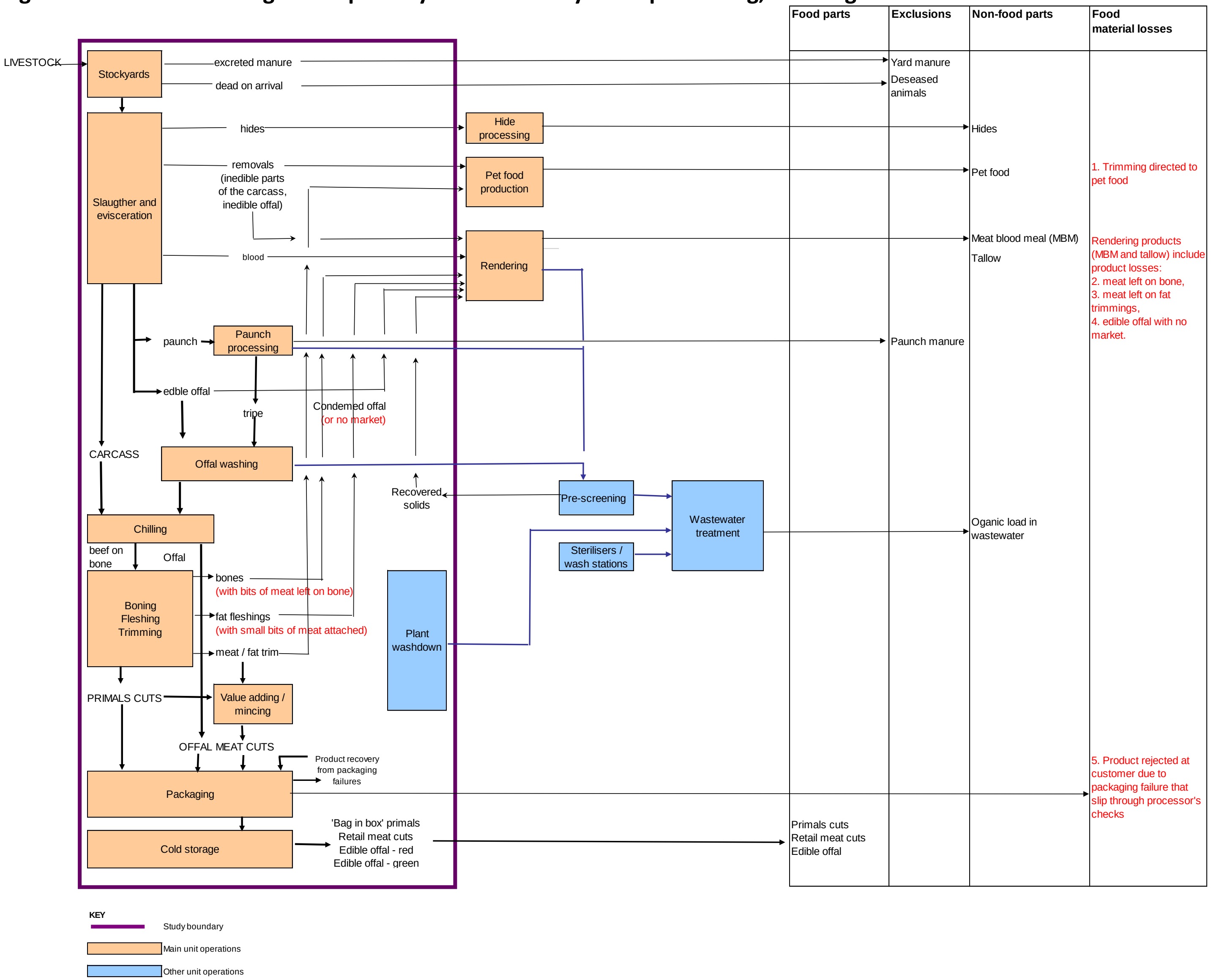
Solutions: Primary Processing

- Slowing down process throughput to enable boning to recover more meat. Downside is higher processing costs due to the higher hourly cost for boning staff.
- Improved monitoring of boning operations, including sensors.
- Automated recovery of left-over fragments of meat bones, using equipment such as 'bone cannon', which forces the meat off. These are expensive and the economic decision to buy might only be considered by larger plants, and it may not suit certain businesses.
- Technology aids for boning/trimming staff to reduce fatigue, such as exo-skeletons and smart gloves.
- Knife sharpening processes to ensure that boning and trimming knives are always sharp.
- Automation is increasingly more reliable and can recover more meat from the bone. The UK is more advanced in the adoption of robotics and AI for meat processing than Australia. Downsides are that robotic boning is significantly slower than manual boning, so slows down the process and robotic equipment takes up a lot more space, and hence significant capital investment in larger footprint facilities.
- Increase domestic demand for edible offal through customer education.

Primary meat processing also influences losses of rejected primal product that occurs further down the supply chain. Since these losses occur at the distribution stage and requires collaborative solutions, they are discussed in detail in Section 4.4 below:

5. Reduced shelf-life due to packaging vacuum seal problems (slow leakers).
6. Reduced shelf-life due to temperature maintenance problems (ineffective pre-chilling).
7. Reduced shelf-life due to sanitary conditions in the manufacturing environment.
8. Insufficient detection (checks).
9. Labelling problems (mislabelling).

Figure 7. Process flow diagram of primary and secondary meat processing, showing material flows and losses



4.2 Secondary processing meat losses

Secondary meat processing further processes primal cuts into small portions and retail ready product, commonly packaged for retail. It is also referred to as ‘value-adding’, ‘case ready’ or ‘retail cutting’. Secondary processing activities include receipt of primal meat cuts from an abattoir, further cutting or processing into smaller cuts, and packaging ready for retail. Processing commonly includes mincing, which is important for loss minimisation, as off-cuts can be directed to mincing.

Secondary processing can be co-located with primary processing in an integrated facility. A co-located secondary processing plant will typically receive primal cuts for the co-located abattoir. One that is not co-located with an abattoir will receive primal cuts from one or a number of different abattoirs.

Sources, loss factors, and destinations

Losses of beef at this stage were found to include:

- offcuts generated during cutting that are not recovered, and
- product that is damaged due to packaging failures.

For offcuts generated during cutting, approximate rates of losses could not be determined. It is very likely that being a high value material they would be recovered via mincing into burger patties for instance or directed to pet food manufacture.

For packaging failures, in many cases there are opportunity to recover these through repackaging (not a loss), reprocessing into other small cuts (maybe a value loss), or downgrading into lower value cuts (trim or mince, etc.) (value loss). The remaining loss fraction that cannot be recovered in these ways is potentially a loss of beef.

Packaging specialists servicing the meat industry were able to suggest estimated rates of meat losses due to packaging failures, based on their experience, which could be considered to be representative of secondary processing:

- meat product that can be repackaged – 4.8%;
- meat product that can be reprocessed – 1.7%;
- meat product that cannot be repackaged or reprocessed – 1.7%, for example;
    - crushed in the equipment, or
    - exposure to heat due to product caught in the shrink tunnel.

Only the last of these is a potential loss and has been accounted for in the waste mapping (Figure 9). These losses may be recoverable if there is access to a mincing, rendering of pet food manufacture to capture value in other products (as discussed in Section 4.1). Plants without access to rendering facilities or pet food manufacturers may dispose of them to landfill, in which case they would not become a food waste. The fractions recovered versus disposed to a waste destination could not be determined, so the amount of food waste from secondary processing is a data gap.

In summary, materials of interest are those that cannot be internally recovered and are sent rendering or pet food manufacture (losses) or sent to landfill (food waste):

- offcuts from trimming, and
- product from packaging failures.

Causes and solutions - Secondary processing meat losses

From the cases studies and subsequent workshops with industry, the following underlying causes of losses generated at secondary processing plants were identified.

1. Skills of line operator in cutting and inspection.
2. Processing, packaging failures, due to:
    a. equipment servicing and maintenance failures.
        i. 'band aid' fixes to equipment.
        ii. need to maintain set service level (pack out) and line speed not allowing for maintenance / repair shutdowns due to high shutdown costs.
    b. problems with vacuum setting on packaging equipment.
    c. temperature gauge on packaging heat sealing equipment.
3. Wrong gas mix in MAP packaging.
4. Contamination of bulk primal inputs with metal or plastics.

Solutions: Secondary Processing
- Address causes of staff turn-over to maintain skilled cutters.
- Address service level pressures.
- Artificial intelligence scanning for contaminants and differences in the colour tones of meat and, to detect failures earlier on so they can be recovered.
- Automated / robotic processes that cut meat to a particular size and shape were noted as both a source of potential losses, but also a potential solution.

Meat processing can also contribute to rejected product losses that occur in downstream distribution stages, which are discussed in detail in Section 4.4:

5. Reduced shelf-life due to packaging vacuum seal problems (slow leakers).
6. Reduced shelf-life due to sanitary conditions in the manufacturing environment.
7. Insufficient detection (checks).
8. Labelling problems (mislabelling).

4.3 Tertiary processing meat losses

Tertiary processing refers to the production of prepared food products that contain beef as a dominant ingredient. These are products retailed at supermarkets or grocers and requiring further home preparation before consumption. The operations that produce these products fall under the broad category of food processing. However, this project focused on food processing activities where beef is the main ingredient.

Sources, loss factors, and destinations

The losses likely to be generated at this stage of the supply chain were derived from observations at case study operations. The identified losses were observed to be:

- meat residues left in batch mixing equipment,
- product losses due to packaging failures, and
- rejected or spoiled meat ingredients.

The first two of these occur regularly and were estimated to represent a 0.2% and 2.0% loss of beef ingredient inputs, respectively. The combined loss factor (2.2%) was used in the waste mapping (Figure 9). The third results from infrequent events, but the scale of loss when it happens can be very high. As it is infrequent and difficult to quantify, it was not accounted for the in the beef loss account. Here, it is important to qualify that that these estimates were drawn from a limited sample, and thus may not be representative of tertiary processing generally.

The main destination for failed food products containing meat is landfill, as there is limited, or no opportunity for product rework. However, for random events when a large batch of product is out of specification but still within use by date, it may be sold cheaply to employees or downgraded to a lower value product.

Causes and solutions - Tertiary processing meat losses

From the cases studies and subsequent workshops with industry, the following underlying causes of losses generated at tertiary processing plants were identified.

1. If the meat ingredient is received as minced meat rather than cuts, there are higher risks in terms of meat quality and higher potential for loss generation.
2. Poor inventory control procedures and data systems used by tertiary processors and their suppliers.
3. No reporting mechanism for receipt of out of spec meat ingredients by tertiary processors, compared with 'corrective action' that can be issued on the supply of rejected product to retailers.
4. Contaminants detected in received meat ingredients or entering the product during processing, which can cause a whole batch to be lost.
5. Inability to detect plastic contamination.
6. Lack of accurate, reliable demand forecasting.
7. Lack of a business case for small firms to invest in better information/data technology.
8. International supply chains for other (non-meat) ingredients, delaying deliveries and causing the use of the meat ingredients to be delayed (potentially spoiled).
9. Inefficient recovery of meat mixtures from bath mixers.
10. Equipment failure on packaging lines.
11. Skills of operators on packaging lines.
12. Few options for recovering failed products.

Solutions: Tertiary Processing

- Receipt of primal cuts rather than mince, so the processor can produce their own mince and have more control over quality.
- Development of an inventory control framework/platform that works for small as well as large companies.
- 2-dimensional (2D) or Radio Frequency Identification (RFID) barcodes for scanning to improve quality of product information.
- Collaboration between large and small firms to improve IT and inventory control.

4.4 Refrigerated transport and distribution losses

This section relates to the movement/transport of packaged beef products from the processor to the retailer. A key element of distribution for beef is the uninterrupted maintenance of products at cold temperatures over the duration of its journey from the processor to the retailer (and to the consumer). Hence it is also referred to as the cold chain.

The functioning and success of refrigerated distribution relies not only on processes occurring during the actual distribution activities but also on processes up-stream and down-stream. As such, the cold chain should not be seen as a discrete step in the supply chain, but as being a whole of supply chain issue.

In this section we consider losses that are generated during the distribution of beef between processing and retailing, most of which occur at the receival point, when product is identified as being out of specification (reject product). However, the underlying causes of these losses and their solutions require a collaborative whole of supply chain perspective. Therefore, this section captures causes and solutions that can relate to all stages and actors in the supply chain.

Sources, loss factors, and destinations

The main losses generated during distribution are the rejection of product when it arrives at retail due to:

- not meeting specification,
- lack of temperature maintenance, and
- packaging failures.

It was not possible to obtain a good estimate of the quantities of rejected beef products, as there seemed to be no specific monitoring or compilation of the quantities of loss. From the study of Brodribb and McCann (2020), which specifically examined meat losses in the cold chain, it was possible to derive an estimated loss rate of 3.4% of produced beef products. However, the study was not transparent enough to understand all the assumptions. From the latest National Food Waste Baseline (FIAL, 2021) the loss rate for distribution was assumed to be 1% of produced meat product.

From the consultations undertaken as part of this study, an estimate of rejects due to packing failures (see ‘slow leakers’ further on) was noted. Packaging failures do not account for all product that is rejected, but were highlighted as an important source. It was suggested that the industry standard loss factor (what is normal for the industry) of ‘slow leaker’ losses may be around 2% for bone-in products and 1% for boneless products. It was assumed that an overall ‘slow leaker’ loss factor could be around 1.5% of meat processed. As losses due to rejects also includes those related to temperature maintenance failure, is can be expected to be greater than 1.5%. For our purposes 1.5% was the loss factor used for the waste mapping (Figure 9), but not considered to be representative.

To address the issue of lack of data on rejected product, it was suggested by industry that the Weigh Price Labels (WPL) system could be a means of capturing data. It enables the capture how much meat product is delivered / shipped to the retailer and how much is sold, with the difference being the amount of rejects (‘processor returns’).

The potential destinations for rejected product were suggested to include:

- return to processor for reprocessing, and rework, for example mincing (rarely, as too costly),
- rescue (donate and send to food charity),
- mark-down and sell at a discounted price (by retailers),
- send to rendering (if available and economically viable), and
- discard, presumably to landfill (through commercial waste management partner)

The dominant destinations and quantities to each could not be identified, and is recognised a data gap for this project.

Causes and solutions – Refrigerated transport distribution losses

From the cases studies and subsequent workshops with industry, the following underlying causes of losses generated during distribution were identified. Those voted at the workshop as the priority ones are bolded.

1. **Fixed shelf-life determination, not allowing for adjustment based on the product's journey.**
2. **Reduced shelf-life due to packaging vacuum seal failures and abuse ('slow leakers').**
3. **Reduced shelf-life due to temperature failures.**
4. Insufficient detection.
5. Labelling problems.
6. Service level pressure.
7. Shared responsibility for co-creation of losses.
8. Insufficient incentives and systems to keep rejected product out of landfill.

In the sections that follow each of these are explained with suggested solutions.

Fixed shelf-life determination

Shelf-life - as indicated on product labels (sell by, best before, use by etc) - has been seen as critical in the causation as well as prevention of food loss at various points along the supply chain. This includes final consumption and households, where date labels have been identified as a key driver of food loss creation. Recently, supermarkets in the UK have started to abolish date labelling for certain product categories, e.g., vegetables and fruit, to prevent food waste. From a production and processing perspective, shelf-life is more than product safety. Remaining shelf-life has come to represent an instrument of commercial value creation as well as commercial risk management. The shelf-life is contingent upon quality management throughout the supply chain, with specific responsibilities discharged at every stage. Failure to discharge responsibilities, for example by interrupting or compromising cold chain temperature maintenance, may diminish shelf-life of produce. Without means to monitor and assure quality outcomes seamlessly, the shelf-life always depends on some unknown variables. As one participant summarised, "shelf-life is not measured, it is (commercially) presumed". There is an inability to change the shelf-life date in the supermarket (once produced on packaging).

Solutions: Refrigerated transport and distribution

- Focus on measures to educate consumers about shelf-life.
- Standards and legislations in Australia need to be reviewed, supported by guidelines on the level of testing needed to support dynamic shelf-life determination.

Reduced shelf life due to packaging vacuum seal failures and abuse ('slow leakers')

Vacuum seal failure

Packaging that employs a vacuum seal has evolved into a highly effective packaging solution for preserving quality and shelf-life of meat products, while offering premium product presentation on display. However vacuum packaging processes can be the underlying driving cause of product defects, which are initially not visible. These are colloquially called "slow leakers", which slip through the internal checks, and are detected downstream in the supply chain by the customer as a 'blown bag' or because of odour/colour change. At that point it generally cannot be recovered and parts of a shipment or the whole shipment can be rejected.

Failures that may damage or compromise the integrity of the vacuum seal, resulting in 'slow leakers' can include:

- creases,
- imperfect sealing,
- incomplete vacuum, and/or
- punctures.

These can be due to variety of errors in the packaging process, including equipment setting, handling and maintenance, line speed, heating, and chilling.

'Slow leakers' are mostly spotted in-process or within normal 24-hour inspections. Some defects however may slip through checkpoints and travel through the supply chain slowly "leaking vacuum" and impairing the edible contents of the product through gradual exposure to oxygen. Early identification may offer better option for re-use and re-work of the edible material, while later identification is more likely to consign the product to waste destinations.

Domestic supply chains may have lower rejection rates compared to export chains due to their greater number of intermittent control and processing points. There are also difference in the amount of rejections between fresh/chilled meats and frozen meats due to differing cycles of freezing and tempering.

An example of one measure to try to mitigate slow leakers is the harmonisation of transport vessels into standard size re-usable plastic totes. It has emerged as a sensible solution for refrigerated transport and distribution, improving efficiencies in storage, transport, and transfer processes. Standard vessels replace custom-sized cartons that were able to prevent sealed (retail-ready) bags from moving during transport. Especially for "bone-in-bag" the in-box movements and collisions of packaging bags may result in punctures and leaks, shortening quality life and causing losses. Different solutions have been discussed, including the use of "bone guards" or an increase in thickness of packaging material.

In summary, the following have been identified as root causes contributing to 'slow leakers':

- Packaging materials incompatible with equipment and processes, potentially resulting in imperfect seals.
- High cost of testing the integrity of every single pack.
- A lack of knowledge and awareness of operators during product handling.
- Export and domestic products made from same machine but in different conveyances.
- Some plants have legacy components cobbled together over time. There can be a lack of standardisation in the machinery used, and problems when different systems are connected imperfectly.

<u>Packaging abuse</u>

Packaging abuse refers to events during handling and transport that result in seal impairment (actual breaks or punctures) to the packaging. Causes include:

– Poor design of conveyance systems for packaged product can contribute to defects.
– Standardisation of conveyance vessels (e.g., plastic tote boxes) may contribute to bones within the product puncturing the packaging, because a one-size-fits-all container may not provide an ideal fit for all products, causing product to move around during transport.
– Meat frozen for long period (up to two years) can result in more accumulated handling and opportunity for seal impairment.

Solutions: Refrigerated transport and distribution

– Sealing integrity testing.
– Using blockchain to identify and trace operational issues that may compromise seal integrity.
– Training and performance monitoring of freight drivers, loading and offloading personnel.
– Consider adequate vessels and processes of transfer during transportation.
– Automated transfers and loading.
– Open-topped ‘crates’ assist with airflow during refrigeration.
– Consider conveyance system design, e.g., how the conveyance operates, how products exit the pack-out stage, in-feed to robotic loading into totes, product moving across drops, turns, and corners, from one belt to another.
– Standardised operating procedures for conveyance systems.
– Investigate fresh and frozen solutions separately.

Reduced shelf-life due to temperature maintenance failures

Seamless temperature maintenance is a perfect example of collaborative supply chain processes. Temperature maintenance and abuse are highly critical aspects of maintaining quality, shelf-life, and economic value of meat products in supply chains (Escavox, 2020). As such, temperature control in cold chains has been highlighted in the scientific literature and in industry reports alike as a key driver of meat loss creation.

Every transfer and hand-over from one supply chain leg to a new mode of conveyance offers a myriad of opportunities for temperature and packaging failure that may ultimately compound to create significant volumes of meat loss. A multitude of loss events, product defects and root causes related to temperature failure have been identified:

- Exposure to ambient heat before transport (left out of chiller at the processing plant).
- Pre-chilling to lower core temperature not completed properly.
- No temperature measurement through dispatching process.
- Truck stopping at rest stop, with refrigeration turned off to save fuel.
- Fridges set with no adequate temperature control.
- Drivers do not know how to operate the refrigeration units (lack of skills).
- Drivers do not know how to use different temperature protocols.
- Packing of product into trucks done badly, for example, box blocking the chilled air outflow.
- In general, distribution requires extensive manual tasks, hence a reliance of people and their skills, and there are different protocols for different types of products.
- Too many points of transfer.

The solutions hinge on temperature control, consistency, traceability, and visibility, especially in logistics and transport. They include temperature tracking devices and data recording and sharing protocols, transport operator training, equipment maintenance, re-design of process flows.

However, the issue of seamless temperature control is still not considered resolved. Importantly, key to successful temperature maintenance are actions that improve collaborative outcomes, such as pre-chilling of meat products as well as transportation vehicles, maintaining core temperatures throughout handovers from one supply chain leg to the next, and creating protocols of data tracking and sharing that permit seamless monitoring across all interfaces in the supply chain.

Even more elusive are quality defects related to temperature abuse which are not only invisible but may produce a sequence of "within spec" quality measurements without guarantees that the product has been within the specified temperature range throughout its entire journey. Product may exceed the maximum temperature and later revert to the compliant temperature range. Temperature breaches that become invisible also include chilled product accidentally frozen and then defrosted back to the intended temperature level. Such issues can be caused by the following root causes:

- Tight packing and loading due to freight cost pressures, leading to the risk of trailer overpacking, which does not leave enough space for air flow.
- No one fully owning responsibility of temperature control.
- Malfunction of trailer refrigeration and/or temperature variations in the trailer (in back/front).
- Uneven distribution of loads means that some areas may disproportionately heat up in hot weather.
- Poor pre-chilling at processing plant.
- Potential for a mismatch between truck width and pallet width leading to sub-optimal packing.
- Use of wrong thermometers for monitoring core temperatures.
- Multiple transport logistics in beef chain make it difficult to maintain temperature.
- Lack of standardisation.

Collaborative loss creation may occur due to insufficient communication and data exchange. Such data exchange is not only supported or limited by the technical feasibility to track and generate data, but also by the willingness and commercial interest to exchange proprietary data and information. Technologies may be able to improve information flow through-out the supply chain, which may help to reduce loss, yet the use of technology is still underpinned by commercial and divergent stakeholder interest. Collaboration to resolve (large scale) systemic issues is therefore an issue of governance as much as a technology, of distribution of risk, benefit, transparency, and trust.

Solutions: Refrigerated transport and distribution

- Standardised data protocols and systems for traceability.
- Tech solutions for building traceability (and trust) as well as visibility of temperature control/abuse in chilling, transport, and logistics.
- Small disposable temperature gauges are now available which give an indication of the remaining shelf life for the pack.
- Automated loading and automated temperature control.
- Use open crates (not boxes) for good temperature circulation.
- Advise transport companies about how to load and wrap the pallets effectively.
- Use integrated GPS and temperature probes.

Insufficient detection of slow leakers and temperature maintenance failures

Defects related to temperature and vacuum may be controlled through inspections and spot-checks, as well as continuous inspection and tracking. Quality control and assurance at any specific point of the supply chain may result in high level confidence of the integrity of product quality. However, in terms of complex, multi-leg supply chains comprising multiple heterogenous actors and agents, currently, there cannot be any complete confidence of product quality due to a lack of seamless visibility and tracking.

This raises issues of collaborative quality control, shared responsibility for commercial acceptance and rejection but also, more broadly of the determination of shelf-life, which is a critical instrument of value creation and risk management in meat supply chains. This is discussed further in the section below.

In terms of quality control and detection of defects, the research participants have cited the following standard methods of quality inspection:

- in process (in-process or 24-hour quality inspection within processing plant).
- at goods receipt (change of ownership), e.g., retail distribution centre. Products change hand numerous times throughout transport and distribution including logistics and freight contracting, warehousing, cross-docking, consolidation, and distribution. Critically, there is difference between “owners” of product and “custodians” who are agents conveying the product. Typically, only owners inspect and reject goods as part of the change of ownership process.
- detection relies on diverse factors such as optical/visual inspection, measurement instruments, product documentation and data, commercial terms and conditions.
- while invisible or collateral product failures may manifest anywhere along supply chains, research participants have observed that the likelihood of detection is significantly higher during early stages, especially during processing or within 24-hour quality inspections.

Export supply chains have an immediate value-add step as a check point for inspection, but domestic supply chain may not have this immediate checkpoint.

Recovery of value or materials is more likely for product failures detected early and closest to the processing stage, where management is offered a greater number of recovery options compared to product failures closer to retail or household/consumption. Research participants have described how primal cuts during their journey toward the retail shelf are successively turned into “shelf-ready” or “ready to eat” product formats by acquiring a greater number of product specifications. While this implies an increased product value-added, the individual retail ready products are delivered as smaller product units, which, accordingly, also have a lower per unit product value. Both, the *higher number of specifications* and *the lower per unit value* limit the available management options and financial incentives for recovery of failed product. Ultimately, this results in an increased likelihood of failed product being diverted to waste rather than value recovery destinations. The type of cut – primal versus retail – also has implications. Primal cuts: larger, longer shelf life, versatile (not yet processed), lower risk; 75% go to export; primal cuts represent high value in 1 single pack; Retail cuts: smaller, shorter (remaining) shelf life, less value per single pack; higher risk, less versatile (specific processing, packaging, labelling); the more value has been added, the more likely products are to be rejected.

The most critical hurdle for meat product moving through supply chains is the quality inspection at the retail distribution centre inlet, at which place the options for material and value recovery are already significantly limited. As meat products move further away from primary processing, not only the potential for loss increases, as outlined in the previous section, but also the capability to recover material or value decreases.

Solutions: Refrigerated transport and distribution

- Understanding what failures/rejects are picked up due to more checkpoints in export supply chain may be useful for domestic supply chains.
- A standardised protocol or affordable technology to detect leakers at earliest point.
- A standard, transparent, seamless quality assurance, and inspection system. Other commodities have achieved seamless systematic testing integrity.
- Consider high-tech imaging being developed to better detect leaks.
- A traceability/2D data system to determine failures along the supply chain.
- Identification of the points (stage gates) with the highest prevalence of slow leakers and work out what is going wrong during transit of products.
- Blockchain can be useful in supply chains with multiple handles, especially for visibility, traceability ad detection for losses.

Labelling problems

Mislabelling is an important cause of rejection for both domestic and exported products. Large scale rejections can occur at ports at the point of assemblage for export due to labelling problems, including: (i) product being labelled incorrectly, and (ii) the label information not being recognised.

Solutions: Refrigerated transport and distribution

- 2D barcodes which carry details like the batch and lot number, expiry dates for tracking.
- Global Standards for Identification (GSI) system for consistent, standardised labelling.
- Tracking systems, facilitated by the above technologies, could also support collection of information about quantities and fates of reject products.

Service level pressures

The concept of "service level pressure" describes a strong urgency to fulfil commitments which may force processes to operate at high speeds. Examples noted during consultations include economic imperatives to maximise utilisation of processing facilities limiting production periods to reduce labour costs, or ongoing commercial or occasional order commitments in terms of quantity, quality, price, and delivery times. These may compound to result in raised service level pressure, which lead to uneven material, product and process flows, blockages, delays, errors, and faults including inadequate equipment maintenance and subsequent breakdowns. All these events may contribute to losses in meat supply chains. Service level pressures can arise internally within a supply chain stage, or externally from influences up and down the supply chain.

Collaborative and systemic loss creation appears related to supply chains that aim to achieve multiple objectives and promote the divergent interests of different actors. Such objectives are in practice often contradictory and call for trade-offs, e.g., between productivity, standardisation, sustainability, earnings, and loss creation. Losses as such may be a calculated trade-off and an accepted cost and may be seen as a consequence of competitive diversity in systems (multi-leg, consolidated supply chains) versus monopolistic structures (single-leg and integrated). Further evidence will be required to determine which types of meat supply chains are more conducive to loss creation or prevention.

Shared responsibility for co-creation of losses

Supply chain systems consist of actors, materials flows, processes, and practices which are governed by different, diverging and at times contradictory objectives and interests. Supply chain practices cannot be designed to resolve all shortcomings and concerns equally and inherently include collateral effects and a level of acceptance of suboptimal outcomes.

- root causes of meat loss that meat processors can influence individually, and that may alter outcomes of loss creation that occurs or is detected downstream in the supply chain (for example at the retailer/home).
- product and process failures resulting from normal supply chain interactions that cannot be readily changed individually (e.g., standards) and may cause loss or a rejection of products at a different stage of the supply chain (including material loss and economic loss of value).

In multi-leg consolidated supply chains, the cost and benefits associated with of loss creation may potentially accrue to different supply chain participants. The allocation of responsibilities, cost and benefits associated with prevailing practices and interventions is governed by commercial terms and conditions agreed between supply chain actors as well as by structural dynamics such as commercial leverage or implicit/de-facto market rules. A stronger focus on collaborative solutions in future may require a re-allocation costs and benefits and novel industry wide approaches to increase transparency and trust.

Solutions: Refrigerated transport and distribution

– Integrated supply chains, in terms of harmonised, collaborative, and technologically connected.
– Commitment by supply chain actors to collaborative systems that govern transparency, traceability and standardised data recording and exchange.
– Clear allocation of responsibilities, cost, and benefits along the whole supply chain

Insufficient incentives and systems to keep rejected product out of landfill

Rejected meat has low level immediate financial impact to producers or retailers, so there is no great incentive to manage it effectively. Rejected meat is not (typically) returned to the processor as it is too costly, and processors may claim the lost value of rejected product on insurance. So, any costs/value loss incurred by processors/retailer may ultimately be borne by the consumer in the cost of the meat.

Furthermore, there is less financial incentive for renderers to recover it. Renderers have a role to play as a destination for rejected product, to recover it as meat meal for livestock (keeping it in the food chain) instead of it being disposed to landfill (or to pet food). However, there are some challenges for directing rejects to rendering instead of landfill, particularly when mark-down or food rescue is not an option.

There are some infrastructure/systems for renderers to receive rejected products (e.g., ‘red’ bins at supermarkets, butcher shops), but there are problems causing it to commonly end up in landfill, including:

- Renderers that are not set up to receive small quantities e.g., packaged meat from retailers. Instead, they need to receive material bulk (typically from abattoirs).
- For the renderer, meat flesh is of less value for them than bone and tallow, as it has higher moisture and hence more costly to process (moisture removal).
- Rejects that are packaged need to be de-packed, which is labour-intensive, and so needs to be performed at the point of loss, at the retailer.
- Ineffective processes for segregation at source. Retail staff tasked with de-packing and segregating product may be floor staff (not butchers) without clear processes or motivation to segregate. Hence, rejects can easily be directed unnecessarily to landfill.
- Contamination of meat with packaging plastic, due to poor segregation practices at the source.
- Lack of education about the role of rendering
    - Misperception that products recovered from meat losses at rendering plants are 'low value'. Lost beef is converted into meat meal which stay in the food supply chain as valuable feed ingredients for other livestock production (e.g., chickens or pigs).
    - Like all other parts of the supply chain, keeping lost meat material cold on its way to the rendering plant is important for successful value adding by the renderer.

Solutions: Refrigerated transport and distribution

- De-packaging systems for rejected product so it can be recovered at less cost for rendering, when other recovery options (marked down or food rescue) are not an option.
- Segregation and collection systems for rejected product (e.g., bins in supermarkets) so it can be recovered by renderers chilled and with no contamination.
- Education/awareness/training about rendering as a destination for rejects.

4.5 Catalogue of solutions

This section compiles and sorts the potential solutions identified through industry consultation and the workshops. They have been grouped into direct causes of loss creation that can be addressed by the induvial businesses, and indirect and systemic causes that require collaborative effort.

Business level / Individual supply chain stage	
PROCESSING SPEED	Slowing down process throughput to enable boning to recover more meat. Downside is higher processing costs due to the higher labour cost for boning staff.
	Robotic boning: significantly slower than manual boning, so slows down the process.
	Improved monitoring of boning operations, including sensors.
PROCESS AUTOMATION	Automated recovering of left-over fragments of meat bones (such as 'bone cannons'). These are expensive and the economic decision to buy might only be considered by larger plants, and it may not suit certain businesses.
	Automation is increasingly more reliable and can recover more meat from the bone. Robotic equipment takes up a lot more space, and hence significant capital investment in larger footprint facilities.
	Automated loading and automated temperature control. Automated transfers and loading. Automation of cutting processing.
STAFF PRODUCTIVITY	Address the causes for high staff turn-over to maintain skilled cutters.
	Technology aids for boning/trimming staff to reduce fatigue, such as exo-skeletons and smart gloves.
	Knife sharpening programs.
MONITORING TECHNOLOGY	Sealing integrity testing improvement through technology and operator training.
	Artificial intelligence scanning for differences in colour tones of meat and contaminants.
	Consider high-tech imaging being developed to better detect leaks. Identify a standardised protocol including affordable technology to detect "leakers" at earliest point.
PROCEDURES FOR PROCESS OPTIMISATION	Advise transport companies about how to load and wrap the pallets effectively.
	Receipt of primal cuts rather than mince step so the processor has more control over the quality and more options for reprocessing off-cuts/reject.
	Evaluate design of the conveyance system: how the conveyance operates, how products exit the pack-out stage, in-feed to robotic loading into totes, the drops, turns and corners where product moves from one belt to another in the conveyance system.
	Consider most adequate vessels and processes of transfer during transportation. For example, 'open topped crates assist with airflow during refrigeration. Use open crates (not boxes) for good temperature circulation.
	A standard operating procedure for conveyance: Investigate fresh/chilled and frozen solutions separately.

Supply chain level / Collaborative	
POLICY	Education/awareness/training about rendering as a destination for rejects (Policy solution).
	Increase domestic demand for edible offal through education.
	Standards and legislations in Australia need to be reviewed, supported by guidelines on the level of testing needed to support dynamic shelf-life determination.
SHELF LIFE	Move away from 'use by' and to 'best before'.
	Development of an inventory control framework/platform that works for small as well as large companies.
	Technology to reduce bacterial growth other than temperature integrity and control.
DATA CONTROL & TRACABILITY	A standard, transparent, seamless quality assurance, and inspection system. Other commodities have achieved seamless "systematic testing integrity".
	A traceability/2D data system to determine failures along the supply chain.
	Identification of the points (stage gates) with the highest prevalence of slow leakers and work out what is going wrong during transit of products.
	Collaboration between large and small firms to improve IT and inventory control.
	Standardised data systems for traceability.
	Using blockchain to track sealing integrity. Tech solutions for building traceability (and trust) as well as visibility of temperature control/abuse in chilling, transport, and logistics.
	Blockchain can be useful in supply chains with multiple handles, especially for visibility, traceability, and loss detection.
	Use integrated GPS and temperature probes.
	2D or RFID barcodes for scanning to improve quality of product information.
	Small disposable temperature gauges are now available which give an indication of the remaining shelf life for the pack.
SUPPLY CHAIN COORDINATION	Ensure pre-chilling at processors.
	Understanding what failures/rejects are picked up due to more checkpoints in export supply chain may be useful for domestic supply chains.
	Tracking systems, facilitated by the above technologies, could also support collection of information about quantities and fates of reject products.
	Integrated supply chains.
	De-packaging systems for rejected product so it can be recovered at less cost for rendering, when mark-down, food rescue not an option.
	Segregation and collection systems for rejected product (e.g., bins in supermarkets) so it can be recovered by renderers chilled and with no contamination.

4.6 Waste mapping

This section compiles the estimates of beef meat losses and waste at key points along the supply chain, derived in this project from literature and from the case study analyses. It cannot be regarded as comprehensive or representative due to limited samples of data, but the following broad observations will help target future loss reduction planning efforts.

The derived loss factors for each stage of the assessed supply chain can be summarised as follows:

- Primary processing loss factors (see Section 4.1) of edible meat and offal are expected to be small as a fraction of input (~0.9%), but may account for a reasonable quantum overall, particularly if the large volumes processed for export are considered. These losses are recovered in products deemed to not be food waste destinations, much of which stays in the human food chain indirectly as animal feed (pet food, meat and bone meal, tallow, and others). Therefore 'food waste' quantities are minimal to zero. However, there are opportunities to keep more of these losses in the direct human food chain.
- Secondary processing loss factors (see Section 4.2) are expected to similarly be a small fraction of inputs (~1.7%) but smaller in total quantum since only beef for domestic supply is processed (36%). When there is access to rendering or pet food manufacturers this can be directed to other non-food waste destinations as per primary processing. Otherwise, losses may go to waste destinations and be food waste, but the fraction and amounts could not be determined.
- Tertiary processing loss factors (see Section 4.3) as a fraction of inputs are expected to be higher than for primary or secondary processing (~2.2%). The total quantum will be low as only 20% of beef post-secondary was assumed to be further processed into prepared foods. Some losses of finished products may be recovered through food rescue, but most is assumed go to landfill as food waste. Those fractions could not be determined.
- Transport and distribution loss factors (see Section 4.4) are expected to be between 1% and 3.4% of distributed product, which are the earlier estimates of the National Food Waste Baseline and a Brodribb and McCann (2020) study, respectively. In this study the rejection of 'slow leakers' at retail door was noted to be 1-2% with the average taken to be 1.5%, but this does not include other causes of product rejection. Destinates were reported to include mark-down, food rescue or collection for rendering (not food waste), or landfill (food waste), but fractions are not known.

The above-mentioned loss factors are compiled in Figure 8, alongside factors that have previously reported by other studies, and showing the data gaps.

Figure 9 translates those loss factors into approximate quantities of beef meat losses potentially generated by Australian beef supply chain at the sector scale. For the domestic supply chain, around 30,000 t/yr of beef meat may be potentially lost between receipt of cattle at the abattoir and the retail door. For beef destinated for export markets, the estimate was around 8,000 t/yr between receipt of cattle to the port. The total is around 38,000 t/yr.

The quantities estimated by this study for all meat processing stages combined (around 23,000 t/yr) are of a similar scale, but lower than quantities using the UK study factor (around 29,000 t/yr).

The quantity estimated for distribution (around 15,000 t/yr) falls between that derived from the loss factors of the most recent Australian National Baseline (around 9,000 t/yr) and the Brodribb & McCann (2020) study (33,000 t/yr). The estimate from this study could only consider loss rates for 'slow leaker' packaging related failures and not temperature related failures, which would account for the value being lower than the Brodribb & McCann (2020) estimate.

Figure 10 combines the information in Figures 8 and 9 to generate an overall approximation of beef meat losses using loss factors estimated by this study (Figure 8) applied to annual quantities of carcass meat processed in Australia, and compared with those reported by other studies. Only losses are reported in Figure 10 to enable comparison with the other studies. Note that losses considered to be food waste will be a sub-set of these values depending on the destination of the losses, which could not be determined for all supply chain stages.

Note that the above approximations were generated for the purpose of understanding the relative scale of potential losses across supply chain stages to help prioritise loss reduction efforts. They are not considered representative of the industry operations due the limited data samples.

Figure 8. Approximate beef loss and waste factors at each supply chain stage, including comparison with other studies (% of meat input to each stage)

	Primary processing		Secondary processing		Tertiary processing		Transport / distribution		In-scope supply chain [1]	Retail / wholesale	Consumption
	Loss	Waste	Loss	Waste	Loss	Waste	Loss	Waste	Loss		
UK study (WRAP 2020)	**2.0%**		ND		ND		ND			**0.3%**	**11.0%**
Aus Gov study (Brodribb & McCann 2020)	ND		ND		ND		**3.4%**				
Aus Food Waste Baseline (FIAL 2021)	ND		ND		ND		**1.0%**			**3.8%**	**10.7%**
This project (2022)	**0.9%** [2]	**0.0%**	**1.7%**	**?**	**2.2%**	**?**	**1.5%** [3]	**?**	**6%**		

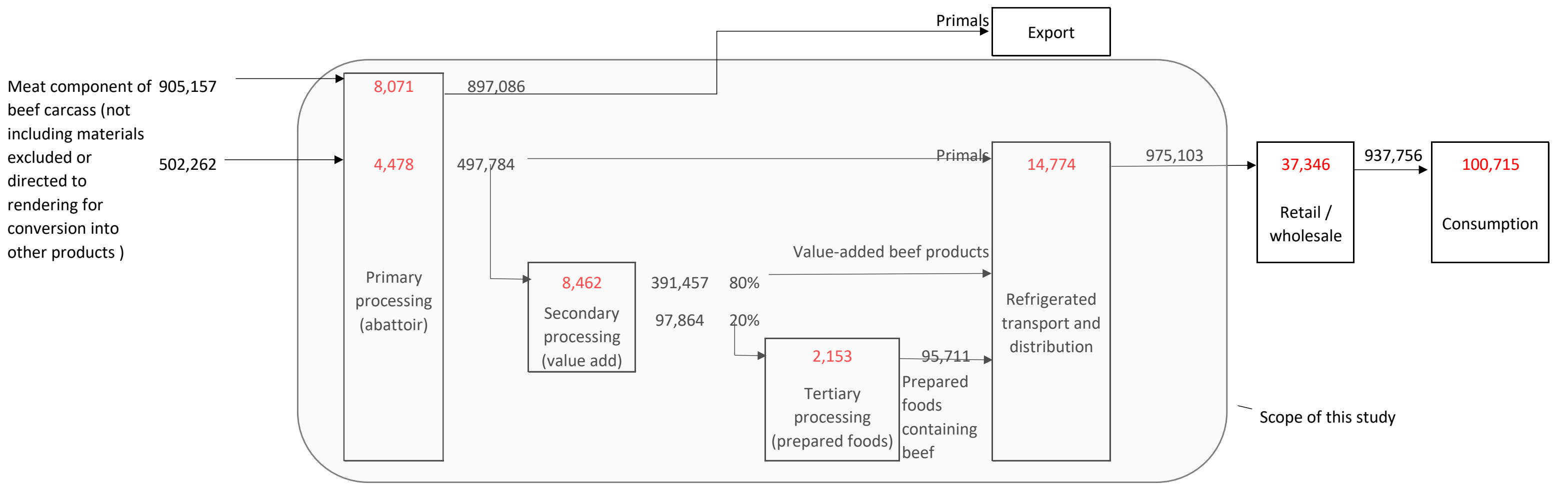
ND=not determined

[1] Combined loss factor across all meat processing and distribution stages (% of the original meat input to primary meat processing)

[2] Does not account for edible offal not directed to human consumption

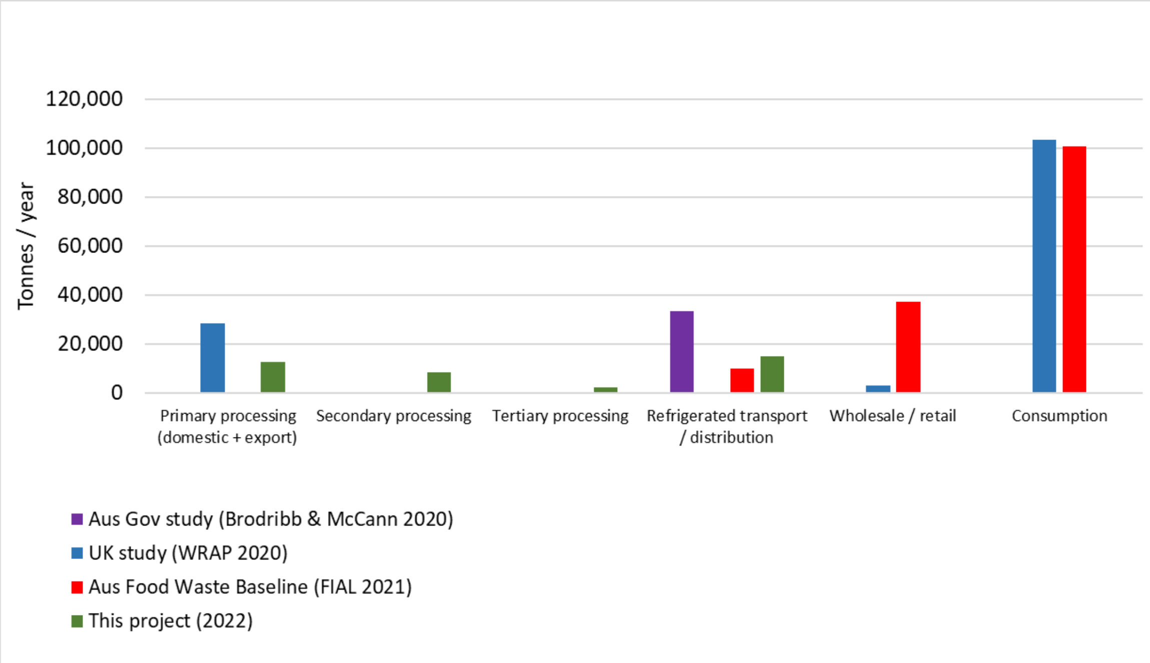
[3] Does not account for losses due to temperature maintenance failures

Figure 9. Approximate quantities of beef meat flows and losses (in red) at each supply chain stage (tonnes / year)[1]



[1] Beef meat flows are for the Australian industry using the same quantities of livestock inputs assumed in the Australian Baseline study (FIAL, 2021). Losses are based on estimated loss factors (Figure 8) for processing and distribution, and the Australian Baseline factors (FIAL, 2021) for retail and consumption.

Figure 10 Approximate annual beef losses for each supply chain stage, including comparison with other studies (tonnes/yr) [1,2,3]



[1] Using the loss factors estimated by this study and other studies (Figure 8) applied to annual quantities of carcass meat processed in Australia.

[2] The reported amount for the UK study represents all meat processing (primary, secondary, and tertiary).

[3] These approximations were generated for the purpose of understanding the relative scale of potential losses across supply chain stages to help prioritise loss reduction efforts. They are not considered representative of the industry operations due the limited data samples.

4.7 Economic cost of beef loss

This section reports findings from the analysis of the economic cost of beef losses in processing stages using the Dynamic Industry Resource Efficiency Calculator Tool (DIRECT) (https://empauer.com/solutions/direct/), details of which can be found in Section 3.5. DIRECT quantifies and categorises food losses of an operation consistent with the FLW Standard and estimates the monetary cost of the material flows and non-product losses to assist organisations to plan and prioritise reduction strategies. This project was the first time the DIRECT tool had been used for meat products. Therefore, as well as adding an understanding of the economic significance of beef losses, it was an opportunity to test its applicability in the context of meat products.

The DIRECT analyses represented hypothetical meat processing operations within Australian domestic beef supply chains, informed by the information compiled in the case studies and generic information about business costs from literature (AMPC, 2019). It was not possible to assess refrigerated transport and distribution operations due to difficulties accessing businesses.

The DIRECT tool tracks and partitions the flow of the operation's food and non-food ingredient material inputs to their various product and non-product destinations, with the latter including co-products as well as more typical loss/waste destinations, such as landfill and sewer (see Table 2 and Table 4). The analysis used the loss factors assumed in the waste mapping (see Figure 8). Entered estimates of businesses operating costs are then assigned to the loss fractions to estimate the 'true cost' of losses and waste (see Section 3.5), going above and beyond the cost of material loss and disposal. Details of the parameters entered into the DIRECT tool can be found in Appendix 8.5.

For the primary processing (abattoir) case, an adjustment was made to the normal DIRECT analysis process, to account for the removals from the cattle carcass that are not intended for human consumption and directed to rendering. DIRECT is set up to typically model food production processes that assemble food and non-food ingredients into food products, and/or track assembled products along the product lifecycle. However primary processing (at an abattoir) is a process of disassembly, with many components of the carcass not intended for human consumption. The inclusion of these inedible components in the analysis was found to skew the analysis of the cost of waste. Therefore, the food 'ingredient' into primary/secondary processing case was taken to be only the meat and offal components of the carcass destined for human consumption. For the tertiary processing case, all inputs were food ingredients (or their associated non-food packaging), so the DIRECT analysis was performed as typical.

The analysis of the primary/secondary processing case (Table 3) estimated the true cost of losses to be $33 million per year, which is around 3% of the estimated income from all product income. A large proportion of the total cost of losses (58%) is associated with the material input cost of the lost beef meat (and thereby the potential revenue of turning that beef into a product), with lost wages making up over half (27%) of the remaining true costs. The true cost per unit of meat/offal lost was estimated to be $5,800 / t lost beef.

The analysis of the tertiary processing case (Table 5) estimated the true cost of losses to be $210,000 per year, which is around 0.4% of product income. In this case, while the material input cost of the lost beef was also the dominant contributor (55%), next to wages (26%), the losses to electricity (5.2%) and waste management (2.7%) were the notable differences. The true cost per unit of lost product was estimated to be $6,360/t, and the true cost of the constituent beef in the lost product (17%) is $1,081/t lost beef.

Table 2. Assumed food material destinations for primary/secondary processing case

Type	Product 1 (primals)	Product 2 (retails cuts)	Product 3 (edible offal)	Co-Product 1 (lost meat and offal to pet food)	Animal feed (lost meat and offal to rendering into MBM)
Meat	67.0%	29.6%		2.0%	0.9%
Edible Offal			80.0%	10.0%	10.0%
Quantity (t/yr)				3,200	2,620

Table 3. Estimated true cost of losses for primary / secondary processing case

Business Cost	Cost ($)	Portion of cost related to material losses ($)	% of Cost of Losses
Electricity	$7,988,074	$647,442	1.9%
Facilities	$22,780,402	$1,846,376	5.5%
Wages	$114,331,099	$9,266,663	27.4%
Freight	$29,329,428	$2,377,182	7.0%
Material losses	$19,632,774	$19,632,774	58.1%
Total cost of losses ($/yr)		$33,770,439	100.0%
Per unit cost ($/t lost meat)		**$5,802**	

Figure 11. Breakdown of the true cost of losses for primary / secondary processing case

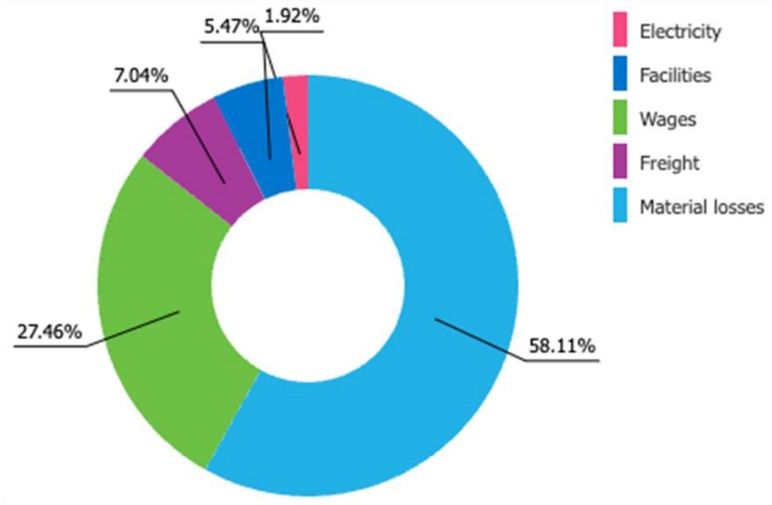


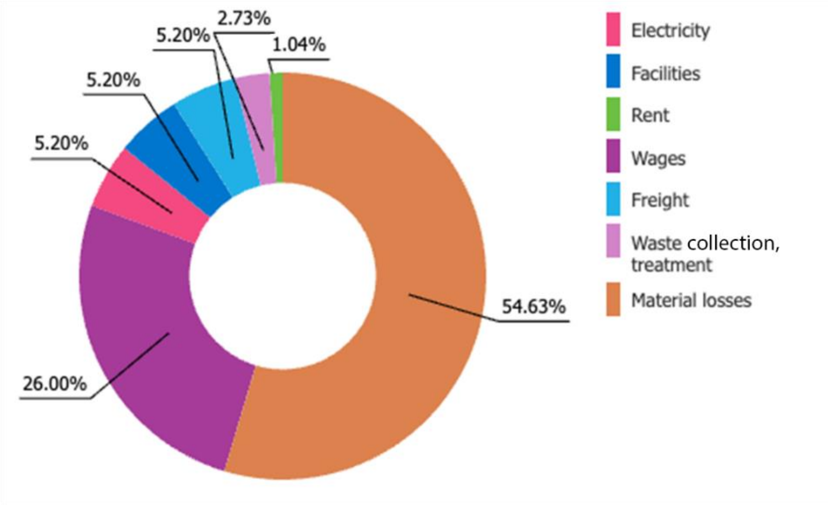
Table 4. Food material destinations inputs to DIRECT for tertiary processing case

Type	Product	Losses to landfill and sewer
Meat Mince	97.8%	2.2%
Vegetable ingredients	97.8%	2.2%
Flavour Mix	97.8%	2.2%
Flour	97.8%	2.2%
Water	97.8%	2.2%
Quantity (t/yr)		33.3

Table 5. Estimated true cost of losses for tertiary processing case

Business Cost	Cost ($)	Portion of cost related to material losses ($)	% of Cost of Losses
Electricity	$500,000	$10,921	5.2%
Facilities	$500,000	$10,921	5.2%
Rent	$100,000	$2,184	1.0%
Wages	$2,500,000	$54,608	26.0%
Freight	$500,000	$10,921	5.2%
Waste collection, treatment		$5,740	2.7%
Material losses		$114,730	54.6%
Total cost of losses ($/yr)		$210,027	100.0%
Per unit cost ($/t lost product)		$6,364	
Per unit cost ($/t lost meat)		**$1,081**	

Figure 12. Breakdown of the true cost of losses for tertiary processing case



If these above estimates of the per unit true cost of meat losses are applied to the estimated loss quantities (Figure 9), then the approximate scale of true costs can be estimated as follows:

Domestic primary + secondary processing = (4,478+8,462) t/yr x $5,802 /t = $75 million /yr

Export primary processing = 8,071 t/yr x $5,802 /t = $46 million/yr

Tertiary processing = 2,153 t/yr x $1,081/t = $2.5 million/yr

A targeted reduction in beef meat losses of 15-25% across each of these processing stages could therefore results in savings in the order of $18-31 million per year.

This is the potential cost savings for the processing stages of the supply chain only, as the cost of losses during refrigerated transport and distribution could not be estimated in this project. Brodribb and McCann (2020) had estimated the value to be $406 million /yr, and a 15%-25% reduction would be an additional $60-$100 million per year.

These approximations were generated for the purpose of understanding the relative scale of potential cost savings to help prioritise loss reduction efforts. They are not considered representative of the industry operations due the limited data samples.

4.8 Limitations

The research was able to compile information and observations from a limited sample of case study operations that are part of the Australian beef supply chain. This small sample did not allow for a definitive estimation of the quantifies of beef meat losses over the assessed supply chain stages. However, it does provide a more granular picture of the relative scales of losses for meat processing, which is an improvement on prior work for the National Food Waste Baseline. While not definitive, it can inform any further industry research or engagement related to the National Food Waste Strategy (Commonwealth of Australia, 2017).

The industry consultation component of the project was more successful in engaging a wider cross-section of the industry. Therefore, the causes and preliminary catalogue of solutions compiled by this research are more robust. However, the limitations of this component were:

– Transport companies were not represented at the workshops, which were the key process for validating key aspects and causes of meat losses. Therefore, the project's findings did not consider the experiences and insights of these supply chain actors. It is recommended that any consultation towards the development of a Meat Industry Sector Action Plan (SAP) under Australia's National Food Waste Strategy should prioritise consultation with these actors.
– Losses related to 'slow leakers' for vacuum packaging were highlighted as a priority for the industry, which relate to a sub-set of package formats. The engagement did not allow for the exploration of problems associated with all packaging formats and substrates used across the industry.

5. Conclusion

5.1 Key findings

The main sources and causes of beef meat losses and waste for each stage were identified to be:

	FOOD LOSSES	FOOD WASTE
Primary processing	Meat that cannot practically be trimmed from bone and fat during boning and trimming. Meat trimmings that drop to the floor. Edible offal with no market as human food.	Nil. Losses go to pet food and meat and bone meal, which are not waste destinations.
Secondary processing	Meat offcuts and products damaged during packaging, that cannot be internally reprocessed or repackaged.	Losses that cannot be recovered to rendering or pet food, and instead go to a waste destination (for example landfill).
Tertiary processing	Rejected or spoiled meat ingredients. Meat residues left in mixing equipment. Product lost due to packaging failures.	Losses that cannot be recovered (food rescue, animal feed), and instead go to a waste destination (typically landfill, composting).
Refrigerated transport and distribution	Product rejected by retailer due to not meeting specification, lack of temperature maintenance and packaging failures.	Losses that are not recovered (mark-down, food rescue), and instead go to a waste destination (landfill).

A preliminary catalogue of loss reduction solutions was compiled ranging from business level (individual) actions, to broader supply chain (collaborative) actions, which can feed into subsequent development of a Sector Action Plan as part of Australia's Food Waste Reduction Strategy (Commonwealth of Australia, 2017).

The most significant loss reductions are expected to come from collaborative supply chain solutions that hinge on greater transparency and communication between supply chain stages.

5.2 Benefits to industry

The benefits to the beef industry from this Phase 1 project are information to enable participation in the National Food Waste Reduction Strategy (Commonwealth of Australia, 2017) and the increased social licence that brings. It also provides impetus for increased collaboration and transparency along the supply chain to unlock innovation. Details of these are provided in the sections that follow.

Consideration of environmental benefits were outside the scope of this Phase 1 project, but some commentary on the links between meat loss reduction and improved environmental outcomes is also provided.

Participation in the National Food Waste Reduction Strategy

The National Food Waste Reduction Strategy (Commonwealth of Australia, 2017) aims to reduce food waste by 50% by 2030. This is a whole of society initiative, with industries making contributions through Sector Action Plans (SAP). The Australian National Food Waste Baseline provides the point of reference against which food loss reductions are tracked.

The information provided by this project will enable participation by the beef industry in the National Food Waste Reduction Strategy and future tracking of loss reduction efforts. This project's findings for beef are likely transferrable to lamb and so contribute to a Sector Action Plan for red meat more broadly.

Innovation through increased supply chain collaboration

Many of the solutions for meat loss reduction call for increased trust and collaboration between industry partners along the supply chain. The benefits of this are less recognised and more difficult to quantify (Richards et al., 2021). However, it has been demonstrated in other supply chain resource efficiency studies to unlock solutions that wouldn't be possible if they were working alone (Lockrey et al., 2019).

Greenhouse gas (GHG) emission reductions

In a recent assessment of the environmental impacts of food loss and waste using life cycle assessment (LCA) (FIAL, 2021) reduction of red meat losses were found to a be an opportunity for reducing greenhouse gas (GHG) emissions. This is because the whole of lifecycle GHG emission intensity of red meat products is relatively high compared to other food products (4.6-14.5 kg CO_2e/kg live weight beef and lamb) (Eady et al., 2011).

Therefore, GHG emission reductions from reduced red meat losses could be expected to be to contribute to the red meat sector's objectives for reduction GHG emissions under the Australian Beef Sustainability Framework (RMAC, 2022) . The presumption is that if less beef meat was lost between the abattoir and the retail door, this would translate to that additional quantity being available as product on retail shelves, then less pull-through demand for beef cattle production. This logic would stand for a demand-driven supply chain, but meat is more typically supply-driven by nature. The consequence of less meat loss may not be lower rates of beef cattle production and therefore lower GHG emissions, since cattle raising is the main driver for GHG emissions rather than processing. This is an aspect for further investigation and enquiry.

6. Future research and recommendations

This study provides approximations of the amount of beef losses, but they are not comprehensive or representative, and there are outstanding data gaps. Filling these gaps and having mechanisms for tracking loss estimates over time will be important for future food loss reduction efforts.

The findings will be useful in the development of a Meat Sector Action Plan (SAP) under Australia's National Food Waste Strategy (Commonwealth of Australia, 2017). In doing that, the following specific recommendations are made:

- Consultation for the SAP should prioritise consultation with transport carriers, who could not be engaged in this project.
- Emphasis increased supply chain collaboration and transparency, which will be central for making material gain in meat loss and waste reductions.
- Further estimations of the costs of losses and waste using the Dynamic Industry Resource Efficiency Calculator (DIRECT) tool to inform cost-benefit analysis and prioritisation of loss reduction initiatives.

Further investigation into the greenhouse gas (GHG) emission reductions from reducing beef meat losses may be warranted, given that emissions reduction from loss reductions may seem logical but are currently not reported in a way that would capture this.

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8. Appendices

8.1 Glossary

ACC	Australian Country Choice (participant of the FFW CRC)
AFCCC	Australian Food Cold Chain Council (participant of the FFW CRC)
AMPC	Australian Meat Processors Corporation
DIRECT	Dynamic Industry Resource Efficiency Calculator Tool (https://empauer.com/solutions/direct/)
DC	Distribution centre
DOA	Dead on arrival
FFW CRC	Fight Food Waste Cooperative Research Centre
FLW	Food Loss and Waste
Food loss	Food losses in the context of meat are fractions of edible meat and offal, which would otherwise be destined for human food, but which are hard to harvest, and which are directed to non-food destinations via rendering as a cost-effective means of value recovery. Rendering processes animal materials into non-food products (meat and bone meal, tallow, pet food), which are important revenue streams for the industry. Animal parts not destined for human consumption are not considered losses (hides, hoofs, bones, inedible and condemned offal) and are directed to rendering.
Food waste	Food waste in the context of meat are losses of edible meat and offal that go to landfill, wastewater, composting, digestion, combustion.
LCA	Life Cycle Assessment
MAP	Modified atmosphere packaging
MBM	Meat and bone meal produced in the rendering process
MFA	Material flow analysis
MLA	Meat and Livestock Australia
Primal cuts	Major component of an animal carcase. For beef these include ribs, butts, chuck and rumps, and loins. (MLA, 2023)
RFID	Radio Frequency Identification, which allows for the location and monitoring of products automatically
RMIT	Royal Melbourne Institute of Technology (participant of the FFW CRC)
QA	Quality Assurance
QDES	Queensland Department of Environment and Science (participant of the FFW CRC)
QUT	Queensland University of Technology (participant of the FFW CRC)
SAP	Sector Action Plan
SRWA	Stop Food Waste Australia
WRAP	Waste Resource Action Program of the UK
WRI	World Resources Institute
2D barcode	Two-dimensional barcode is a graphical image that stores information both horizontally and vertically, has can hold more information than a traditional 1D barcode

8.2 Project personnel

Table 6. Key project personnel and their roles

Name	Organisation	Research team	CRC	Industry / gov partners	Steering C'tee	Workshop participants
Marguerite Renouf (project lead)	QUT	✓			✓	✓
Rudolf Messner	QUT	✓				✓
Anthony Mann	QUT	✓				✓
Allister Hill	RMIT	✓				✓
Carol Richards	QUT (in-kind)	✓			✓	✓
Bree Hurst	QUT (in-kind)	✓			✓	✓
Simon Lockrey	FFW Reduce		✓		✓	
Mark Barthel / Carolyn Cameron	SFWA		✓		✓	✓
Kylie Hughes / Cara McNicol	QDES			✓	✓	✓
Long Huynh / Ian Jenson	MLA			✓	✓	✓
Greg Picker / Mark Mitchell	AFCCC			✓	✓	✓
Paul Gibson / Rebecca Bennett	ACC			✓	✓	✓
Matthew Deegan	AMPC				✓	✓
Alan Adams	Sealed Air (representing AIP)				✓	
Luke Wood	Escavox				✓	✓
Paul-Antoine Bontinck	Lifecycles				✓	
Rowen West-Henzell	WRAP (UK)				✓	
Patrick Youil	Coles RROA				✓	✓

8.3 Project steering committee terms of reference

The purpose of the steering committee was to provide a joint leadership forum of industry, government and research partners.

The roles of members were to:

1. Provide constructive and active input to help maximise the value and benefits the project's outputs and adoption, ensuring that:
   - project scope, activities and outputs are technically achievable and practically relevant;
   - directions and progress of the project remains on track to generate the expected outputs;
   - project activities and deliverables are regularly reviewed and revised as necessary;
   - inputs and/or resources are available to enable or improve the project outputs; and
   - case studies are effective and suitable to help deliver industry-ready outputs.
2. Provide support for the uptake/adoption of the project outputs.
3. Attend committee meetings and respond to requests for information from the research team.

Refer to Section 8.2 for membership of the steering committee.

8.4 Human ethics approval

QUT

18 May 2022

Dear Dr Marguerite Renouf,

We are pleased to advise that your application has been reviewed and approved by the University Human Research Ethics Committee (UHREC) or delegated review body as meeting the requirements of the National Statement on Ethical Conduct in Human Research (2007, updated 2018).

Project title:	Whole of meat supply chain waste mapping and interventions
Approval number:	4923
Approved version:	LR 2022-4923-8857
Approval date:	18/05/2022
Expiry date:	18/05/2027

Documents approved:

Document Type	File Name	Date	Version
Default	Research Questionnaire V1	26/04/2022	1
Default	Case study DIRECT data requirements V1	26/04/2022	1
Default	Drivers and causes of meat losses checklist V1	26/04/2022	1
Default	PICF Case Studies V2	17/05/2022	V2
Default	PICF Workshop V2	17/05/2022	V2
Default	Contact letter - Case Study V2	17/05/2022	V2
Default	Contact letter- Workshop V2	17/05/2022	V2

Research team approved:

Dr Marguerite Renouf , Mr Cumhur Bakir, Dr Anthony Mann, Dr Rudolf Messner, Dr Bree Hurst, Aspro Carol Richards, Dr Simon Lockrey, Mr Allister Hill

This approval is subject to the standard conditions of approval as well as any additional conditions of approval indicated by the UHREC or delegated review body.

Kind regards,

Office of Research Ethics and Integrity

QUT Human Research Ethics Advisory Team | humanethics@qut.edu.au | +61 (0)7 3138 5123
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8.5 DIRECT analysis inputs, assumptions and outputs for meat processing

Table 7. DIRECT material inputs (integrated primary and secondary meat processing)

Category	Product/Co-Product material destinations	Packaging	Mass per time period (t)	Cost per time period ($)	Food (%)	Inedible parts (%)
Edible Cattle Parts						
Meat	Product 1, Product 2, Co-Product 1		97,204	$492,035,677	100%	0%
Edible Offal	Product 3, Co-Product 1		12,546	$31,190,382	100%	0%
Water	No		4,473	$0	100%	0%
Packing Materials						
Shrink Plastic Bags (primal cuts & offal)	Product 1, Product 3	Yes	304	$1,062,814		
Plastic Trays (retail cuts)	Product 2	Yes	581	$5,812,033		
Cardboard Boxes (primal cuts & offal)	Product 1, Product 3	Yes	1,039	$5,194,212		
Cardboard Boxes (retail cuts)	Product 2	Yes	291	$2,179,501		
Shrink Wrap	Product 1, Product 2, Product 3	Yes	12	$240,753		
Total			116,450	$537,715,372		

Table 8. DIRECT food input destinations (primary and secondary meat processing)

Type	Product 1	Product 2	Product 3	Co-Product 1	Animal feed	Environmental losses
Meat	67.0%	29.6%		2.5%	0.9%	
Edible Offal			80.0%	10.0%	10.0%	
Water						100%

Table 9. DIRECT non-food input destinations inputs (primary and secondary meat processing)

Type	Product 1	Product 2	Product 3
Shrink Plastic Bags (primal cuts & offal)	85.8%		13.2%
Plastic Trays (retail cuts)		99.0%	
Cardboard Boxes (primal cuts & offal)	85.8%		13.2%
Shrink Wrap	62.6%	27.7%	9.7%

Table 10. DIRECT material output income inputs (primary and secondary meat processing)

Destination	Output Cost (as related to material loss)	Income
Product 1		$601,768,582
Product 2		$380,945,135
Product 3		$50,185,801
(Loss) Co-Product 1		$5,832,221
(Loss) Food		
Animal Feed		$2,073,922
(Loss) Non-Food		
Landfill		
Wastewater		

Table 11. DIRECT business cost inputs (primary and secondary meat processing)

Business Cost	Cost per life cycle stage ($)	Carried over cost	Total Cost	Portion of cost related to material losses ($)
Electricity	$7,988,074	$0	$7,988,074	$647,442
Facilities	$22,780,402	$0	$22,780,402	$1,846,376
Wages	$114,331,099	$0	$114,331,099	$9,266,663
Freight	$29,329,428	$0	$29,329,428	$2,377,182

Table 12. DIRECT analysis outputs – quantities of meat losses and true costs (primary and secondary meat processing)

Food material 'loss' destination	Mass (t)	
Co-Product 1	3,685	
Animal Feed	2,129	
	Cost ($)	**% of Cost of Loss**
Electricity	$647,442	1.9%
Facilities	$1,846,376	5.5%
Wages	$9,266,663	27.4%
Freight	$2,377,182	7.0%
Material losses	$19,632,774	58.1%
Estimated Cost of Waste	$33,770,439	100.0%

Figure 13: DIRECT analysis output – quantities of meat losses chart (primary and secondary meat processing)

Table 13. DIRECT material inputs (tertiary processing)

Category	Product/Co-Product material destinations	Packaging	Mass per time period (t)	Cost per time period ($)	Food (%)	Inedible parts (%)
Food Ingredients						
Beef Mince	Product 1		254	$3,408,895	100%	0%
Vegetable Ingredients	Product 1		589	$589,680	100%	0%
Flavour Mix	Product 1		63	$635,040	100%	0%
Flour	Product 1		483	$483,840	100%	0%
Water	Product 1		121	$377	100%	0%
Packing Materials						
Plastic Pouch	Product 1	Yes	10	$139,401		
Cardboard Boxes	Product 1	Yes	10	$74,379		
Total			1,532	$5,331,612		

Table 14. DIRECT food input destinations (tertiary processing)

Type	Product 1	Landfill	Sewer
Food			
Beef Mince	97.8%	2.0%	0.2%
Vegetable ingredients	97.8%	2.0%	0.2%
Flavour ingredients	97.8%	2.0%	0.2%
Flour	97.8%	2.0%	0.2%
Water	97.8%	2.0%	0.2%

Table 15. DIRECT non-food material destinations inputs (tertiary processing)

Type	Product 1	Landfill
Non-Food		
Plastic Pouch	99.0%	1.0%
Cardboard Boxes	99.0%	1.0%

Table 16. DIRECT material output income inputs (tertiary processing)

Destination	Output Cost (as related to material loss) ($)	Income ($)
Product 1		$15,120,000
(Loss) Food		
Landfill	$3,018	
Sewer	$2,722	
(Loss) Non-Food		
Landfill		

Table 17. DIRECT business cost inputs (tertiary processing)

Business Cost	Cost per life cycle stage ($)	Carried over cost ($)	Total Cost ($)	Portion of cost related to material losses ($)
Electricity	$500,000	$0	$500,000	$10,921
Facilities	$500,000	$0	$500,000	$10,921
Rent	$100,000	$0	$100,000	$2,184
Wages	$2,500,000	$0	$2,500,000	$54,608
Freight	$500,000	$0	$500,000	$10,921

Table 18. DIRECT analysis outputs – quantities of meat losses and true costs (tertiary processing)

Food material 'loss' destination	Mass (t)	
Landfill	30.2	
Sewer	3.02	
Category	**Cost ($)**	**% of Cost of Waste**
Electricity	$10,921	5.2%
Facilities	$10,921	5.2%
Rent	$2,184	1.0%
Wages	$54,608	26.0%
Freight	$10,921	5.2%
Waste & loss collection and treatment	$5,740	2.7%
Material losses	$114,730	54.6%
Estimated Cost of Waste	$210,027	100.0%

Figure 14: DIRECT analysis output – quantities of meat losses chart (tertiary processing)

Table 19. Processor operating business costs

Derived from (AMPC, 2019). Cost data reported for 2015 was adjusted to costs for 2022, based on a consumer price index over the period of 1.16.

Costs per head	2015	2022
Labour	$210.54	$244.25
Electricity	$9.20	$10.67
Fuel	$5.51	$6.39
Water and sewerage	$4.51	$5.23
Waste disposal	$2.41	$2.80
Certification / audits	$7.29	$8.46
Packaging	$26.80	$31.09
Transport (product)	$54.01	$62.66
Repairs and maintenance	$14.76	$17.12
Processing consumables	$5.70	$6.61
Other	$19.90	$23.09
Total	**$360.63**	**$418.37**