A study of waste in the cold food chain and opportunities for improvement

Prepared for:

Department of Agriculture, Water and the Environment and Refrigerants Australia

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1 Executive summary

This study examines the size and characteristics of the cold food chain in Australia and explores the benefits of an efficient cold food chain. It uses public and private data to quantify the size and location of failures in the cold chain to estimate the extent of food loss and waste and the associated environmental and energy use consequences.

The production and transport of food is a major global industry and it is projected to grow strongly in Australia over the next 20 years as export capacities expand. In 2018, more than 23 million tonnes of foodstuffs worth $42 billion based on farm gate values passed through the Australian cold food chain.

Given the huge distances refrigerated foods often travel to reach Australian and export markets, the cold food chain has been extraordinarily successful. However, there is room for improvement, both in how refrigeration technology is used and opportunities to expand the cold food chain to produce better outcomes.

Food waste in Australia is often due to poor temperature management. The greatest risks for perishable food occur during transportation and handling between mobile and stationary refrigeration points when there are sometimes huge temperature variations between truck or trailer, loading docks and storage facilities.

Estimates of food waste attributable to breaks and deficiencies in the cold food chain are provided for the first time. Preliminary and conservative estimates put the cost of food waste within the cold food chain at $3.8 billion at farm gate values comprising:

- 25% (1,930,000 tonnes) of annual production of fruit and vegetables worth $3 billion
- 3.5% of annual production of meat (155,000 tonnes) worth $670 million, and seafood (8,500 tonnes) worth $90 million
- 1% (90,000 tonnes) of annual dairy production valued at $70 million.

The greenhouse gas emissions from food waste attributed to sub-par refrigeration technology, practices and processes in the cold food chain are estimated at 7.0 Mt CO_2-e in 2018, which is about 1.3% of Australia's annual greenhouse gas emissions. This is equivalent to more than 35% of the total emissions (direct and indirect) from operating the cold food chain in the same year (18.9 Mt CO_2-e). This estimate is based on using accepted estimates of greenhouse gas emissions intensity for production of various food types.

This study concludes there is significant food waste in the supply lines at the wholesale and retail stages, and in hospitality. Some of this waste can be avoided by better refrigeration practices. Food damage is also more likely to occur in the transport and handling of refrigerated product than at stationary points in the cold food chain. If food is poorly handled during transport and handling, the losses at the consumer end are compounded. Food that has not been kept at a suitable temperature throughout the supply chain will have a shorter shelf life in the domestic refrigerator.

While there are many and varied causes of food loss and waste, this study identifies many simple practices that would cost-effectively reduce perishable food waste. They involve better food handling, such as reducing the time food spends outside refrigerated environments during transfer, more accurate measurement of food temperatures, and better cohesion and monitoring at all steps in the cold chain.

Losses could be better predicted, avoided, or reduced by improved 'chain of custody' documentation involving a mix of better practices and the use of rapidly emerging monitoring and reporting technologies. These improved practices throughout the cold food chain have the potential to reduce food loss in the supply chain and extend shelf life and reduce food loss in the hands of consumers.

2 Introduction

Globally, more than one third of food produced each year is not consumed. The environmental, economic and social impacts of this waste are significant. If wasted food were a country, it would be the third-largest greenhouse gas emitter on the planet (FLW 2016).

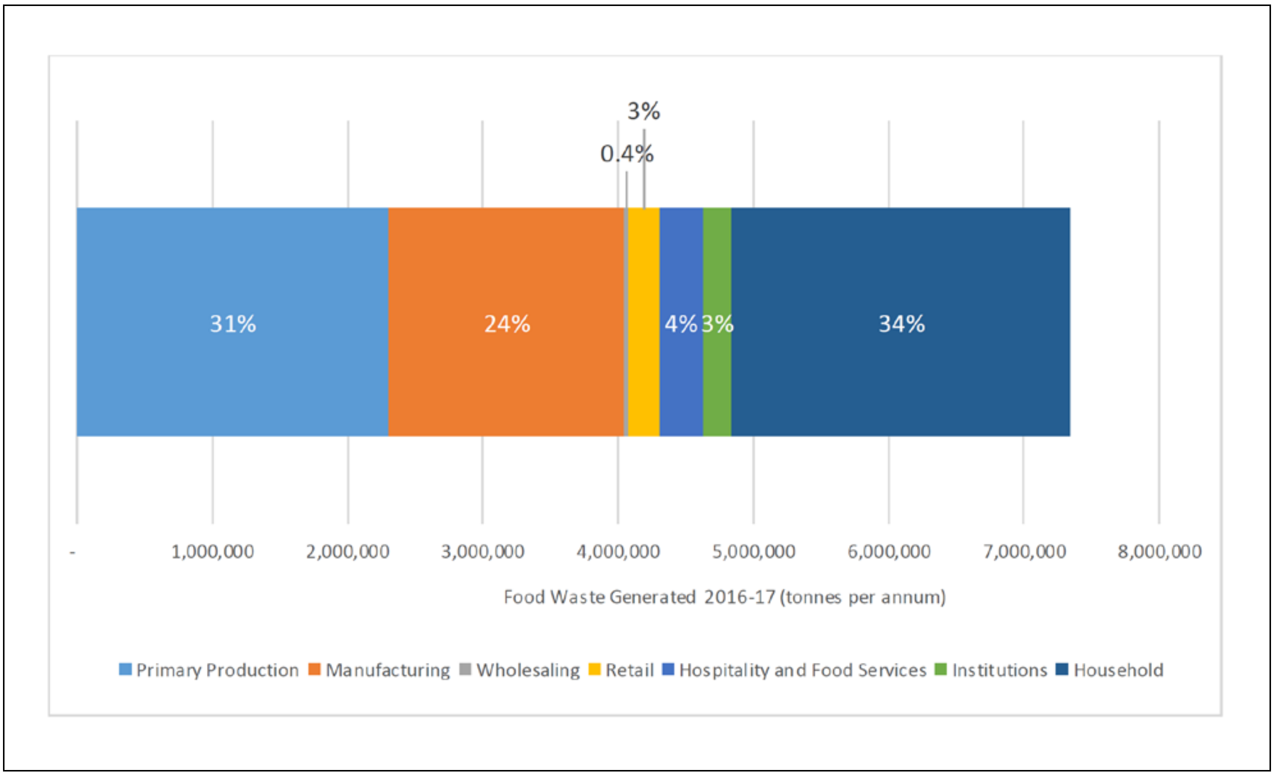
At least 7.3 million tonnes of food grown in Australia was wasted in 2016-17, equating to almost 290 kilograms per capita (DoEE 2019a).

This study is concerned with the causes of food waste within the refrigerated cold food chain in Australia and suggests ways to avoid or reduce these losses.

The growth of microorganisms and the rate of chemical changes in food are two of the main causes of perishable food spoilage. Controlled refrigeration can substantially slow the rate at which food deteriorates, increasing its post-harvest life from just a few days to weeks or even months.

Households and primary production are estimated to be the largest waste generating sectors, together accounting for 65% of national food waste. Another 24% of wastage occurs in food manufacturing.

Figure 1: National Food Waste Baseline Study estimate of food waste generation by sector, 2016-17



(Source: DoEE 2019a)

Table 1 shows production volumes of refrigeration-dependent agricultural produce, including export volumes and values as well as minimum estimates of waste volumes and values.

Table 1: Summary of agriculture and foodstuff dependent on refrigeration per annum

<table>
<tr><th></th><th>Production volumes</th><th>Production values</th><th>Export volumes</th><th>Export values</th><th colspan="2">Food loss and waste in cold chain</th></tr>
<tr><th></th><th>(million tonnes)</th><th>($ billion)</th><th>(million tonnes)</th><th>($ billion)</th><th>(million tonnes)</th><th>($ billion)</th></tr>
<tr><td>Fruit</td><td>4.575</td><td>$7.030</td><td>0.541</td><td>$1.878</td><td rowspan="2">1.931</td><td rowspan="2">$2.96</td></tr>
<tr><td>Vegetables</td><td>3.695</td><td>$4.346</td><td>0.206</td><td>$0.255</td></tr>
<tr><td>Meat</td><td>4.583</td><td>$19.819</td><td>2.167</td><td>$11.440</td><td>0.155</td><td>$0.67</td></tr>
<tr><td>Seafood</td><td>0.237</td><td>$2.903</td><td>0.052</td><td>$1.433</td><td>0.009</td><td>$0.09</td></tr>
<tr><td>Dairy products and eggs</td><td>10.264</td><td>$8.898</td><td>0.843</td><td>$3.438</td><td>0.088</td><td>$0.07</td></tr>
<tr><td>Totals</td><td>23.354</td><td>$42.996</td><td>3.809</td><td>$18.445</td><td>2.183</td><td>$3.79</td></tr>
</table>

(Sources: ABARES 2018a to ABARES 2018e, ABARES 2019, ABS 5386.0 2019, ABS 7121.0 2019, ABS 7215.0 2019, ABS 7503.0 2019) Note: Quantity and value data in most instances relate to the year ended 30 June 2018, with some 30 June 2017, and includes some forecasts for 2017-18 FY by ABARES.

This study concludes there is significant food waste in the supply lines at the wholesale stage, at retail, and in hospitality. At least some of these losses can be avoided by better refrigeration practices. Food damage is also more likely to occur in the transport and handling of refrigerated product than at other stationary points in the cold food chain and the losses from previously poorly handled food result in food losses at the consumer end despite the triggering event occurring earlier in the supply chain.

The major sub-par practices that contribute to cold food waste and the opportunities for improvements in the cold food chain are included in Section 5 of this study.

3 Scope of this study

This study uses the term ‘food waste’ to encompass both food waste and food loss.

The United Nations Environment Programme (UNEP) definitions of food loss and food waste are:

Food loss refers to food that gets spilled, spoilt or otherwise lost, or incurs reduction of quality and value during its process in the food supply chain before it reaches its final product stage. Food loss typically takes place at production, post-harvest, processing and distribution stages in the food supply chain.

Food waste refers to food that completes the food supply chain up to a final product, of good quality and fit for consumption, but still doesn't get consumed because it is discarded, whether or not after it is left to spoil or expire. Food waste typically (but not exclusively) takes place at retail and consumption stages in the food supply chain.

Australia’s National Food Waste Strategy adopts a broad and inclusive definition of food waste that covers solid or liquid foodstuff that is intended for human consumption and does not reach the consumer or reaches the consumer but is thrown away.

This study examines food that does not reach the consumer and is thrown away due to failures in the refrigerated food cold chain.

The food waste boundaries within the cold food chain are illustrated in four main food sectors – fruit and vegetables, meat, seafood, and dairy and eggs in *Appendix B*. The boundaries capture the components of the cold food chain before the food reaches the consumer.

3.1 Refrigerated cold food chain

The refrigerated cold chain maintains perishable food within a desired temperature range. It is used to preserve food and to extend and ensure produce shelf life.

Refrigeration is used in a multi-channel supply chain that moves food from field to market involving numerous participants with a wide range of skill sets. The sheer number of farms, wholesalers, food retail outlets and eateries illustrate the complexity of the supply chain and logistical challenge faced by refrigerated transport and the potential for time and temperature issues.

The broad boundaries of the refrigerated cold food chain and this study are:

- primary produce – on farm harvesting or at the abattoir
- seafood sector – on a fishing trawler or an aquaculture farm
- food losses on the farm, secondary processing, transport through the cold chain, retailing and food service channels
- wholesale storage facilities, intermediaries to food service channels, independent cold storage and distribution, central distribution centres of major supermarket chains
- transport in refrigerated vehicles fit for purpose, sub-optimal refrigerated transport and non-refrigerated transport.

Some of these elements of the supply chain can be vertically integrated, where one company controls several steps from primary production through manufacturing, storage and transport.

Areas excluded from this study:

- food sectors and produce not dependent on refrigeration such as grains, cereals, oils and bakery[1]
- food waste at the point of consumption and failure of the cold food chain at the consumer end
- non-perishable drinks (alcoholic) – except perishable fruit juices
- transport of food by the consumer from the retailer to the household, typically by passenger vehicle.

The study does not identify the destinations of food waste such as food rescue, animal feed, bio-based materials, anaerobic digestion, composting, food ploughed in at the farm, disposal or landfill. When calculating emissions this study assumes all waste goes to landfill.

[1] *Some pastry and bakery processes include refrigeration such as walk-in cold rooms.*

4 Food sector profiles

This study focusses on the specific cold chain requirements for effective management of different food sectors by identifying food groups with common optimal refrigerated conditions.

The following sections investigate the nature of the refrigeration tasks within each of the four main food sectors used in this study – fruit and vegetables, meat products, seafood and dairy (including eggs).

4.1 Fruit and vegetable sector

4.1.1 Supply chain profile

Australia produced 8.2 million tonnes of fruit (including wine grapes), vegetables and nuts in 2018, of which 9% was for export. Some fruits are processed into juices. Of the 400 million litres of fruit juice consumed in 2018, more than two thirds were Australian produced (Statista 2019 and HIA 2019).

The role of the cold chain in the supply of fruit and vegetables is expanding, with increasing volumes picked early and ripened in climate controlled environments, which allows control over the timing of the ripening process and can reduce waste in the supply chain.

Table 2: Main types of fruit and vegetable produce

	Number of businesses	Production volumes (million tonnes)	Production value ($ billion)	Average value ($ per tonne)	Fresh export volume (million tonnes)	Fresh export value ($ billion)
Fruit	5,790	2.658	$5.015	$1,887	0.444	$1.085
Vegetable	3,810	3.695	$4.346	$1,176	0.206	$0.255
Wine grapes	3,260	1.660	$0.971	$585	n/a	n/a
Nuts	-	0.189	$0.987	$5,226	0.096	$0.793
Total	-	8.201	$11.320	-	0.746	$2.133

(Sources: HIA 2019, ABARES 2018a, ABS 7121.0 2018, ABS 7121.0 2019, and ABS 7503.0 2019, refer to *Section 9.3* for detailed notes on sources, definitions and assumptions)

Food waste of fruit and vegetables can be caused by factors other than, but related to, temperature management, such as storage humidity, respiration rates, amounts of ethylene released and sensitivity to ethylene during transport. These are topics that would benefit from further research and developing guidelines for transport of mixed foodstuffs with different and interactive characteristics. For example, five days storage of cabbage at 5°C results in the same amount of deterioration due to respiration as nine days storage at 0°C (AFCCC 2019a).

4.1.2 Role of the cold food chain

The primary role of refrigeration is in storage, transport and retailing of fresh produce in walk-in cold rooms, refrigerated transport vehicles, cold storage facilities, refrigerated display cabinets for retailing and refrigerated storage cabinets in food service channels.

Refrigerated storage of fresh fruit and vegetables is critical as it slows the products' natural ripening process and inhibits the growth of microorganisms and eventual decay that damages produce.

Main causes of food waste are:

<u>Farm to secondary food processor or retail:</u>

- damage from pests after harvest
- moulds and bacteria
- cold storage malfunction
- inadequate temperature and humidity control
- poor inventory management (for example, not putting oldest out first)
- technical transport malfunction
- failure to maintain proper shipment temperature
- logistical transport issues (for example, incorrect goods loaded and transported that are uneconomical to return)
- food rejected by receiving party (for example, product out of size, shape or appearance specification)
- excessive trimming of vegetables for retail or food processing to ensure acceptable size or shape
- rejection for aesthetic reasons
- configuration of pallets – for example, stabiliser sheets blocking airflow and creating hot spots in container
- switching off transport refrigeration systems to save fuel
- insufficient cooling capacity to cool down produce prior to loading into truck (incorrect loading temperature)
- not enough refrigerated vehicles during peak season
- logistical issues such as missing a time slot, incorrect consignment paperwork or shipping the wrong product – sometimes more economical to dump rather than return.

<u>Retail including supermarkets and greengrocers:</u>

- packaging failure
- culling of edible products because of appearance
- large quantities on display and a wide range of products which are more at risk of being wasted before being sold
- inadequate temperature management in loading bay, cold rooms or display cases
- inadequate cold storage
- over-ordering due to difficulty predicting consumer demand.

One large supermarket chain confirmed that the majority of food waste in supermarkets is fruit and vegetables. Once refrigerated and past their use-by date they are typically sent to landfill. Some may be diverted to animal feed or to composting, which may be a viable alternative to avoid landfill and emissions.

The fruit and vegetable sector generates the biggest losses, as a percentage of production volume from primary production. *Mapping Australian Fruit and Vegetable Losses Pre-retail* (CSIRO 2019)[2] found that fruit and vegetable losses incurred prior to reaching the market ranged between 18% and 22% of the total reported fruit and vegetable primary production (on farm and packing houses), amounting to up to 1,456,000 tonnes.

[2] *https://publications.csiro.au/publications/#publication/PIcsiro:EP191660*

According to the United Nations Food and Agriculture Organization (FAO) around 45% of fruit and vegetables harvested globally is either lost or wasted along the supply chain.[3]

This study assumes losses prior to purchase by consumers of 38%, which is consistent with the estimate by the Food and Agriculture Organization of the United Nations (FAO 2011).

With no empirical research available, this study assumes that three quarters of this waste can be attributed to sub-par refrigeration technology, practices and processes, equating to 29% of total production, or more than 1,930,000 tonnes of fruit and vegetables annually, worth more than $3.76 billion at farm gate value.

An estimate of the agricultural and landfill impacts on the environment (including, for example, emissions from fuel used on-farm, fertiliser use, emissions from methane and nitrous oxide and land use but excluding post-harvest handling, storage, processing, transport and consumption) attributed to fruit and vegetable food waste in the cold food chain is greenhouse gas emissions of 3.04 Mt CO_2-e per annum. This uses the World Business Council for Sustainable Development's Food Loss and Waste Value calculator.

Refer to *Section 9.2 Food waste assumption and factors,* for emission factor assumptions for different food types.

4.2 Meat sector

4.2.1 Supply chain profile

Meat and poultry are the most refrigeration-intensive industries. Their supply chains are subject to the most intensive standards and regulatory scrutiny.

The four main meat types (*Table 3*) in order of production volumes in Australia are beef and veal (49%), poultry (26%), sheep (16%) and pork (9%). Other meat types including wild harvested kangaroo, goat, and deer account for less than 0.1% of annual production.

Approximately 36% of Australia's meat production by volume is for export, which was worth about $11.44 billion in 2018. At the same time Australia imported approximately $230 million worth of fresh, frozen, salted and preserved meat products (ABS 5368.0 2019).

Table 3: Main types of meat produce

	Number of farms	Production volumes (million tonnes)	Farm gate value ($ billion)	Average value ($ per tonne)	Export volume (million tonnes)	Export value ($ billion)
Beef and veal	44,119	2.238	$12.019	$5,372	1.123	$7.963
Sheep meat	10,315	0.735	$3.970	$5,402	0.457	$3.283
Poultry	1,040	1.193	$2.682	$2,248	0.037	$0.065
Pork	881	0.417	$1.145	$2,745	0.035	$0.133
Total		4.583	$19.819		1.652	$11.44

(Sources: ABARES 2018b, ABS 8165.0 2019, ABS 7503.0 2019, ABS 7215.0 2019, refer to *Section 9.3* for detailed notes on sources, definitions and assumptions)

[3] *http://www.fao.org/save-food/resources/keyfindings/infographics/fruit/en/*

4.2.2 Role of the cold food chain

The Australian meat industry produces meat products with shelf life ranging from a few days (entire cuts, roasts and ground meats) to several months (vacuum-packed) to more than one year (frozen meat).[4]

The refrigerated cold food chain starts at the abattoir where the control of refrigerating conditions is critical because of its impact on product quality and its role in minimising bacterial load on the product throughout the rest of the supply chain.

Refrigeration requirements in abattoirs and meat processing facilities include:

- intensive refrigeration for carcass chilling and freezing
- positive pressurisation and heat loads for cooling, wash down and steam extraction on the abattoir kill floor
- blast freezing to rapidly freeze large quantities of product in a short time, creating low temperature thermal stability and maximising shelf life
- stable boning room temperatures to ensure product quality, product yield, condensation control and operator comfort
- spray chilling carcases to prevent dehydration and shrinkage.

The objective of chilling carcases immediately after slaughter is to cool the meat quickly enough to prevent bacterial growth, but not so quickly as to cause toughening of the meat.

Most hazard analysis and critical control points (HACCP) plans for production of chilled carcasses and carcass parts, including cartons or packages of the product, nominate chilling as a critical control point.

High pH meat such as lamb will spoil faster than meat with a pH of 5.3 to 5.7 and the storage life can also be reduced by high initial levels of bacterial contamination on the surface of the meat because spoilage numbers of bacteria are reached sooner. The initial load on carcasses is made up of a wide range of bacteria, many of which do not grow on meat and others that will not grow under refrigerated conditions. Further, the types of bacteria initially present can change with geographical location and climate (MLA 2016).

Generally, beef will keep longer than lamb, because lamb carcasses tend to have higher initial numbers of bacteria due to differences in slaughter and dressing processes.

Meat & Livestock Australia (MLA) recommends that chilled red meat should be stored as cold as possible to maximise the storage period and that a temperature of -1°C to 0°C is desirable and practical (MLA 2016).

Optimal storage temperatures of the majority of fresh meats listed in the *Best Practice Guide for Energy Efficient Walk-in Cold-Rooms* (Australian Institute of Refrigeration Air conditioning and Heating [AIRAH]) range from -2ºC to 1ºC with a relative humidity above 85%, whereas the temperature range of supermarket and food retail meat cases is -1ºC to 4ºC (M0 temperature class defined in *ISO 23953, Refrigerated Display Cabinets).*

Freezing meat can increase its shelf life to more than one year which can assist with seasonal demands and export. For example, hams and turkeys are frozen and placed in cold storage to satisfy the high demands in the weeks leading up to Christmas.

[4] *Shelf life of Australian red meat, Second Edition, Meat & Livestock Australia, August 2016 (MLA 2016)*

Meat & Livestock Australia states that the Australian industry's experience is that accepted shelf life times are very conservative, claiming, for example, that frozen manufacturing beef usually has 24 months shelf life at -18°C. The International Institute of Refrigeration recommends the same temperature of -18°C for deep frozen food.

Dry aging meat is another meat processing technique that is refrigeration intensive, with a high value add to the final product. This is a very precise process that requires consistent airflow and specific storage temperature.

There are almost 150 meat and poultry processing facilities in Australia.[5] Following processing, the supply chain for meat products is not dissimilar to many other food stuffs as most meat is delivered to butchers deboned and to retailers packaged.

4.2.3 Sources of waste

Main causes of food waste are:

<u>Farm to retail:</u>

- packaging failure
- cold storage malfunction
- poor inventory management with frozen foods (for example, not putting oldest out first)
- transport malfunction and/or transport refrigeration not at optimal temperature
- inefficient practices and inadequate refrigeration at loading docks resulting in time and temperature issues
- rejection of meat for food safety reasons (for example, pathogen contamination).

<u>Retail including supermarkets and butchers:</u>

- packaging failure
- inadequate temperature management in loading bays, cold rooms or retail display cases
- discarding product due to unappealing colour changes
- over-ordering due to difficulty predicting consumer demand
- spoilage as a result of reaching critical bacterial loads
- confusion regarding use-by or best-before dates.

While there is no specific hard data on food waste attributed to refrigeration aspects of the cold food chain in Australia, the Food and Agriculture Organization estimates that globally, around 20% of meat is either lost or wasted along the supply chain[6] (Food and Agriculture Organization 2011).

The Red Meat Advisory Council has developed a 10-year strategic plan that encompasses supply chain efficiency and integrity including waste management. No hard data of loss and waste rates is available (RMAC 2018). This study found meat waste in the supply chain was around 13% and in the absence of hard data, it is assumed that a quarter of this waste is attributed to sub-par refrigeration equipment, practices and processes.

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[5] *ABS 8165.0 Counts of Australian Businesses, as of June 2018 and includes codes 1111 Meat Processing and 1112 Poultry Processing. There were 52 business with more than 200 employees and 96 businesses with more than 20 and less than 200 employees. There were a further 710 businesses that were classified as non-employing or with less than 20 employees that are unlikely to have sufficient scale for an ammonia plant.*

[6] *http://www.fao.org/save-food/resources/keyfindings/infographics/meat/en/*

This level of waste equates to almost 155,000 tonnes of meat annually worth $670 million dollars at farm gate value.

An estimate of the agricultural and landfill impacts (including, for example, emissions from fuel used on-farm, fertiliser use, emissions of methane and nitrous oxide and land use, and excluding post-harvest handling, storage, processing, transport and consumption) attributed to waste of meat in the cold food chain is greenhouse gas emissions of 3.46 Mt CO_2-e per annum. This uses the World Business Council for Sustainable Development's Food Loss and Waste Value calculator.

Refer to *Section 9.2 Food waste assumption and factors,* for emission factor assumptions for different food types.

4.3 Seafood sector

4.3.1 Supply chain profile

The three main seafood types in order of production volumes are fish (74%), crustaceans (16%) and molluscs (10%).

Approximately 22% of Australia's seafood product by volume is exported, valued at $1.433 billion in 2018. At the same time, Australia imported seafood products (including fresh, frozen, salted and preserved) to the value of $1.41 billion based on customs value (ABS 5368.0 2019).

The seafood supply chain is refrigeration intensive, the key segments being the primary production stage, the manufacturing stage of seafood processing and the distribution and retail stages.

A wide range of seafood products are processed in Australia, including crustaceans, molluscs and oysters, fish fillets, preserved scallops, seafood paste and pate, canned fish, dried or smoked fish, canned mixed seafood, preserved seafood and whole frozen fish.

The distribution and retail stage for the majority of seafood products involves management of fresh and frozen seafood which generally has a very short shelf life (fresh ≤1 week – frozen ≤3 weeks).

Unlike many countries, Australia's seafood supply exceeds demand. High global prices see premium fresh fish, crustacean and mollusc products exported, generally by refrigerated air freight. Imports are dominated by lower value products such as frozen fillets, frozen prawns and canned fish, predominantly from Thailand, New Zealand, Vietnam and China.

Given the reliance of the fisheries industry on control of refrigerating conditions along the supply chain, this industry would almost certainly be open to cost effective technological improvements to refrigeration technology or practices that improve product life.

Table 4: Main types of seafood produce

	Production volumes (million tonnes)	Production gross value ($ billion)	Average value ($ per tonne)	Export volume (million tonnes)	Export value ($ billion)
Fish	0.175	$1.408	$8,060	0.032	$0.381
Crustaceans	0.038	$1.063	$27,942	0.015	$0.783
Molluscs	0.024	$0.380	$12,679	0.003	$0.187
Others	-	$0.052	-	0.002	$0.082
Total	0.237	$2.903		0.052	$1.433

(Sources: ABARES 2018c, refer to *Section 9.3* for detailed notes on sources, definitions and assumptions)

Employment in the Australian commercial fishing and aquaculture industry as of June 2017 comprised 7,500 employees in fishing and 8,350 in aquaculture with around three quarters full time and the balance part time (Australian Bureau of Agricultural and Resource Economics and Sciences ABARES 2018d).

As is the case with many food supply chains, more people are employed downstream in the distribution, transport, wholesaling and retailing of the food, than in the production of the food.

4.3.2 Role of the cold food chain

There are 400 and 450 commercial fishing vessels greater than 15 metres long which are likely to have substantial refrigeration systems. Smaller vessels typically use ice to chill their catch and return to port daily.

Land based seafood wholesale markets and processing facilities including freezing and canning are highly dependent on refrigeration.

4.3.3 Sources of waste

According to the Food and Agriculture Organization around 35% of seafood harvested globally is either lost or wasted along the supply chain.[7]

While there is no accurate data available for seafood loss or waste in Australia, wastage is estimated to total around 9,000 tonnes annually, worth almost $112 million at gross production value. Reports from seafood distributors indicate that with seafood such as prawns or lobster worth more than $20,000 per pallet, workers in this sector apply very disciplined processes to minimise waste. Therefore, this study attributes most of the loss and waste of seafood to transport and retail.

Main causes of food waste are:

- packing and mechanical damage during processing
- non-compliance with a quality standard where the product fails to meet essential quality, composition and/or labelling provisions
- product branded as boneless, containing bones greater than or equal in length and diameter to specification
- pathological damage (such as diseases and parasites)
- transport refrigeration with multiple steps in the supply chain resulting in shortening the post-harvest lifespan
- inefficient practices and inadequate refrigeration at loading docks resulting in time and temperature issues
- seafood displayed on ice in retail stores, providing non-uniform storage temperatures that can result in waste.

Seafood is more likely to be wasted than other foods due to physiological defects. It is highly perishable and can give off strong smells that are not always associated with food safety risks but may raise safety and quality concerns.

Companies that process fish, such as canning, creating fish fingers and other crumbed or battered fish generate waste due to processing inefficiencies and practices.

An indication of the emission impacts (excluding post-harvest handling, storage, processing, transport and consumption) attributed to food waste in the cold food chain is greenhouse gas emissions of 0.03 Mt CO_2-e per annum. This uses the World Business Council for Sustainable Development Food Loss and Waste Value calculator.

[7] *http://www.fao.org/save-food/resources/keyfindings/infographics/fish/en/*

An estimate of the agricultural and landfill impacts (including, for example, emissions from fuel used on-farm, fertiliser use, emissions from methane and nitrous oxide and land use but excluding post-harvest handling, storage, processing, transport and consumption) attributed to food waste of seafood in the cold food chain is greenhouse gas emissions of 3.46 Mt CO_2-e per annum. This uses the World Business Council for Sustainable Development's Food Loss and Waste Value calculator.

Refer to *Section 9.2 Food waste assumption and factors*, for emission factor assumptions for different food types.

4.4 Dairy and egg sectors

4.4.1 Supply chain profile

The dairy industry is one of Australia's major rural industries. Based on a farm gate value of production of $4.3 billion in 2018, it ranks third behind the beef and wheat industries. It is estimated that approximately 42,600 people are directly employed on dairy farms and by dairy companies within Australia (DA 2018). Dairy produce includes fresh milk, and processed products such as butter, cheese, and milk powders.

Around 27% of milk produced in Australia is sold as fresh milk and the remaining 73% is used for manufacturing dairy products. Around 36% of Australian milk production is exported as butter, cheese and milk powders (DA 2018).

The processed dairy products in order of production volumes are cheese, skim milk powder, butter and whole milk powder. Approximately 49% of manufactured products (in milk equivalent terms) were exported in 2017-18 (DA 2018). The export value for all milk, dairy products and eggs was $3.67 billion in 2017–18.

Table 5: Main types of dairy produce and eggs

	Number of farms	Production volumes	Gross value	Average value	Export volume	Export value
Units	Number	Million litres	$ billion	Cents per litre	Million litres	$ billion
Milk	5,699	9,289 ml	$4.273	46 c/l	224.0 kt	$0.262
Dairy products						
Units		Kilo tonnes			Kilo tonnes	$ billion
Butter		92.7 kt			16.2 kt	$0.116
Cheese		378.0 kt			171.0 kt	$0.947
Yoghurt		231.2 kt			-	-
Skim milk powder (SMP)	n.a.	191 kt	n.a.	n.a.	157.0 kt	$0.454
Whole milk powder (WMP)		82.5 kt			48.7 kt	$0.293
Other dairy products		n.a.			227.0 kt	$1.350
Subtotal: dairy products		n.a.			619.4 kt	$3.160
Eggs						
Units	Number	Million dozen	$ billion	Cents per dozen	n/a	$ billion
Fresh eggs	399	360 md	$0.828	230 c/d	n/a	$0.016

(Sources: ABARES 2018e, ABARES 2019, ABS 5386.0 2019, ABS 7121.0 2019, refer to *Section 9.3* for detailed notes on sources, definitions and assumptions)

4.4.2 Role of the cold food chain

Dairy farmers are required to chill fresh milk from 34°C to 4°C prior to pick up by bulk tankers. The milk is refrigerated in large insulated vats, ranging in capacity from 5,000 to 40,000 litres. In order to guarantee milk quality standards, the milk must be chilled in less than four hours and be stored at 4°C for no more than three days. Maintaining milk and dairy products at or below this temperature will prevent or reduce bacterial growth and any bacterial toxin production.

Most dairy transport vehicles used for bulk milk transport are not refrigerated, but adequate tanker insulation and short transport journeys minimise growth of bacteria.

4.4.3 Sources of waste

According to the Food and Agriculture Organization around 20% of all milk produced globally is either lost or wasted along the supply chain.[8]

[8] *http://www.fao.org/save-food/resources/keyfindings/infographics/fish/en/*

There is no hard data available on milk or dairy waste in industrialised countries due to the cold food chain, and this study assumes that 1.0% of all dairy product is wasted due to deficiencies and breakage in the cold food chain. This equates to waste of around 170,000 tonnes worth more than $70 million of which 90% mass is liquid milk.

Main causes of food waste are:

- milk losses at dairies and processors during equipment washing, line changeovers and through product rejections
- cleaning-in-place systems required for flushing pipelines, vessels, filters and process equipment – processes with long pipe runs result in waste of up to 5%
- separating cream from the milk, which produces a liquid backflush residue known as ‘separator de-sludge’
- damage and breakage during distribution, transport and retailing
- large quantities in retail displays increasing the likelihood of use-by dates being reached before being sold.
- poor inventory management with frozen foods (for example, not putting oldest out first).

An estimate of the agricultural and landfill impacts (including, for example, emissions from fuel used on-farm, fertiliser use, emissions from methane and nitrous oxide and land use (excluding post-harvest handling, storage, processing, transport and consumption) attributed to dairy waste in the cold food chain is greenhouse gas emissions of 0.49 Mt CO_2-e per annum. This uses the World Business Council for Sustainable Development Food Loss and Waste Value calculator.

Refer to *Section 9.2 Food waste assumption and factors,* for emission factor assumptions for different food types.

5 Sub-par practices and opportunities for improvement

5.1 Sub-par practices

Sub-par practices in equipment operation and maintenance, and in product handling, can have drastic impacts on the shelf life and the value of food.

Even the slightest variation in the conditions of cold stored produce, particularly early in the supply chain when the goods are the greatest distance and time from the point of consumption, can result in costly spoilage or shortening of shelf life.

For example, a box of mangoes picked in Katherine in the Northern Territory might be handled and moved through stationary and mobile refrigerated spaces as many as 14 times by multiple owners, on its 3,400 km journey to a retail outlet in a Melbourne suburb. Any period of exposure to damaging temperatures (too high or too low) or to higher risk atmospheric conditions (high ethylene concentrations or high humidity that allows fungal growth), or simply rough handling that damages the product or the packaging, can dramatically reduce the shelf life and the value of the product.

Consistent and well understood handling and storage practices by participants along this supply chain are the key to delivery of high-quality product.

5.1.1 Fruit and vegetable sector specific practices

The fruit and vegetable sector is the least regulated food sector and has the highest waste rates and greatest opportunity for improvement from best practice refrigeration technology, processes and practices.

From the point of view of supply chain efficiency, resource management and greenhouse emissions, there is clearly a case in Australia to improve cold chain management of these perishable foods.

Major causes of loss:

- Peak harvest limitations: waste levels are generally higher in peak harvesting season when production is at its greatest and either overwhelms farm storage capacity or pushes it to its absolute limit. During peak harvest period for some crops, refrigerated transport capacity is inadequate resulting in product waiting on the farm for long periods post-harvest or being shipped without refrigeration.
- Inadequate pre-load cooling on farms: farms commonly do not have sufficient cooling capacity to properly cool produce to optimal preservation temperatures prior to loading into trucks. Transport refrigeration systems are not designed to lower core temperatures of product, but rather to keep them stable, if possible, at the loaded temperature.
- Inadequate refrigeration expertise and lack of uniform optimum product temperature knowledge: such knowledge is critical where higher or lower temperature is used to hasten or control ripening during transport to market.
- Functioning of refrigeration system, either stationary or mobile: greater maintenance attention is required when operating in dusty or high vibration environments.
- Combination of poor air flow and inappropriate mixed loads: one type of food can be exposed to damaging levels of off-gassing from another food. Airflow can be impeded due to design of trucks and how pallets are stacked.

5.1.2 Commonly observed failures with all food types

In September 2019 the Australian Food Cold Chain Council (AFCCC) conducted a focus group session to identify the most commonly observed failures that lead to a substantial source of food waste in the cold food chain.

After identifying 26 specific failure areas, it was agreed that the main challenge was largely about the product handling process and ensuring that people understood the process. Having effective and consistent processes adopted throughout the supply chain was considered the biggest issue and that ‘people’ were an integral part of any process. Training and education were listed prominently as being the key to achieving real improvements in the cold food chain to limit food loss and wastage.

Table 6: Cold food chain failures

Category of failure	Cold food chain failure
People	Lack of suitable training and education/materials for training
Process	Absence of a process for goods handling or insufficient or inadequate process
Process	Lack of ability to verify that a process has been maintained throughout the chain
Process	No means of identifying process failure through the chain
Process	Failure to understand or properly implement an existing process
Process	Lack of product traceability
Process	Lack of validation of post-harvest treatment prior to pick-up
Process	Overloading the trailer
Process	Incompatible mixed loads
Process	Incorrect segregation in mixed loads
Process	Lack of regular cleaning of refrigerated spaces
Process	Incorrect or absence of pre-chilling
Process	Poor packing/stacking/wrapping
Process	Operational pressures that force mixed loads
Process	Poor demand forecasting, leading to over-supply and therefore an extended timeframe between transit and consumption
Process	Excessive transit distances – sub-par distribution planning
Process	HACCP – not just about hygiene, but also temperature
Cargo	Incorrect or high pre-loading temperature
Infrastructure	Badly designed loading docks, time delays, weather/temperature exposure
Equipment	Training specific to equipment
Equipment	Lack of validation of refrigeration equipment and trailers
Equipment	Poor airflow in the trailer and packaging
Equipment	Lack of appropriate equipment at the right time
Equipment	Poorly repaired containers
Equipment	Poor maintenance
Equipment	Trailer age
Equipment	Poor air distribution in refrigerated space
Equipment	Poor trailer mapping

5.1.3 Lack of insulation specifications

Lack of standards for insulation of refrigerated spaces is one of the main reasons for poor equipment performance.

Australia has thermal insulation specifications and regulations covering the majority of built structures via the National Construction Code, yet there are no regulated insulation specifications for walk-in cold rooms, refrigerated vehicles or cold storage facilities.

The control of heat flow through insulated surfaces, effective external vapour sealing, and low air leakage are vital performance criteria for maintaining uniform and controlled conditions in refrigerated spaces.

The regulatory environment in Australia for refrigerated enclosures is disjointed across the jurisdictions and does not cover the thermal performance or efficiency of the main components of the cold food chain, or actively works against thermal efficiency.

- The maximum width of trucks in Australia is limited to 2.5 metres, compared to 2.6 metres in Europe and the United States. This impacts on the internal space needed to accommodate international standard pallet widths, meaning that Australian rigid body truck manufacturers are unable to produce truck bodies and containers to the same insulation standards as European manufacturers. Because of this width limit, container walls are limited to 38mm of insulation if two pallets are to be stacked side by side. With pallets at 1,170mm x 1,170mm, it leaves only 28mm of clearance between pallet and wall which is not enough for the average refrigerated load in Australia.
- Meat, poultry and seafood transport vehicles must be licensed in Victoria and New South Wales, but not elsewhere, with requirements to satisfy hygiene standards such as AS4696: 2017. However, there is no thermal insulation specification.
- Refrigerated trucks or vans are registered as trucks or light commercial vehicles by the transport authorities with no reference to refrigeration type, cooling capacity or insulation specification.
- There is no regulated insulation specification for window film for refrigerated delivery vans.
- Thermal performance and energy efficiency of walk-in cold rooms are unregulated, with no minimum requirements or standards.

5.2 Opportunities for best practice improvements

5.2.1 All food sectors

- Improved traceability throughout the cold chain:
  - Better record keeping identifying critical control points and monitoring temperature, humidity, shock and movements for consistency and compliance across the supply chain, from farm gate to retailer. This could be facilitated with emerging Internet of Things solutions.
  - Correct use of thermometers and evidence collected (such as geotagged photo) of product temperature of a representative sample on dispatch and receipt of goods.
  - Refrigerated transport monitoring programs to track the vehicle fleet and monitor the temperature inside vehicles at all times.
  - Use of time temperature integrators (see *Section 5.2.4)*.
- Improved equipment and insulation standards:
  - Refrigerated spaces including walk-in cold rooms, cold storage facilities and loading docks.
  - Best practice guides for design, installation, commissioning and maintenance.
  - Types of equipment used to measure interior and exterior temperatures, for equipment that is designed to operate below zero and specifies the maximum K coefficient for thermal characteristics (see *Section 5.2.4*).
  - Registration of refrigerated trucks or vans under a unique class stipulating specifications related to refrigeration type, cooling capacity and insulation specifications. Registration authorities could undertake inspections to check compliance with agreed specifications and standards.
- Refrigeration systems that work effectively, are well maintained, easy to operate, easy to interrogate on the shop floor and remotely, and understood by all users.
- Training and educational materials for the cold food chain, covering storage, handling, temperature measurement, packing and transporting, to be more widely available.

- Improved processes across the cold food chain that address the key issues highlighted by the Australian Food Cold Chain Council focus group outlined in *Section 5.1.2 Commonly observed failures.*

5.2.2 Example opportunities by food sector

Meat

- Greater use of vacuum packing and freezing will improve shelf life.
- Refrigeration display cases with doors can ensure that temperatures are uniformly maintained and will reduce losses due to unappealing meat colour changes. It will also increase the shelf life of products. In open display cases, temperature variations mean product is often exposed to sub-par conditions. A recent study published by researchers from France's National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA), demonstrated the improved shelf life of product displayed in refrigerated display cabinets with doors. The variation of temperatures in open display cases means product is often exposed to sub-optimal conditions which results in food waste at either the retailer or consumer end of the chain (IRSTEA 2019).

Seafood

- Improve cold storage practices when seafood is in transit or trading rooms. For example, seafood on display for wholesalers at the Sydney Fish Market is commonly not refrigerated, relying on cold spill from surrounding cold rooms to provide some cooling effect. This chilling effect is quickly negated by the high humidity of the trading floors that are almost always wet from wash-downs.
- If more fish were sold frozen instead of fresh, seafood spoilage would be reduced.
- Improved retailing practices – seafood displayed on ice in retail stores can be at non-uniform storage temperatures that can result in waste.

Fruit and vegetables

- Simple, safe and inexpensive post-harvest refrigeration technology, utilising cold shock treatment to manipulate physiological and biochemical activities could be a practical approach to extend the green life and shelf life of avocados during storage.[9]
  - Extending application of cold shock treatment for avocado which has high commercial value ($7,000 per tonne at farm gate) and a short post-harvest life (≤1 month). Avocados are immersed in ice water for 30 minutes, then subjected to natural or ethylene-induced ripening.

5.2.3 Australian Cold Chain Guidelines

The voluntary *Australian Cold Chain Guidelines, 2017* by the Australian Food & Grocery Council provides an industry guideline for all involved in the food chain to improve the safety and quality of chilled and frozen food. Although some aspects of the guide are no longer considered best practice, it provides signposts that the industry could use to improve the performance of the refrigerated supply chain, including:

Basic Concepts

To maintain the integrity of the cold chain three simple principles, apply:

1. Never warmer than: Specifies the maximum temperature at which food can be transported, stored and handled. Where chilled foods are concerned a minimum temperature or 'keep above' temperature should be specified to ensure food is not damaged by becoming frozen.
2. Maximum out of refrigeration: Specifies the length of time that a food product can be at a temperature that exceeds the maximum temperature specified without breaking cold chain conditions.

[9] *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5734781/*

3. First expiry first out: Stock rotation should be based on the first product to expire being the first out. This may not always be applicable because of stock being delivered in an incorrect date sequence.

Ignorance of these rules is considered to be the reason for the majority of damaging conditions leading to shortening of shelf life and food waste. They are common conditions covering all stages of refrigerated preservation.

Record keeping

Without good record keeping and effective 'chain of custody' documentation it is not possible to track if food products have been maintained within suitable cold chain conditions.

The Australian Food Waste Baseline Study found that many organisations do not have reporting frameworks to track their food losses by volume or economic value. Any data collected can be highly variable, with uncertain protocols on data management and food waste definitions.

Keeping effective records of the conditions of foodstuffs in the cold chain is fundamental and could also provide data for industry research.

Record keeping is essential to demonstrate compliance. During audits, records and logs are used to provide evidence that food safety and food quality standards have been met. In some jurisdictions, such record keeping may be mandatory.

Good records enable sound decisions to be made where the cold chain conditions have been broken.
A variety of certifications and standards impose requirements for different food types, some of them include:

- Certified HACCP-Based Food Safety Plans, includes Hazard Analysis and Critical Control Points (HACCP) risk assessment and implementation.
- *Australia New Zealand Food Standards Code*, is a series of legislative instruments that cover food standards and primary production standards for each food type (fruit and vegetables, different meat types, seafood, dairy products and eggs).[10]
- *AS4696: 2017, Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* 2007 and in export control orders.

Opportunities for improvement in sectors of the cold chain to reduce food waste

Temperature monitoring and recording improvements include:

- an efficient process of temperature measurement, monitoring, recording and verification
- clearly defined and documented responsibilities at critical control points
- essential training to resolve weak links in the cold chain
- temperature measuring and recording devices to be fit for purpose, accurate and calibrated to ensure accurate readings

Manufacturing improvements include:

- cold chain conditions set by manufacturers for manufactured food that is refrigeration dependent
- maximum and minimum temperatures and maximum out-of-refrigeration times documented and circulated
- temperature management processes to include how to identify problems and their resolution

[10] *https://www.foodstandards.gov.au/code/Pages/default.aspx*

- food products to be packaged in materials that are fit for purpose and clearly identified for traceability
- consumer packs to include information relating to product holding temperature and handling plus storage instructions to ensure durability, quality and safety after purchase
- priority goals for food processors to cover safety, quality, practicality and standardisation.

Despatch and delivery improvements include:

- despatch and transport operators working together at the point of despatch to ensure goods do not exceed specified temperature limits or maximum out-of-refrigeration time
    - despatch operators to record and document dates, times and recorded temperatures
    - documentation provided to transport operators to include maximum and minimum temperatures experienced by the product, and maximum out-of-refrigeration times
    - documentation to identify if, when, and under what conditions the cold chain has been broken
- transport and receiving operators working together at the point of receipt to ensure goods have not exceeded the specified temperature limits or maximum out-of-refrigeration time
    - transport operator to provide documentation to the receiving operator to show times, dates and recorded temperatures including maximum and minimum temperatures and maximum out-of-refrigeration times
    - documentation to identify if, when, and under what conditions the cold chain has been broken
- receiving operator to identify and record details of the goods for stock management including batch identification and date markings.

Transportation improvements include:

- strict schedule of equipment maintenance
- loading regulations to eliminate the risk of warm product creating heat transfer issues in mixed loads that could create microbiological hazard –refrigerated transports are designed to maintain temperature but are not expected or designed to significantly reduce product temperatures
- air circulation in refrigerated transports to ensure even temperature control, reduce risk of build-up of harmful gases and limit conditions conducive to microbiological activity
- vehicles to be designed and operated with adequate refrigeration capacity to ensure maximum and minimum temperatures and maximum out-of-refrigeration times are not exceeded
- in unrefrigerated vehicles ensure maximum and minimum temperatures and maximum out-of-refrigeration times are not exceeded.

Storage and warehousing improvements include:

- training to ensure key issues of air circulation, temperature control and record keeping are understood and specifications are adhered to
- storage areas not to be over-packed and have adequate air circulation around product and between walls, floors and ceiling – the default rule is minimum 16cm from walls and floors and 60cm from ceilings
- door openings and traffic movement to be kept to a minimum to maintain temperature
- adhere to stock rotation policies.

Retail outlet improvements include:

- training for staff and managers to ensure they understand, identify and act on breaches in the cold chain
- written procedures to detail actions to be taken in case of equipment or power failure
- regular maintenance and cleaning of refrigerated display cases in retail environments to reduce build-up of microbiological loads and to ensure adequate refrigerated preservation
- temperature monitoring and record keeping as essential components of cold chain management
- maximum and minimum temperatures and maximum out-of-refrigeration times not to be exceeded when loading display cases with product from the cold store.

Retail home delivery improvements include:

- maintaining cold chain conditions
- not exceeding maximum and minimum temperatures and maximum out-of-refrigeration times
- mandatory logging of temperatures and times.

Food service industry improvements include:

- temperature monitoring and record keeping procedures
- delivery and storage guidelines to be circulated to all staff
- stock rotation procedures to be documented and followed
- equipment maintenance schedules to be documented and followed
- caution to be exercised if storing cooked or ready-to-eat foods with uncooked foods.

Consumer education improvements include:

- constant consumer education to be the responsibility of all participants in the cold chain
- information to assist consumers to maintain the safety and quality of all refrigerated foods.

5.2.4 Product temperatures and use of thermometers

The safety and quality of chilled and frozen food depends on maintaining the food at the correct temperature to prevent or minimise the growth of pathogens and microorganisms that cause spoilage. Optimal temperature varies, depending on the product. Accuracy of temperature measurement is a key to cold chain management.

There are many different thermometer types and technologies for measuring the temperature of refrigerated product, so knowing which type of thermometer to use is a skill. For example, pointing an infrared thermometer used for non-contact temperature measurement at the packaging of a product is unlikely to provide a true indication of the product's real temperature.

Air temperature measurement can indicate whether refrigerated equipment is functioning correctly, but it cannot reflect the food temperature in that area as this depends on many parameters such as the food's thermal properties, packaging and airflow.

The best temperature measurement method for accurate product temperature is the core/pulp temperature, requiring the insertion of a thermometer's probe into the core of the product.

The quality, safety and shelf life of products can be maintained only if each party in the cold chain maintains the integrity of the chain, and records product temperatures at points of dispatch and on delivery.

Time temperature: Time temperature integrators are 'smart labels', simple devices attached to food that are capable of detecting and tracking temperature variations during a product's lifetime. These devices can be expected to optimise stock rotation, reduce waste, and provide shelf-life management from production to the consumer's table.

5.2.5 Transport refrigeration

In Australia there is a voluntary standard for refrigerated trucks and trailers *AS 4982:2003 R2016: Thermal performance of refrigerated transport equipment, specification and testing*, that covers the thermal performance of insulated equipment that is fitted with any type of refrigeration system and is intended for the transport of perishable goods by road. However, because the Australian standard is voluntary it has been largely ineffective. One factor is the split incentives between fleet owners and other parties that benefit from optimal insulation.

5.2.6 Walk-in cold rooms

A well-designed, installed and maintained cold room can minimise product spoilage, improve shelf life, reduce operation and maintenance costs, improve system reliability and safety, and deliver a longer system service life and better working environment for staff.

Because cold rooms are accessed frequently, door openings allow heat infiltration which has a negative impact on internal conditions which can result in food spoilage and increases energy consumption. Sometimes operators can unnecessarily leave doors open for hours at a time.

Best practice in the design, installation and operation of the walk-in cold room, including, for example, tight door seals, plastic strip curtains, automatic door closers or alarm systems and staff training on door management procedures, has been proven to achieve much narrower storage temperature bands, better food preservation and energy savings. Refer to the Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH) Best Practice Guide for Energy Efficient Walk-in Cold Rooms for guidance.

5.2.7 Cold storage facilities

Many cold storage facilities include a combination of chilled and frozen stores within the same facility or even multiple temperature zones inside single storage rooms to accommodate different products that require different temperatures.

The largest new-generation facilities feature a high level of automation with high bay designs which allow more efficient use of space and stock movements with unmanned stacker cranes, conveyors and automated truck unloading systems.

In frozen storerooms, food safety is not an issue provided the room temperature is maintained below -10ºC, which is the temperature generally accepted as the threshold for microbe growth.
However, food quality changes can occur if food is stored below its glass transition temperature (the temperature at which water can be frozen no further). For most food types the glass transition temperature is below -30°C. Most frozen storage facilities will operate at between -18°C and -22°C (IIR 2018).

5.3 Improve product longevity

The most common method to extend product longevity and expand market reach is by freezing fresh produce. There are many examples where the post-harvest life of fresh produce of less than three weeks can be extended to six or twelve months by freezing:

- wild catch prawns snap frozen on trawlers and stored at -30ºC on board and marketed as fresh months later or held to meet peak demand periods
- fresh fish post-harvest life is 1 to 2 weeks, but frozen fish is good for 6 to 12 months

- tuna from Port Lincoln vacuum packed and deep frozen to -60°C before being transported by road to Adelaide and then distributed throughout Australia or air freighted overseas[11] – the super-cooled freezing process uses liquid nitrogen technology which maintains the tuna in prime condition for use as sashimi without consumers suspecting it had been frozen[12]
- hams for the Christmas trade frozen well beforehand to accommodate the seasonal peak – fresh pork post-harvest life is less than a week, whereas frozen ham can be stored from 4 to 8 months
- snap freezing vegetables can extend shelf life
- freezing fruits means produce can be shipped via sea freight
- cryogenic freezing of fresh fruits, using liquid nitrogen, is the best method of preserving quality during frozen storage[13] whereas traditional freezing of products has some impacts
- greater use of vacuum-packed primal cuts of beef will improve product longevity and reduce meat waste.

Dry Ice
Dry ice can keep product very cold over extended periods. Convenience and weight loss meals commonly use dry ice. Meals packed in a sealed styrofoam box, partitioned for frozen and chilled foods, containing dry ice and a gel ice pack can sit on homeowner's doorstep all day without product degradation. One disadvantage is that as dry ice melts it turns into carbon dioxide, removing oxygen from the container which can affect some food products.

Eutectic Gel
Eutectic gel is used to protect heat-sensitive products such as food and pharmaceuticals during refrigerated transportation.
Eutectic gels maintain temperatures over longer periods and can be used several times. They are not toxic, do not contain gas or sensitising and mutagenic materials, and can be used in contact with foods. They are flexible and available in different sizes which make them convenient.

Ethylene absorption technology
All fruits release small amounts of ethylene during growth and some release much larger amounts during ripening. Excess ethylene emissions can accelerate the ripening process, resulting in food waste.

Ethylene levels and the rate of ripening can be reduced using air hygiene satchels or sheets that absorb moisture from the air to environmentally activate and release a reactive oxygen species vapour into the refrigerated space. The ethylene molecules are attacked by the vapour and under the right conditions oxidise to carbon dioxide and water.

There is growing interest in ethylene absorbers for packaging where they can be embedded into paper bags or corrugated fibreboard packaging used for fruit and vegetable storage and transport.[14]

[11] *https://www.abc.net.au/news/2019-07-17/tuna-available-all-year-thanks-to-new-freezing-technology/11310140*
[12] *https://www.frdc.com.au/media-publications/fish/FISH-Vol-24-1/Port-Lincoln-rides-the-tuna-tide*
[13] *https://www.sciencedirect.com/science/article/pii/S1658077X15300783*
[14] *https://www.sciencedirect.com/topics/food-science/ethylene-absorbers*

6 Future research

This study of waste in the cold food chain and opportunities for improvement identifies the scale and technical degree of difficulty in reducing food losses and waste. This initial research needs to be followed up to resolve data gaps and add to knowledge.

Recommended tasks and research:

- annual collection and publication of the key metrics of food waste in the cold chain to help identify data gaps, and to track industry performance
- encourage industry to collect better data and improve reporting
- targeted case studies in problematic areas where there are significant opportunities for improvement
- review of emission factors used to calculate the climate change impacts associated with food waste – available Australian emission factors and methods for calculating agricultural impacts (kg CO_2-e per tonne of a food type), land fill impacts (kg CO_2-e per tonne of a food type) and additional lifecycle impacts (based on losses at post-harvest handling and storage, processing, packaging and distribution)
- implementation and demonstration of selected best practice refrigeration initiatives.

There is scope to expand and deepen the understanding of compatible food types and groups to include other considerations such as:

- respiration and transpiration of fruit and vegetables
- amount of ethylene released by each fruit type
- which fruit and vegetables benefit from controlled environments of CO_2 or O_2 and the levels for optimal conditions
- supply chain complexity that assesses the number of steps in the cold chain and their food waste risks
- the way in which shelf life is assigned to food groups and communicated to consumers – simple labelling information declaring ‘use-by’ and ‘best-before’ dates.

7 Taxonomy, data collection, methodology

A data collection method has been developed for refrigeration dependent agricultural products and foodstuffs.

The Cold Chain Food Loss & Waste Taxonomy comprises:

1. List of agricultural produce and foodstuffs

A comprehensive list of food types and food properties (storage temperature, humidity and approximate post-harvest life) was created from the food properties requirements in Australian Institute of Refrigeration, Air conditioning and Heating (AIRAH) Best Practice Guide for Energy Efficient Walk-in Cold-rooms, a reference which itself was derived from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook: Refrigeration: 2018.

Based on commonly accepted but approximate post-harvest life, foods are grouped into post-harvest categories to identify which food types have a shorter life (i.e. ≤3 Days; ≤1 Week or ≤2 Weeks) and therefore which pose higher risk of spoilage compared to food types with a longer life (i.e. ≤6 Months or > 1 Year).

2. Retail display case temperatures

Supermarket and food retail refrigeration display cases (RDCs) are classified into types and operating temperature ranges defined by *ISO 23953 Refrigerated display cabinets and commercial beverage coolers*. CC FLW Taxonomy groups food types into RDC temperature classes defined by *ISO 23953* as follows:

- Meat: Fresh: M0 (-1ºC to 4ºC)
- Seafood: M0 (-1ºC to 4ºC)
- Dairy: M1 (-1ºC to 5ºC)
- Deli: M1 (-1ºC to 5ºC)
- Seafood: >4ºC
- Drink: M2 (-1ºC to 7ºC)
- Produce – fruit and berries: M2 (-1ºC to 7ºC)
- Produce – fruit and berries: H1 (+10ºC to +1ºC)
- Produce: >10ºC
- Produce: Vegetable: M2 (-1ºC to 7ºC)
- Produce: Vegetable: H1 (+10ºC to +1ºC to 10ºC)
- Produce: >10ºC
- Frozen: L1 (-18ºC to -23ºC)
- Dry goods: ≤10ºC
- Dry goods: >10ºC.

3. Fruit and vegetable storage temperatures

There is opportunity for fruit and vegetables to be stored and transported in common temperature baskets.

The initial assessment uses the following:

- Temperature Basket A: ≤ 2ºC
- Temperature Basket B: ≤ 4ºC
- Temperature Basket C: ≤ 10ºC
- Temperature Basket D: ≤ 16ºC

Temperature is only one of many factors that can affect the condition and quality of fresh produce during storage and transit. Other factors include humidity, respiration rates, amounts of ethylene released, and knowledge of which products are sensitive to ethylene during transport.

4. Production and export volumes and values

This data collates and aggregates production and export volumes in million tonnes and litres, and values of each major food sector, category and sub-category.

5. Food waste rates

Food waste rates are provided in *Appendix B*, which includes notes on the sources and assumptions for each food category, sub-category and specific food types where data is available.

Multiplication of the production volumes by the total food waste factor provides an estimate of food waste for each major food sector, category and sub-category in volume (tonnes or litres) and farmgate value ($).

6. Climate change impact factors

The refrigerated cold food chain produces indirect emissions from electricity consumption of equipment, consumption of liquid fuels for transport and direct emissions from leakage of refrigerant.

Climate change impacts associated with food waste include other emissions such as agricultural impacts (kg CO_2-e per tonne of a food type), land fill impacts (kg CO_2-e per tonne of a food type) and additional lifecycle impacts based on losses at post-harvest handling and storage, processing and packaging, and distribution.

Multiplication of the emission factors, as used in the FLW Calculator, by the food loss volumes for Australia for each food type calculates emissions attributed to food waste.

7.1 Major food sectors, categories and sub-categories

The major food sectors, categories and sub-categories align with the categories classified by the Australian Bureau of Statistics (ABS) and Australian and New Zealand Standard Industrial Classification (ANZSIC) (Table 4) that are dependent on refrigeration. This is also used in other publications by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and the Australian Horticulture Statistics Handbook.

7.2 Methodology

The definition of food waste and the methodology used in this report is based on the flexible framework under the international Food Loss and Waste Accounting and Reporting Standard (FLW Standard), Version 1.[15]

This standard was developed by the FLW Protocol for companies, countries, cities and others to quantify and report on food waste so they can develop targeted reduction strategies and realise the benefits of tackling this inefficiency.

The FLW Protocol is a global multi-stakeholder partnership led by a steering committee of seven expert institutions including the Consumer Goods Forum (CGF), the Food and Agriculture Organization of the United Nations (FAO), EU-FUSIONS, the United Nations Environment Programme, the World Business Council for Sustainable Development (WBCSD), the Waste & Resources Action Programme (WRAP), and the World Resources Institute (WRI) which serves as the secretariat.

This study largely adopts boundaries, definitions and methods consistent with the FLW Protocol and preferences publications, research and opinions based on the FLW Reporting Standard and methodologies.

The scope of this study covers the full extent of the Australian food supply and consumption chain and encompasses the key food sectors classified by the Australian Bureau of Statistics (ABS) and Australian and New Zealand Standard Industrial Classification (ANZSIC) (Table 4) that are dependent on refrigeration.

The four broad food sectors defined in ANZSIC are fruit and vegetables, meat, seafood, and dairy and eggs which includes liquid milk, cheese, butter and other processed products.

In this report fruit and vegetables are addressed as one supply chain.

[15] *https://www.flwprotocol.org/wp-content/uploads/2019/03/FLW_Standard_Exec_Summary.pdf*

References

AACS 2018	Australasian Association of Convenience Stores State of the Industry Report 2017, published April 2018.
ABARES 2018a	Agricultural commodity statistics 2018, Fruit, nuts and vegetables, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, December 2018.
ABARES 2018b	Agricultural commodity statistics 2018, Meats and dairy, September Quarter 2018, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, 2018.
ABARES 2018c	Fisheries Statistics - Agricultural commodity, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, March 2018.
ABARES 2018d	Australian fisheries and aquaculture statistics 2017, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, December 2018.
ABARES 2018e	Agricultural commodity statistics 2018, Tables 6: Dairy, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, December 2018.
ABARES 2019	Agricultural commodities – June 2019, Tables 10 and 12: Dairy, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, 2019.
ABS 3101.0 2019	Australian Bureau of Statistics, catalogue 3101.0, Australian Demographic Statistics, population at September 2018, published March 2019.
ABS 5368.0 2019	Australian Bureau of Statistics, catalogue 5368.0, Table 13b, Merchandise Imports, Customs Value, 2019.
ABS 5386.0 2019	Australian Bureau of Statistics, catalogue 5368.0, International Trade in Goods and Services, Australia, Table 12b. Merchandise Exports, 2019.
ABS 7121.0 2019	Australian Bureau of Statistics, catalogue 7121.0, Agricultural Commodities, Australia- 2017-18, published April 2019.
ABS 7215.0 2019	Australian Bureau of Statistics, catalogue 7215.0, Livestock Products, Australia, Table 4: Chicken Meat Produced, 2019.
ABS 7503.0 2019	Australian Bureau of Statistics, catalogue 7503.0, Value of Agricultural Commodities Produced, Australia, 2017-18, published April 2019.
ABS 8165.0 2019	Australian Bureau of Statistics, catalogue 8165.0, Counts of Australian Businesses as at June 2018, published February 2019.
AFCCC 2019a	Cold Food Code: Guiding Principles of Fresh Produce Transport and Storage, by the Australian Food Cold Chain Council 2019.
AFCCC 2019b	Basic principles of Thermometers and How to Use Them, Australian Food Cold Chain Council 2019.
AIRAH 2019	Best Practice Guide for Energy Efficient Walk-in Cold-rooms, Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH), December 2019.
Arcadis 2019	National Food Waste Baseline, Arcadis Design & Consultancy, funding from the Australian Government’s National Environmental Science Program, 2019.
CSIRO 2019	Mapping Australian Fruit and Vegetable Losses Pre-retail, Cristiana Ambiel, Amanda Adell, Peerasak Sanguansri, Debra Krause, Thambaramala Gamage, Rodolfo Garcia-Flores and Pablo Juliano, June 2019.
DA 2018	Australian Dairy Industry In Focus 2018, Dairy Australia Limited, 2018.
DA 2014	The Australian approach, Dairy Food Safety by Dairy Australia, 2014.
Deloitte 2017	Assessing the Potential of the Cold Chain Sector to Reduce GHG Emissions through Food Waste Reduction, Deloitte Touche Tohmatsu Limited, January 2017.

DoEE 2019a	National Food Waste Baseline, Arcadis Design & Consultancy, funding from the Australian Government’s National Environmental Science Program, 2019.
DoEE 2019b	Cold Hard Facts 3: 2019, A study of the refrigeration and air conditioning industry in Australia and associated model, prepared by Expert Group for the Department of the Environment and Energy, Ozone and Synthetic Gas Team, November 2019.
DoEE 2019c	Data (i.e. bulk and pre-charged equipment import statistics by quantity, mass, species, licence holder, product category from 2006 to 2018) provided by the Department of the Environment and Energy, Ozone and Synthetic Gas Team, February 2019.
DoEE 2019d	Australian Energy Statistics 2018, Department of the Environment and Energy, March 2019.
FAO 2011	Global Food Losses and Food Waste, Extent, Causes and Prevention, Food and Agriculture Organization of the United Nations (FAO), 2011.
FLW 2016	Food Loss and Waste Accounting and Reporting Standard, Version 1.0, FLW Protocol Steering Committee and Authors, comprising the Consumer Goods Forum (CGF), the Food and Agriculture Organization of the United Nations (FAO), EU-FUSIONS, the United Nations Environment Programme, the World Business Council for Sustainable Development (WBCSD), the Waste & Resources Action Programme (WRAP), and the World Resources Institute (WRI). WRI serves as the Secretariat, 2016.
FSANZ 2009	Primary Production and Processing Standard for Dairy Products, Chapter 4 of the Australia New Zealand Food Standards Code (Australia only), Food Standards Australia New Zealand, 2009.
HIA 2019	Australian Horticulture Statistics Handbook: Vegetables, Fruit and Nuts, 2018, by Horticulture Innovation Australia, April 2019.
IIR-UN 2018	Cold Chain Brief on Fishing Vessel Applications, International Institute of Refrigeration and Ozone Action, United Nations Environment, Economic Division, 2018.
MLA 2018	Market Snapshots, Meat & Livestock Australia, October 2018.
MLA 2016	Shelf life of Australian red meat, Second Edition, Meat & Livestock Australia, August 2016.
NFF 2017	Food, Fibre & Forestry Facts published by the National Farmers Federation, Nov 2017.
NPF 2014	A study of refrigeration technology options from catch to market Final, by Expert Group for Northern Prawning Fleet and Sydney Fish Market, 2014.
Statista 2019	Non-Alcoholic Drinks Report 2019 – Juices, Statista, 2019.
SFM 2018	Sydney Fish Market, Annual Report 2018.
SR 2019	Energy Performance of Industrial, Cold Storage Facilities, Star Refrigeration, 2019.
USDA 2018	Expert Panel on Technical Questions and Data Gaps for the ERS Loss-Adjusted Food Availability (LAFA) Data Series, Economic Research Service, United States Department of Agriculture, 2018.

8 Appendix: A: Equipment taxonomy, energy and greenhouse intensity

8.1 Introduction

The Expert Group has developed a taxonomy of refrigeration technology to help manage the mass of data processed in the refrigeration and air conditioning (RAC) stock model that underlies the Cold Hard Facts research series. Refer Cold Hard Facts 2019 for further details (DoEE 2019b).[16]

The Cold Hard Facts series publishes the major metrics of the cooling economy in Australia. This refrigeration and air conditioning industry report card uses the taxonomy of RAC technology to build a stock model of all the equipment installed in the economy, and to calculate the bank of refrigerant with high global warming potential used, the direct emissions of refrigerant from various classes of equipment and the energy intensity of refrigeration.

The four major classes of RAC equipment the taxonomy uses are:

- stationary air conditioning
- mobile air conditioning
- refrigerated cold food chain (RCFC)
- domestic refrigeration.

Knowing what equipment is manufactured in Australia, assembled in Australia from imported components, or imported fully assembled and already charged with a refrigerant, is important for policy makers determining the most effective way to influence equipment design to, for instance, deliver improved energy efficiency.

Understanding the stock of equipment that is already installed is essential to identify opportunities for improving performance of the cold food chain through changed practices, adoption of new technologies and policies intended to drive technological transitions.

The following estimations are made using *Table 7* below:

- The majority of equipment in marine refrigeration, cold storage distribution and process refrigeration is manufactured or assembled or charged with refrigerant in Australia.
- Around one third of road transport equipment is manufactured or assembled or charged with refrigerant in Australia.
- While supermarkets employ a range of equipment including some smaller pieces that are likely imported, most plant and equipment in supermarkets is manufactured or assembled or charged with refrigerant in Australia.
- Less than 15% of self-contained refrigeration cabinets are manufactured or assembled in Australia, the balance being imported as pre-charged equipment.
- Less than 15% of water dispensers, including bottles, are manufactured or assembled in Australia.

[16] *https://www.environment.gov.au/protection/ozone/publications/cold-hard-facts-2019*

Table 7: Refrigerated cold food chain taxonomy

REFRIGERATED COLD FOOD CHAIN					
Item no	Segment	Application	Category code	Product category	Stock 2018
31	RCFC1: Small Commercial Refrigeration	Self-contained	RCFC1-1	Refrigeration cabinets: self-contained	715,000
32		Self-contained	RCFC1-2	Refrigeration beverage vending machines	137,500
33		Self-contained	RCFC1-3	Beverage cooling (post mix)	54,000
34		Self-contained	RCFC1-4	Ice makers	73,000
35		Self-contained	RCFC1-5	Water dispensers (incl. bottle)	243,500
36		Self-contained	RCFC1-6	Other self-contained refrigeration equipment	110,000
37		Self-contained	RCFC1-7	Walk-in cold rooms: small: Slide-in/Drop-in	9,100
38		Remote	RCFC1-8	Walk-in cold rooms: small: remote	212,000
39	RCFC2: Medium Commercial Refrigeration	Remote	RCFC2-1	Walk-in cold rooms: medium	20,500
40		Remote	RCFC2-2	Walk-in cold rooms: large	21,300
41		Remote	RCFC2-3	Refrigeration cabinets: remote	13,500
42		Remote	RCFC2-4	Beverage cooling (beer)	9,300
43		Remote	RCFC2-5	Milk vat refrigeration (direct expansion)	5,100
44		Remote	RCFC2-6	Packaged liquid chillers (including milk vat)	12,600
45		Remote	RCFC2-7	Process, and mfg. refrigeration (<40 kWr)	21,000
46		Remote	RCFC2-8	Other remote equipment	51,000
47	RCFC3: Supermarket	Supermarkets	RCFC3-1	Supermarket refrigeration: small	2,397
48		Supermarkets	RCFC3-2	Supermarket refrigeration: medium	1,306
49		Supermarkets	RCFC3-3	Supermarket refrigeration: large	470

REFRIGERATED COLD FOOD CHAIN					
Item no	Segment	Application	Category code	Product category	Stock 2018
50	RCFC4: Transport refrigeration	Transport refrigeration	RCFC4-1	Mobile refrigeration: road: trailer - inter-modal	12,000
51		Transport refrigeration	RCFC4-2	Mobile refrigeration: road: diesel drive	8,400
52		Transport refrigeration	RCFC4-3	Mobile refrigeration: road: off engine	24,700
53		Transport refrigeration	RCFC4-4	Mobile refrigeration: marine	400
54	RCFC5: Process and industrial refrigeration	Industrial refrigeration	RCFC5-1	Cold storage and distribution	15.5 Million m^3
55		Industrial refrigeration	RCFC5-2	Process and mfg. (>=40 kWr)	-
Total RCFC					>1,758,000

(Source: DoEE 2019b)

Notes

1. Stock values are rounded to the nearest hundred.
2. Total numbers of stock in the cold food chain includes the count of supermarkets which accounts for centralised systems and the remote display cases connected to the system. Some of the stock of smaller classes of equipment such as self-contained merchandisers are counted separately in RCFC1-1.

Main metrics

In 2018, the refrigerated cold chain in Australia contained more than 1.7 million installations and pieces of equipment that contained approximately 13% of the bank of refrigerant in Australia, or around 7,100 tonnes.

The RCFC used an estimated 1,340 tonnes of all HCFCs[17] and HFCs to charge new equipment and replace leaked refrigerant. This represents around 37% of all HCFCs and HFCs used in Australia's refrigerant bank in 2018.

Table 8: Refrigerated cold food chain main metrics: 2018

Metric	2018
Size of high GWP (1) refrigerant bank	7,100 tonnes
Annual usage of high GWP refrigerants	1,340 tonnes (2)
High GWP refrigerants in pre-charged equipment imports	61 tonnes
Estimated stock of equipment	1.7 million devices
Annual electricity consumption	19,600 GWh
Annual GHG indirect emissions	15.93 Mt CO_2-e
Annual GHG direct emissions (ODS) (3)	0.01 Mt CO_2-e
Annual GHG direct emissions (SGG)	2.99 Mt CO_2-e

(Source: DoEE 2019b)

Notes:

1. For the purposes of this report this term is used to refer to refrigerants commonly used today with GWPs greater than 1400. This includes the widely employed HFC-404A (GWP of 3922), HFC-410A (GWP of 2088) and HFC-134a (GWP of 1430).
2. Includes charging new equipment, replacing leaked refrigerant and repairs.
3. Emissions of ODS are not counted as part of the GHGs reported under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, as they managed through the Montreal Protocol.

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[17] *Maximum imports of HCFCs for 2016, 2017 and 2018 were capped at 2.5 ODP tonnes per annum, which equates to 45.5 metric tonnes of HCFC-22. The additional usage across all RAC in those years of 210, 179 and 117 tonnes of HCFC refrigerants is possible because the material has been reclaimed and reconditioned to AHRI 700 standard so that it can be resold. There would be additional HCFC-22 recovered by contractors and re-used.*

8.2 Refrigerant bank and usage

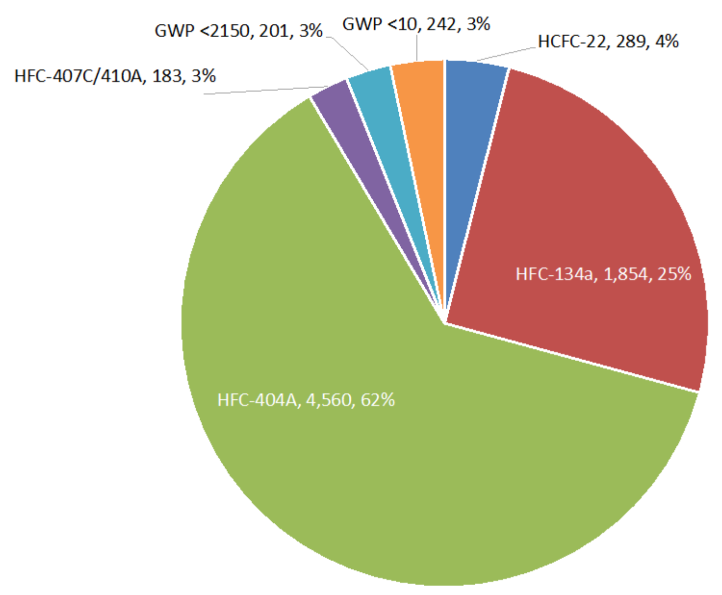
The five segments and 25 product categories that are employed in the refrigerated cold food chain in Australia contain approximately 13% of the bank of refrigerant in Australia, or around 7,100 tonnes.

As illustrated in *Figure 2*, HFC-404A makes up 62% of the bank of refrigerant in the cold food chain, followed by HFC-134a with 25% share, and HCFC-22 a declining share of 4%.

The more than 1.7 million installations and pieces of equipment in the refrigerated cold food chain used an estimated 1,340 tonnes of HCFCs and HFCs to charge new equipment and replace leaked refrigerant in 2018. This represents around 37% of all HCFCs and HFCs used in Australia in that year.

Figure 2: HCFC and HFC refrigerant bank excluding domestic refrigeration by mass in tonnes and percent, in the refrigerated cold food chain

HCFC and HFC Bank excluding domestic refrigerators (tonnes) in RCFC



(Sources: DoEE 2019b)

Notes:

1. The ammonia (R717) bank is estimated to be around 5,000 tonnes.
2. The domestic refrigeration bank is estimated to contain 1,700 tonnes of HFC-134a and 475 tonnes of hydrocarbon refrigerant.

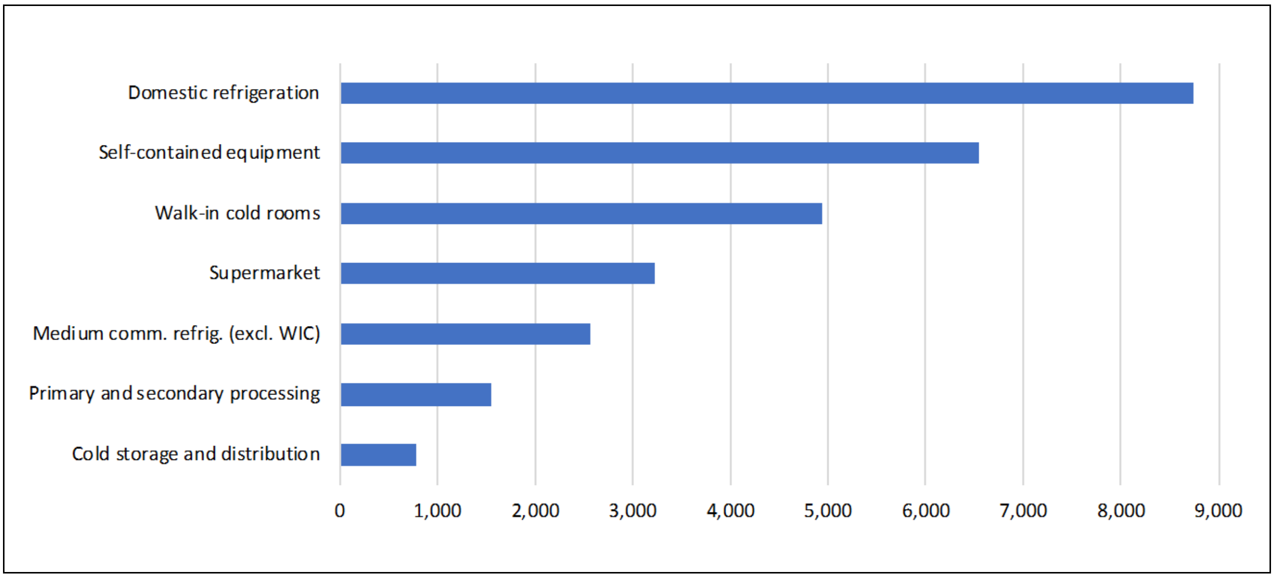
8.3 Energy consumption

The portion of total electricity consumed by RCFC equipment in Australia in 2018 was around 8% of all electricity generated.[18] If domestic refrigeration equipment is included then total electricity consumption in the refrigerating task for food preservation rises to 11% of all electricity generated.

Figure 3 and Table 9 illustrate and tabulate the estimated electricity consumption of each equipment category across the cold food chain.

Electricity price increases of more than 30% from 2016 to 2018 have placed significant emphasis on energy saving initiatives in commercial settings, particularly with large refrigeration equipment and plant in the supermarket and cold storage industries.[19] Electricity price rises have resulted in some supermarket chains undertaking door retrofit programs on medium temperature meat, dairy and liquor open display cases. These relatively simple equipment retrofits have very short payback periods (less than six months) and are very effective in both reducing the energy use and increasing the effectiveness of refrigerated food preservation due to better temperature homogeneity, even with a high door-opening frequency.

Figure 3: Electricity consumption across the cold chain, including domestic refrigerators, in GWh per annum



(Sources: DoEE 2019b)

[18] *Australian Energy Statistics, Electricity generation by fuel type, prepared by the Department of the Environment and Energy, March 2019 estimate the Australian electricity generation (i.e. sent out) by all fuel types (i.e. Non-renewable and renewable) was 261,405 GWh. This is 1% higher than 2016, estimated at 258,481 GWh.*

[19] *AEMO National Electricity and Gas Forecasting, Neutral Scenario, 1981 to 2037 by State, wholesale and retail prices, Australian Energy Market Operator, published 2017. Residential, Commercial and Industrial national average prices have increased from 0.28, 0.16 and 0.13 c/kWh in 2016 to a projected 0.36, 0.24 and 0.21 c/kWh in 2018. Prices for 2018 used AEMO projected prices, as the AEMO 2018 Electricity Statement of Opportunities now only publishes the Price Index, not the actual prices.*

Table 9: Electricity consumption by product category, GWh in 2018

Equipment segment	Proportion by equipment segment (%)	Energy consumption (GWh/yr)
Self-contained equipment	23%	6,544
Walk-in cold rooms (incl. drop-in/slide-in and remote)	17%	4,946
Medium commercial refrigeration (excl. WIC)	9%	2,566
Supermarket	11%	3,220
Cold storage and distribution	3%	775
Primary and secondary processing	5%	1,550
Domestic refrigeration	31%	8,738
Total	100%	28,340

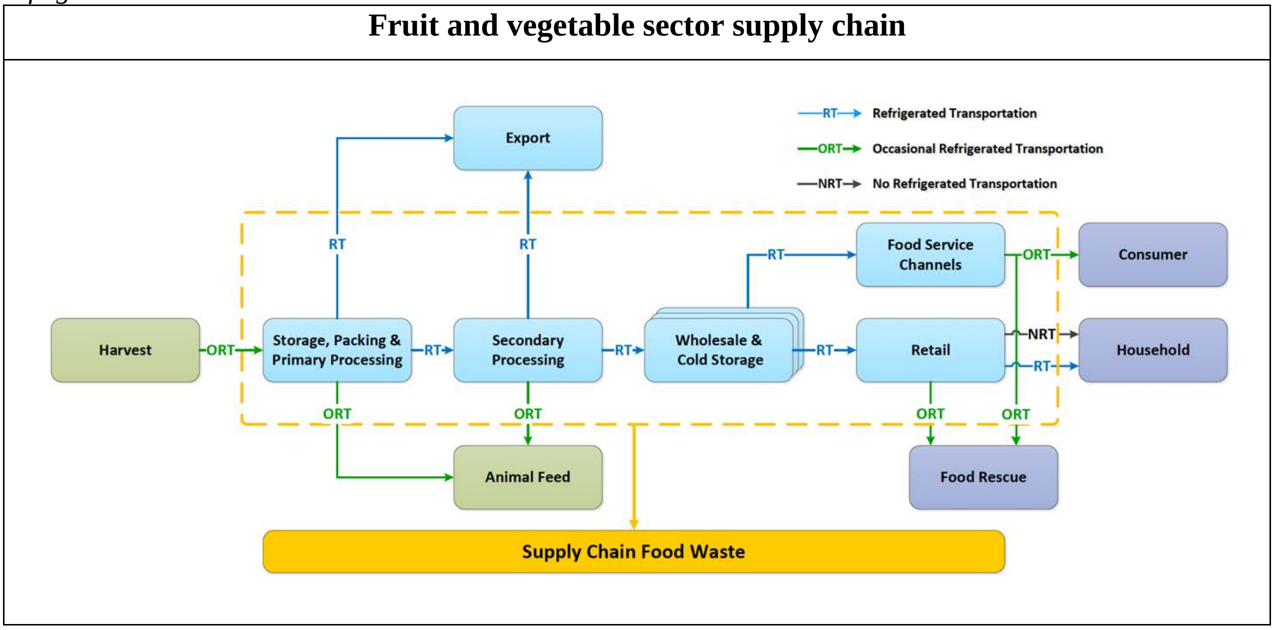
9 Appendix B: Supply chain maps and assumptions

9.1 Supply chain maps

Figures 4, 5, 6 and 7 illustrate the supply chains and food waste boundaries for the fruit and vegetable, meat, seafood, and dairy and egg sectors.

The commercial refrigeration boundary denotes where precise temperature control is essential to maximise the post-harvest life and minimise food waste. The supply chain map shows the multiple steps and critical role played by refrigerated transport in maintaining the integrity of the cold chain. Each transport link in the supply chain is a critical control point with a risk for temperature and time breach in the cold chain.

Figure 4: Fruit and vegetable supply chain and food waste boundary attributed to commercial refrigeration



Notes for all supply chain maps:

1. Wholesalers and cold storage include specialist wholesalers that are intermediaries to food service channels, independent cold storage and distribution facilities, and central distribution centres of major supermarket chains.
2. Not refrigerated transport (NRT) typically occurs from the retailer to the household via passenger vehicle.
3. Occasional refrigerated transport (ORT) covers a variety of food transport scenarios including refrigerated transport, no refrigerated transport and sub-optimal refrigeration.
4. Culling of sick and injured livestock, pet food, and removal of inedible parts (bone, skin, separable fats) that can account for as much as 30% of production volume are outside the food waste boundary of this study.
5. In the dairy sector bulk milk trucks that pick up from farms are not refrigerated, however they are insulated and must have a documented Food Safety Program approved by State Dairy Food Authorities that includes product traceability and temperature and time controls to minimise food safety risks. Delivery of eggs may be refrigerated.

Figure 5: Meat sector supply chain and food waste boundary attributed to commercial refrigeration

Meat sector supply chain

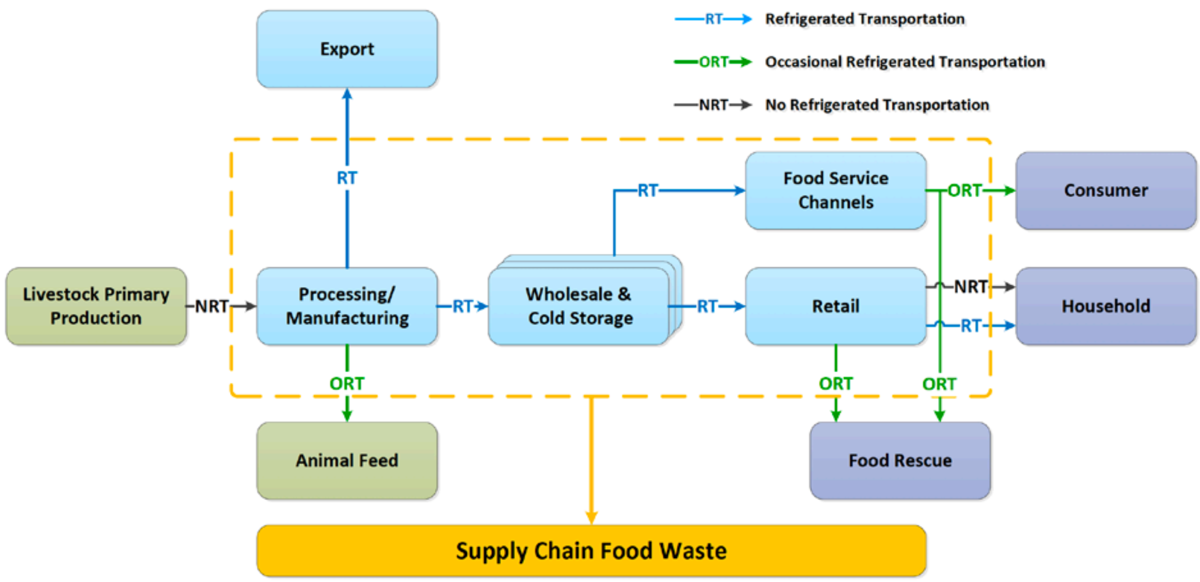


Figure 6: Seafood sector supply chain and food waste boundary attributed to commercial refrigeration

Seafood sector supply chain

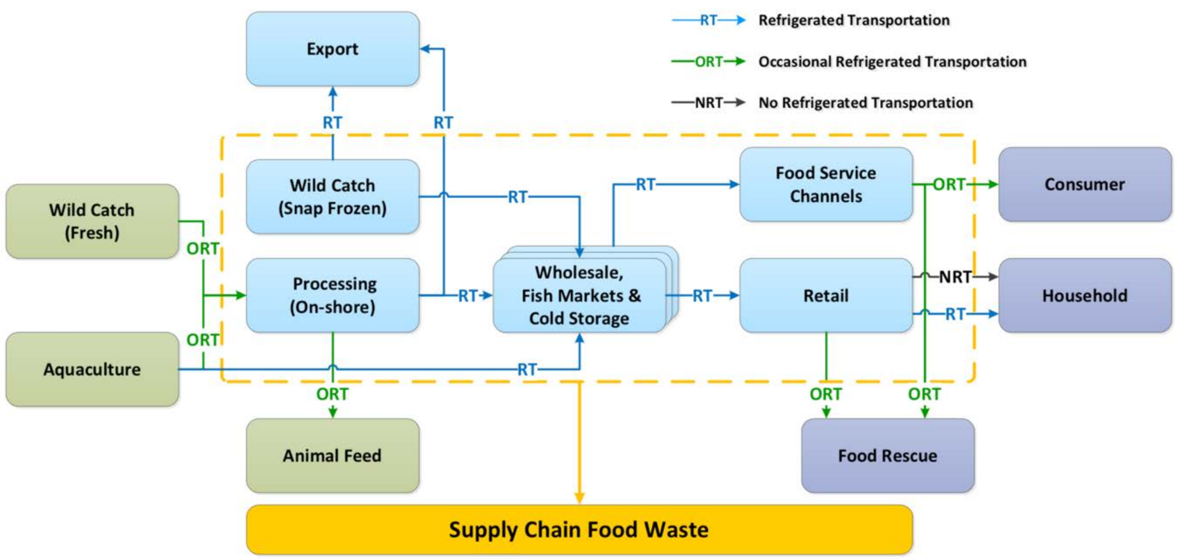
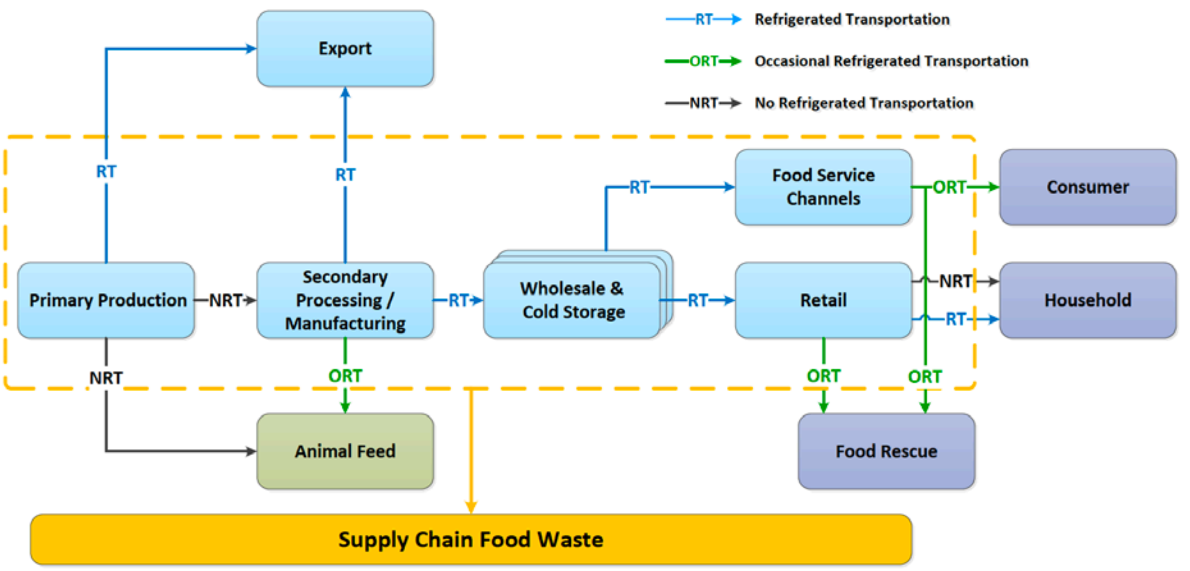


Figure 7: Dairy sector supply chain and food waste boundary attributed to commercial refrigeration

Dairy sector supply chain



9.2 Food waste assumption and factors

The table below lists the food waste rates and Figure 8 provides a graphical illustration.

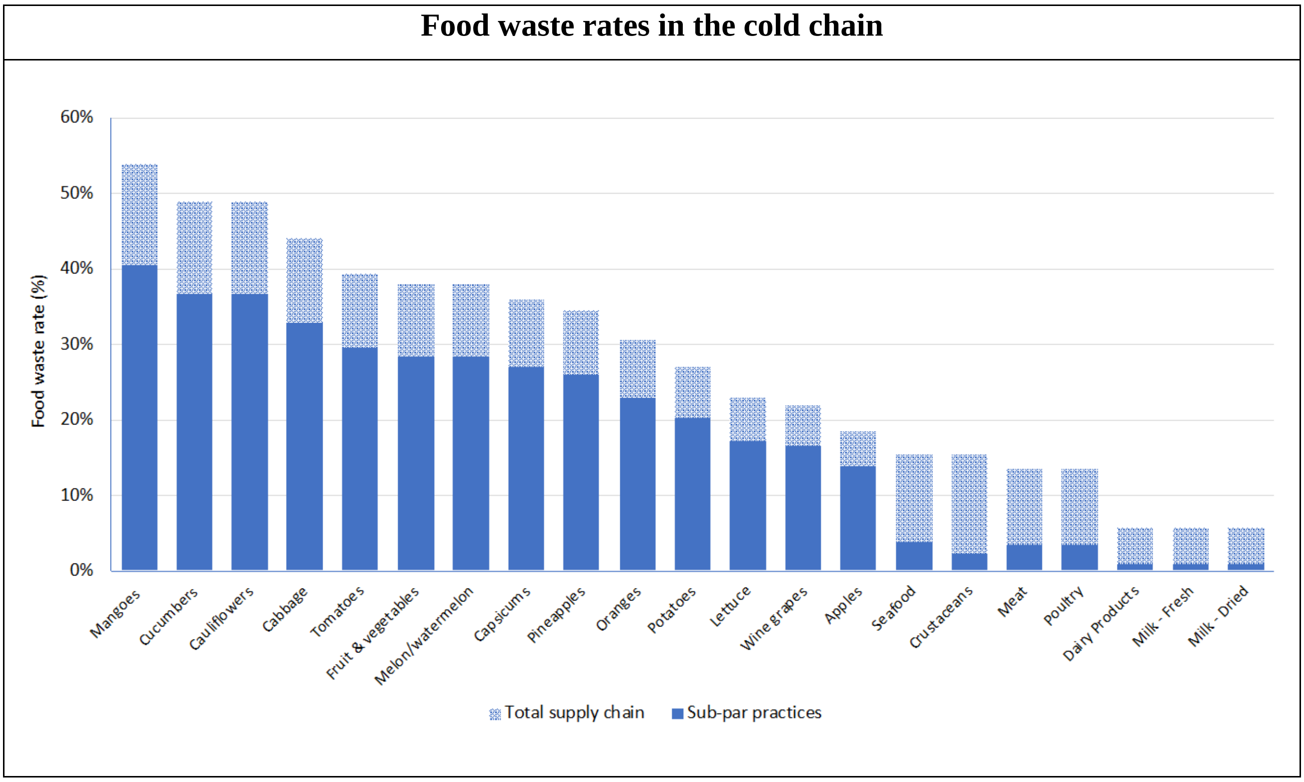
Table 10: Food waste rate assumptions in the supply chain

Food type	Supply chain	Proportion attributed to RCFC sub-par practices (supply chain)	Total across supply chain
Fruit (all types not specified) (1)	38.0%	75%	29%
Melon/watermelon	38.0%	75%	29%
Mango	54.0%	75%	41%
Apple	18.5%	75%	14%
Wine grapes	22.0%	75%	17%
Orange	30.5%	75%	23%
Pineapple	34.5%	75%	26%
Vegetable (all types not specified)	38.0%	75%	29%
Tomato	39.5%	75%	30%
Cucumber	49.0%	75%	37%
Lettuce	23.0%	75%	17%
Capsicum	36.0%	75%	27%
Cabbage	44.0%	75%	33%
Cauliflower	49.0%	75%	37%
Potato	27.0%	75%	20%
Meat	13.5%	25%	3%
Poultry	13.5%	25%	3%
Seafood	15.5%	25%	4%
Crustaceans	15.5%	15%	2%
Dairy products	5.7%	15%	1%
Milk – fresh	5.7%	15%	1%
Milk – dried	5.7%	15%	1%

Notes:

1. The CSIRO study, Mapping Australian Fruit and Vegetable Losses Pre-retail (CSIRO 2019) found fruit and vegetable wastes typically ranged from 20% to 40%. An average of this range is assumed in this study plus 8% for retail, equating to 38% for all fruit and vegetables not specified which is consistent with the FAO estimate of 38% (FOA 2011). Where fruit and vegetable types are specified, the CSRIO pre-retail estimates were used plus 8% for retail:
   - melons/watermelons (20 to 40%), wine grapes (20% to 24%), oranges (22% to 23%), mangoes (46%), pineapples (26% to 27%) and apples (4% to 17%)
   - tomatoes (27% to 36%), potatoes (19%), cucumbers (41%), cauliflowers (41%), cabbages (36%), head lettuces (15%) and capsicums (28%)
   - no retail waste for wine grapes.

Figure 8: Total food waste rates in the supply chain and the portion attributed sub-par practices



Producing food and disposing of waste food produces greenhouse gas emissions that can be estimated using emission factors (for example, kg CO_2-e per tonne) for different food types. The table below lists the agricultural and landfill impact emission factor assumptions used in this report.

This study assumes all food waste goes to landfill for emission calculation purposes. The full lifecycle emissions that includes electricity consumption for chilled and frozen foods, energy consumption for cooking and emissions from transport were not included in this assessment.

Figure 9 provides an illustration of the comparative scale of emission intensity based on kg CO_2-e/kg of food waste.

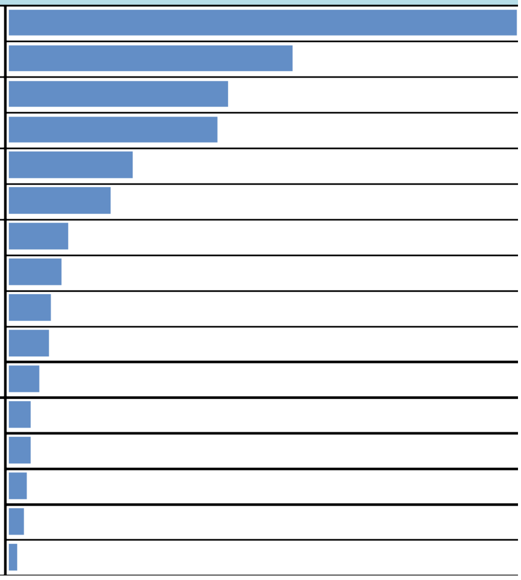
Table 12: Food waste emission factors

Food type	Agricultural impacts (kg CO_2-e/tonne)	Landfill impacts (kg CO_2-e/tonne)	Total (kg CO_2-e/tonne)
Fruit & Vegetable	212.5	1,265.4	1,477.9
Apple	112.7	1,350.1	1,462.8
Banana	207.8	2,345.9	2,553.7
Carrot	101.7	1,094.9	1,196.6
Grape	217.6	1,819.5	2,037.1
Lettuce	160.3	469.4	629.7
Tomato	475.1	512.4	987.5
Meat	14,933.0	3,419.0	18,352.0
Beef	28,482.6	4,273.0	32,755.6
Pork	10,578.6	3,640.9	14,219.5
Poultry	5,737.8	2,343.1	8,080.9
Seafood	0	3,419.0	3,419.0
Dairy	4,293.3	2,340.9	6,634.2
Cheese	8,741.6	4,684.4	13,426.0
Milk	1,714.9	942.5	2,657.4
Yoghurt	2,423.4	1,396.0	3,819.4

Note: The FLW Calculator makes assumptions on electricity consumption for chilled and frozen foods, energy consumption for cooking and emissions from transport. These were not included as they were considered to be too low.

Figure 9: Comparative scale of emission intensity based on kg CO_2-e/kg of food waste

Food type	Comparative scale of emission intensity based on kg CO_2e/kg of food waste type		
Beef	**Very High**	>15	
Meat (Average)	**Very High**		
Pork	**High**	>10 and ≤15	
Cheese	**High**		
Poultry	**Medium**	>5 and ≤10	
Dairy Product (Average)	**Medium**		
Yoghurt	**Low**	>2 and ≤5	
Seafood	**Low**		
Milk	**Low**		
Banana	**Low**		
Grape	**Low**		
Fruit & Vegetable (Average)	**Very Low**	≤2	
Apple	**Very Low**		
Carrot	**Very Low**		
Tomato	**Very Low**		
Lettuce	**Very Low**		



9.3 Agriculture and foodstuff production and export data sources and notes

This section provides detailed notes on sources, definitions and assumptions of the tabulated production and export data provided for each sector.

Fruit and vegetable sector notes for **Table 2**:

1. The production and export volumes and values for fruit, vegetables and nuts were sourced from the Australian Horticulture Statistics Handbooks: 2018, by Horticulture Innovation Australia, published April 2019 for the year ended 30 June 2018 (HIA 2019).
2. Fruit includes all other types of grapes and excludes wine grapes.
3. The source for the number of fruit and vegetable agricultural businesses is ABS 7121.0 2019. The number of fruit businesses includes 536 businesses producing grapes (excluding wine grapes).
4. Wine grape data is for the year ended 30 June 2017. The production volume is sourced from ABARES 2018a, production value from ABS 7503.0 2019 and the number of wine grape agricultural businesses from ABS 7121.0 2018.
5. Approximately 61% (1.61 million tonnes) of local fruit production is supplied fresh, with 22% (0.59 million tonnes) supplied for fruit processing and the remaining 17% (0.44 million tonnes) is exported (HIA 2019).
6. Approximately 59% (2.2 million tonnes) of local vegetable production is supplied fresh, with 35% (1.3 million tonnes) supplied for vegetable processing and the remaining 6% (0.21 million tonnes) is exported (HIA 2019).
7. The nut production volumes in millions of tonnes is the in-shell equivalent weight.
8. Nut exports includes both the kernel and in-shell forms.

Meat sector notes for **Table 3**:

1. Australian Bureau of Statistics, catalogue 8165.0, Counts of Australian Businesses is as at June 2018, published February 2019.
2. Quantity and value data relate to the year ended 30 June 2018.

3. The farm gate value is based on gross prices. For example, produce can be sold into the wholesale or retail market, to factories for processing and/or export. Each market value is calculated by multiplying the production quantity data by the average gross market price (ABS 7503.0 2019).
4. The gross market prices are those realised at the point(s) of valuation where ownership of the commodity is relinquished by the agricultural industry. This includes transport and marketing costs of moving the product from the place of production (i.e. farm) to the marketplace. These costs include freight, cost of containers, commission, insurance, storage, handling and other charges necessarily incurred by the producer in delivering commodities to the marketplace.
5. The value of livestock disposals includes domestic slaughtering and export of live animals.
6. The number of beef cattle farming business includes 37,873 non-employing businesses (85% of total businesses) which are either family run or owner operated business (ABS 8165.0 2019).
7. The number of sheep farms includes those with livestock for producing both wool and sheep meat. The number of sheep farms includes 6,313 non-employing businesses (ABS 8165.0 2019).
8. The number of poultry farming (meat) business includes 309 non-employing businesses (ABS 8165.0 2019).
9. The number of pig farming business includes 535 non-employing businesses (ABS 8165.0 2019).
10. The export values are based on free-on-board (FOB) values and are not directly equivalent to gross farm gate value.
11. Export values are estimates by ABARES, Agricultural commodity statistics (ABARES 2018b).
12. Source for poultry production volumes is ABS 7215.0 2019, and source for poultry exports is ABARES 2019b.

Seafood sector notes for **Table 4**:

1. Fish includes tuna, salmonids and other fishes.
2. Crustaceans include prawns, rock lobsters, crab and other crustaceans.
3. Molluscs include abalone, scallop, oyster, pearls, squid and other molluscs.
4. Quantity and value data in most instances relate to the year ended 30 June 2018, and includes forecasts by ABARES, Agricultural Commodity (ABARES 2018c).
5. The export values are based on free-on-board (FOB) values and are not directly equivalent to gross farm gate value.
6. Includes seafood types not included elsewhere, comprising \$0.048 for other crustaceans and molluscs and \$0.027 for other fisheries products.
7. Other export volume includes crustaceans and molluscs.
8. Other export value includes crustaceans, molluscs, and fisheries products.

Dairy and egg sector notes for **Table 5**:

1. Quantity and value data relate to the year ended 30 June 2018.
2. Australian Dairy Industry: In Focus 2018, Dairy Australia Limited, 2018.
3. Butter includes butter concentrate, butter oil, dairy spreads, dry butterfat and ghee all expressed as butter.
4. Excludes processed cheese.
5. Yoghurt includes yoghurt and other snack products, with imports less than 1% of consumption (Source: Dairy Australia 2019).

6. Other dairy products include casein and food preparations identified by industry as containing a high proportion of dairy products.
7. Australian Bureau of Statistics, catalogue 7121.0, Agricultural Commodities, Australia 2017-18, published. 2019.
8. 6,741 million litres (73%) of fresh milk is consumed for manufacturing, and the remaining 2,548 million litres is sold via retail and food service channels for human consumption.
9. Agricultural commodities - June 2019, Tables 10 and 12: Dairy, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Canberra, 2019.
10. Agricultural commodity statistics 2018, Tables 6: Dairy, Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES 2018e).
11. ABARES 2019 cites eggs for human consumption whereas Australian Eggs Limited Annual Report 2017-18 cites a higher number of 515.7 million dozen.
12. The export values are based on free-on-board (FOB) values.
13. Australian Bureau of Statistics, catalogue 5368.0, International Trade in Goods and Services, Australia, Table 12b. Merchandise Exports, 2019.