



# Making Australian Country Choice circular



Australian Government  
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Energy and Resources

**AusIndustry**  
Cooperative Research  
Centres Program

Author: Dr Stephan Tait, Dr Peter Harris, Professor Bernadette McCabe (Project Leader)  
Centre for Agricultural Engineering, University of Southern Queensland



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Level 1, Wine Innovation Central Building, Cnr Hartley Grove and Paratoo Road, URRBRAE SA 5064

[enquiries@fightfoodwastecrc.com.au](mailto:enquiries@fightfoodwastecrc.com.au) +61 8 8313 3564

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## Industry partner foreword

Australian Country Choice (ACC) is the largest family-owned, fully vertically integrated beef and cattle company in the world, being a third-generation business over 50 years of experience in beef and cattle. We manage nearly 2.4 million hectares of pastoral, grazing and farming land, with a carrying capacity of over 300,000 head on our cattle stations and strategically located feedlots, and we operate an important meat processing facility at Cannon Hill Brisbane able to process 350,000 cattle annually to manufacture 75,000 tonnes of retail ready and value-added products annually for Woolworths and others domestically and internationally. Environmental stewardship is core to our business and is evidenced by imbedded environmental best practice in our business systems. We understand the critical importance of natural capital (energy, nutrients and water) to our business and we aspire to control and fully utilise imbedded resource value in every input to our supply chain for feed, fibre and food production.

The current project aligned well with our environmental values, specifically helping our company to identify on-going and emerging opportunities to extract value from our organic processing wastes to profit our business. We have carried out several past investigations on circularity and closed-loop concepts, but this project provided a constructed review and consolidation of these past initiatives, and clarified opportunities, project concepts and strategies which we could consider and adopt to continue to move ACC towards a circular economy.

By further developing and adopting closed-loop technologies and concepts described in this project report, we anticipate that our business could benefit from transforming food waste into energy, food and usable water. In this way, we could achieve a substantial reduction non-renewable electricity and fossil fuel use, could substantially decrease organic waste and wastewater management costs. We would like to see future funded research and development to bring the concepts and strategies described in this project report to commercial maturity. Towards this end, the project identified and scoped out a set of short, medium and long-term actions for our business to consider to progress towards increasing circularity.

We look forward to working with the investigators, the Fight Food Waste CRC and other relevant stakeholders on future projects that further develop and translate closed-loop concepts into our business.

## Executive Summary

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As much as 675,000 tonnes of organic waste with a significant food waste component is produced by red meat processing (RMP) across Australia every year. A significant amount of this waste ends up in relatively low-value end uses, providing opportunities for valorisation using closed-loop technologies that cycle waste resources such as energy, water, organic matter and nutrients. This has the potential to increase industry profitability and to produce food, fibre and other value-added products.

This project was a scoping project. The aim was to screen closed-loop technologies and project concepts, via an investigation centred around an important red meat processor, namely Australian Country Choice (ACC). The investigation was to further identify and define prospective initiatives for application/piloting of closed-loop concepts, to lay the foundation for future spin-off projects within the Fight Food Waste Cooperative Research Centre (FFW -CRC) or other (e.g. Meat and Livestock Australia (MLA) or Australian Meat Processors (AMPC) funding rounds).

An in-depth desktop review was carried out using project and past investigations data provided by ACC as well as information available in the reputable scientific and technical literature in the public domain, including work published by MLA and AMPC. Specific closed-loop technologies were then identified and screened, based on commercial readiness, impacts, likely profitability gains, and business and technical certainty. This led to a short-listing of technologies and concepts for further analysis. Several technologies were also identified which were not yet commercially mature or feasible, but showed significant promise, either due to on-going research and development attention, or because of notable anticipated benefits to the RMP sector. Short-listed technologies were then further evaluated for the specific context of ACC and for the broader RMP sector. This included concepts where several technology solutions were integrated as appropriate to provide multiple benefits.

The project used analysis to identify important data gaps to be addressed by future work to enable adoption of closed-loop technologies across the Australian red meat sector. One important knowledge gap was a scarcity of published data on RMP organic waste availability, making actual estimates of food waste uncertain. For example, a recently published Aggregated Waste to Energy Tool developed by an AMPC funded project, indicated that organic waste produced by Australian RMP and potentially containing a significant food waste component, could be as little as 129,000 tonnes per annum or as much as 715,000 tonnes per annum. The uncertainty in estimates of waste availability introduces uncertainty in the evaluation of closed-loop concepts.

Other important data gaps included a need for technology performance testing and scale up to commercial scale, business case development for closed loop concepts, and assessments of markets and credentials for products of closed-loop technologies.

Potential synergies and opportunities for translation of closed-loop concepts were identified between RMP and milk processing, because of similar high-strength waste streams, requirements for onsite energy, and some similar waste management practices.

A set of more specific short, medium and long-term strategies were defined for ACC specifically, to help increasingly move towards circularity. With the implementation of closed-loop technologies across the RMP sector, significant recycling of food waste resources could occur, increasing the profitability of the sector. This also has potential to extend benefits further up the livestock supply to intensive feeding and on-farm production, which is described in the report. It is recommended that the project concepts and important data gaps identified in this report be progressed towards definition of a strategic set of research projects under the FFW -CRC Program 2: Transform.

<b>Objective(s)</b>	<b>Result(s)</b>
1. Address Activity 2.1 of the FFWCRC, namely identify and prioritise products from waste streams, specifically engaging the RMP sector.	1.1 The project analysed waste resources for an important red meat processor, namely ACC. 1.2 ACC was engaged in a collaborative project. 1.3 Closed-loop options were identified and evaluated based on relative potential value-add in terms of generating products and reducing waste in the red meat processing sector.
2. Identify techno-economically feasible closed-loop concepts for products derivation from RMP waste streams.	2.1 The project identified and defined some prospective initiatives for application/piloting of closed-loop concepts, to lay the foundation for future spin-off projects within the FFW -CRC or other (e.g. MLA or AMPC funding rounds).
<b>Next Step(s)</b>	<b>Timing</b>
1. Contact MLA and AMPC about joint/co-funded initiatives investigating whole of supply chain resource use, with potential for state government and industry co-funding where these have common interests. This could culminate in the production of a resource map for the red meat sector and possibly a valorisation roadmap (i.e. a decision support tool) building on the directions provided by the current project (see for example WRAP UK (Fisher, 2020)).	6-12 months
2. Develop a program of strategic research under the FFW -CRC to expand the project portfolio around circular technologies, which can build on opportunities and prospects scoped out in the current project.	6-12 months (Scoping of program of projects)
3. Progress projects recommended from the current scoping study (see Section 3.4), including projects that will benefit ACC and continue meaningful engagement with ACC and the broader Australian RMP sector.	1-5 years
4. Link business evaluation tools currently under development in the Australian livestock sectors to case studies extracted from projects implementing circular technologies, as per (2.) and (3.). This can expand the current tools, which are predominantly focussed on livestock sectors, to also include food waste more broadly.	1-5 years

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## Project Milestones Addressed

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Milestone	Description:
1. Review of closed-loop concepts at ACC - technical memo	Technical memo summarising findings of past initiatives, highlighting potential closed-loop concepts worth further consideration – Party responsible University of Southern Queensland (USQ)
2. Current and future opportunities from closed-loop concepts at ACC - progress report	Closed-loop concept scoping report complete. Progress report submitted - Party responsible USQ
3. Modelling circular waste management and recovery initiatives at ACC	Develop a model approach for circular waste management and recovery initiatives piloted at ACC – Party responsible USQ
4. Translation of closed-loop initiatives across other food processing sectors	Scoping work on high priority areas as identified by ACC to submit co-funded project proposals - Party responsible USQ, Queensland University of Technology (QUT), University of Queensland (UQ)
5. Completion of the Project	Final report submitted - Party responsible USQ

All milestones have been achieved as stated in the project agreement.

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## Project Impacts

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By identifying and analysing closed-loop circular concepts for RMP waste, the project contributed to the following FFW -CRC impact areas:

1. food waste reduction - by exploring approaches to transform food waste into energy and nutrient products.
2. industry profitability gains - by clarifying opportunities for bioenergy recovery to offset industry energy costs, and to reduce solid wastewater treatment sludge thus reducing costs of handling and disposal. This included potential opportunities to establish closed-loop resource cycling between meat processing and higher-order onsite food production systems such as microbial protein growth or high-rise farming systems.
3. creating circular economy jobs – by planning future projects to implement and operate closed-loop technologies, which creates industry jobs during construction and with on-going operation;
4. saving greenhouse gas emissions – by clarifying opportunities for bioenergy recovery which offsets fossil-fuel use and can reduce fugitive methane emissions from wastewater and waste management.

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## Utilisation/Commercialisation Opportunities

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A set of potential piloting concepts and projects have been identified to achieve circularity/closed-loop systems for ACC, for the broader red meat sector, and for other industry sectors with similar waste streams to RMP. Funding external to the CRC could be sought to pursue these prospective project concepts for further development and piloting.

Next project stages should aim to clarify baseline estimates of food waste from Australian RMP.

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## IP

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A set of potential piloting concepts and projects to explore, to increase circularity/closed-loop recovery of waste resources. Formal protection is *unlikely* to be required, with proposed concepts being mostly commercially available and/or in the public domain under existing IP protection arrangements.

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## Confidentiality

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NOT CONFIDENTIAL – Information used has been cleared by the participant organisation and/or is sourced from the public domain.

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## Approved By

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Prof. Bernadette McCabe  
Paul Gibson

Project Leader  
Participant Representative

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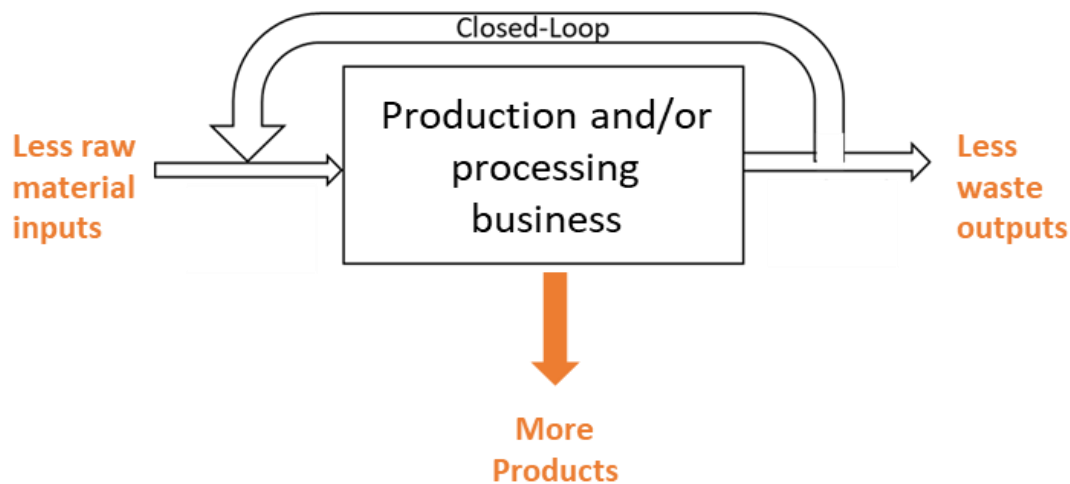
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# 1 Background

## 1.1 Project context

This project fits within *Program 2: Transforming Waste Resources*, specifically addressing *Activity 2.1: Identify and prioritise products from waste streams*, engaging with the red meat processing (RMP) sector via Australian Country Choice (ACC). The project aims to facilitate a progressive transition of the red meat sector (and ACC specifically) towards an increasingly circular economy using closed-loop concepts. Closed-loop concepts allow recycling of natural resources in waste (e.g. water, energy and nutrients) within a value-chain such as red meat production. This maximises conversion of inputs into products and minimises waste, which can also reduce inputs, reduce costs, and increase business profitability (Figure 1).



**Figure 1** Closed-loop concepts allow recycling of natural resources present in waste streams (e.g. water, energy and nutrients) within a value-chain such as red meat production.

## 1.2 Related national and international sustainability goals

A circular economy aligns with key sustainability goals outlined in the *Red Meat 2030 Strategy* (Red Meat Advisory Council, 2019). The strategy specifically aims to double the value of Australian red meat by 2030 and aims to achieve this via a set of specific goals, including (1) to triple the value of capital accessed and (2) to achieve carbon neutrality. Capital can include natural capital, such as land, water, energy and nutrients. For this, closed-loop concepts increasingly value-add to natural capital, reducing wastage, minimising costs and increasing profitability. This also aligns with:

- global sustainable development goals of the United Nations, specifically *goal 2 - zero hunger* (by wasting less food resources), *goal 3 - healthy lives and promoting well-being* (by treating organic waste and displacing fossil fuels with waste energy resources to reduce emissions and improve air quality), *goal 6 – clean water and sanitation* (by increasing water use efficiency), *goal 7 – affordable and clean energy* (by extracting bioenergy from wastes), *goal 9 - build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation* (closed-loop technology adoption to allow waste resource recycling, including energy and water, to increase profitability and decrease wastage), *goal 11 – making cities and human settlements inclusive, safe, resilient and sustainable* (by reducing greenhouse gas emissions, improving air quality, and displacing fossil fuel use by industry), *goal 12 – responsible consumption and production* (by minimising inputs) and *goal 13 – climate action* (by reducing dependency on fossil fuels);
- national sustainability goals outlined in Australia’s *National Food Waste Strategy* (Commonwealth of Australia, 2017), specifically *priority area 2—business improvements*; and
- environmental stewardship goals of the Australian red meat sector as outlined in the *Australian Beef Sustainability Framework* (Bondfield et al., 2017).

### 1.3 Red meat industry overview

Australia has approximately 1,000 meat processing companies, the majority of which processes red meat (i.e. 65%) (Arcadis, 2019). The red meat and livestock industry is important to the Australian economy with a turnover of \$65.7 billion in 2017-18 (Meat & Livestock Australia, 2019). The sector is Australia's largest food manufacturer and its largest food exporter (McCabe et al., 2020; Ridoutt et al., 2015). The sector supported 172,000 direct jobs and 232,000 indirect jobs in 2017-18 (Meat & Livestock Australia, 2019). Australian beef cattle are primarily grass-fed, with about one third eventually ending up in intensive feeding feedlots (Agrifutures, 2017). The cattle and sheep supply chain usually has an intermediary stage of sale at saleyards, either to an abattoir for processing or for live export (Arcadis, 2019), but some animals are sold directly from farm to an abattoir or for live export (Arcadis, 2019). Processed products are sold packaged or fresh, directly to the market or to a wholesaler (Arcadis, 2019).

### 1.4 Red meat processing food waste

The most important part of the livestock production chain in terms of food waste is meat processing (Arcadis, 2019), accounting for an estimated 123,000 tonnes of food waste sent to compost or bio-based products across beef, lamb, pork and chicken industries in 2016/17 (Arcadis, 2019). The bio-based products included here is expected to be a portion of a larger quantity of bio-based products. For example, some processed by-products are also used for animal feed, which is not considered food waste because it does not leave the human food supply chain (Arcadis, 2019).

Red meat processing facilities usually have a kill floor and boning room, dedicated wastewater treatment (Arcadis, 2019), and in many cases an integrated rendering facility to process by-products into value-added products (Johns, 1995; McCabe et al., 2020). This means a high extent of recycling is possible, with minimal wastage. Most waste produced by RMP is organic, consisting predominantly of paunch solids, manure and sludge from wastewater treatment (Ridoutt et al., 2015).

Much of the organic waste is not directly fit for human consumption and is thus not food waste. However, a significant proportion could be food waste. For example, some blood and meat components are entrained in sterilization and cleaning water, being diluted and making recovery more difficult, and also very quickly becoming contaminated and spoilt with other wastes which are not fit for human consumption (e.g. manure and paunch contents). It is therefore logical that wastewater from meat processing has frequently been a target for development of closed-loop and waste transformation technologies, to value add to potential waste resources.

Solid waste from meat processing sent to landfill is relatively minimal (Australian Meat Processors Corporation, 2010a), consisting mainly of miscellaneous mixed wastes that cannot be recycled (Ridoutt et al., 2015) and is unlikely to be a major food waste reduction target.

### 1.5 Vertically integrated businesses and opportunities for closed-loop concepts

The livestock supply chain in Australia is highly fragmented with several operators (Arcadis, 2019). Fragmented supply chains could pose challenges for closed-loop cycling of natural resources across the supply chain, because multiple different stakeholders would need to be engaged and collaborate across the supply chain to make such closed-loop initiatives a reality.

Vertical integration is increasingly seen at the processing end of the meat supply chain, such as with supermarkets and exporters (Arcadis, 2019), and in cases, vertical integration stretches across the entire supply chain. ACC is an example, owning the whole supply chain, including seedstock production, breeding and backgrounding, lot-feeding, processing, value-adding, retail packaging and distribution. Such vertical integration allows better control of inputs and value across the whole supply chain and could facilitate closed-loop initiatives to minimise inputs and reduce wastage.

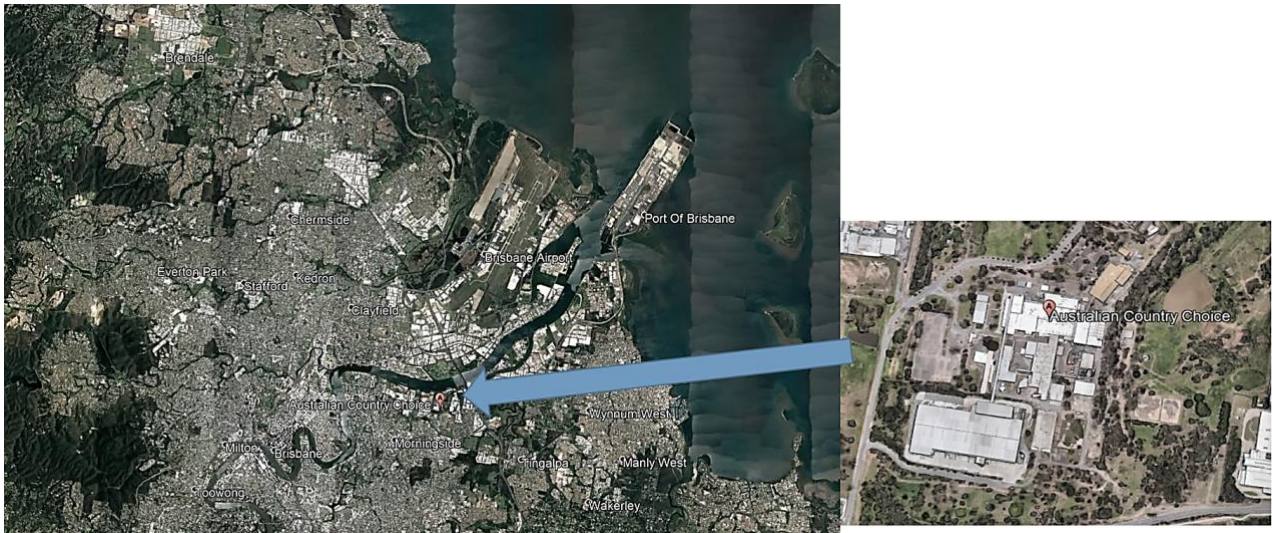
## 1.6 Australian Country Choice overview

ACC is the largest family-owned, fully vertically integrated beef and cattle company in the world (Australian Country Choice, 2019). ACC is a third-generation business with more than 50 years of experience in beef and cattle production (Australian Country Choice, 2019). The ACC Group manages nearly 2.4 million hectares of pastoral, grazing and farming land (Figure 2) (Australian Country Choice, 2019). ACC has a capacity to run over 300,000 cattle on its cattle stations and strategically located feedlots and operates a meat processing facility at Cannon Hill strategically located within the port of Brisbane precinct (Australian Country Choice, 2019). The ACC Cannon Hill facility is able to process 350,000 cattle annually to manufacture 75,000 tonnes of retail ready and value-added products annually (Australian Country Choice, 2019). ACC supplies high-quality beef products to Woolworths and others. The ACC group creates employment for over 1,400 people (Meat & Livestock Australia, 2019).



**Figure 2** Indicative locations of ACC's production operations across Queensland. Green-coloured regions indicate ACC's ACBH northern and central breeding and backgrounding operations; Blue-coloured regions indicate the ACC AGRI South-western breeding and backgrounding operations, which together with ACC's MB9+ full-blood Wagyu stud herd, feeds into ACC's feedlots in South-Western Queensland. This production chain provides consistent high-quality livestock to ACC's processing facility in Cannon Hill, Brisbane (Australian Country Choice, 2019).

ACC considers environmental stewardship to be core to their business. ACC has demonstrated this by adopting several relevant business tools including environmental management systems, cleaner production methods and environmental footprint evaluation mechanisms, all of which bridge the entire supply chain, and aim to achieve best practice management of water, energy, waste, air and land, cleaner production and eco-efficiency. ACC's environmental stewardship is underpinned by certified international standards for environmental management (ISO 14001). Like other meat production companies, ACC aspires to control and fully utilise every input across their supply chain for feed, fibre and food production. Consequently, ACC has previously carried out several investigations of potential closed-loop options for their wastes. Reports from these past investigations were made available to the project team to review as part of this project.



**Figure 3** Aerial photograph showing approximate location of ACC’s Cannon Hill meat processing facility, strategically located in the port of Brisbane precinct. Source: Adapted from Google Earth Pro

**1.7 Project purpose**

This project aimed to identify and clarify economically feasible closed-loop concepts (FFW -CRC Output 2.1) available to ACC and with potential to be extended to the broader RMP sector. This was to aide a transition towards a circular economy. Meat processing was considered a logical target, being the majority producer of food waste from the livestock supply chain (Section 1.4). The fully vertically integrated business of ACC, its notable environmental stewardship aspirations, and similarities with other meat processors, made ACC particularly well suited for collaborative investigations of closed-loop concepts in this project. The project also has the potential to contribute to FFW -CRC project 3.2.2, *Food waste reduction roadmap for Woolworths*, by providing information towards a future case study for inclusion in the roadmap.

## 2 Methodology

Key project activities included (as per the original project agreement):

1. A desktop review of past ACC project initiatives, peer reviewed scientific literature, and meat industry scientific and technical reports in the public domain. This review sought to:
  - a. identify and prioritise waste streams in terms of waste quantities and natural resource value (water, nutrients and energy). The focus was solely on the organic waste streams from meat processing but closed-loop cycling of waste resources further up the livestock production chain was also considered. A simple Excel mass balance model was constructed to track wastes via the waste management systems of ACC Cannon Hill, and to study the effects of transformation technologies; and
  - b. identify suitable technologies to transform the priority wastes into products. The technology review emphasised novel, practical and cost-effective technology options.

A request for information (RFI) was compiled during the project and sent to ACC for information on past initiatives, quantities and costs of natural resources used by the Cannon Hill meat processing facility, and organic wastes produced by the facility. Inorganic and general waste (i.e. plastics and cardboard boxes) were excluded from analysis in the project, because these have no relation to food waste from RMP.

2. Collaborative workshops with an ACC engineering representative to discuss, evaluate and sort priority waste streams and transformation technologies for further analysis. This considered cost benefit, technology risk, level of complexity, and environmental impacts.
3. Develop model approaches for circular waste management and recovery initiatives in the RMP sector, and also specific concepts for ACC. This included;
  - a. further evaluation of short-listed priority wastes and technology options, considering important aspects such as cost-benefit, important data gaps, and needs or opportunities for further testing/piloting of closed-loop concepts;
  - b. a comparison of waste streams from meat processing with that from other food processing sectors (specifically identified milk processing) to identify similarities and therefore synergistic opportunities for transference of closed-loop concepts developed for meat processing to these other sectors; and
  - c. ACC was particularly interested in a set of short, medium and long-term strategies to be identified from the analysis, so that closed-loop concepts could be further considered to be progressed in their business.
4. Working in collaboration with Queensland University of Technology (QUT), University of Queensland (UQ), ACC and other relevant FFW -CRC research partners, to develop further project proposals to secure leveraged co-funding to further develop and pilot closed-loop concepts.
  - a. This involved a project workshop during which project findings were shared, and potential spin-off projects were identified and discussed for prospective future funding applications.
5. Document the project to form the basis for a future case study under Project 3.2.2, Woolworths Zero Food Waste Roadmap (Fight Food Waste CRC, 2019).

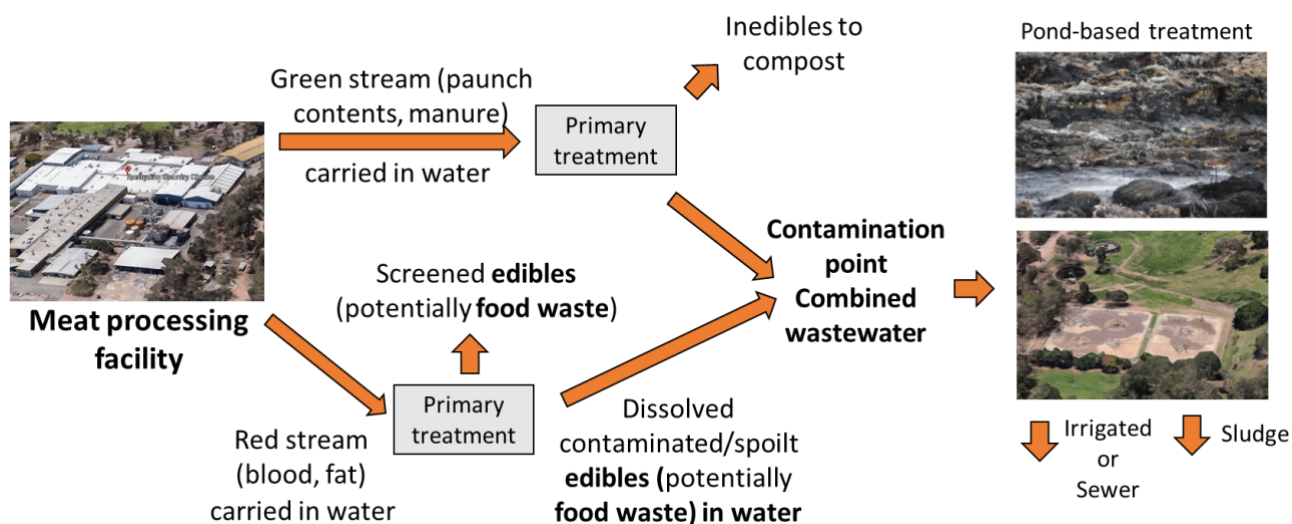
### 3 Results and Discussion

#### 3.1 Desktop Review

##### 3.1.1 Key organic wastes from red meat processing

Australian RMP utilises a fine-tuned sequence of processing steps to produce high-quality meat products and useful by-products. The sequential processing includes preparation for slaughter with livestock unloading and holding; slaughter including stunning, dehiding, evisceration, trimming and washing; offal processing including emptying of stomach contents and washing; chilling (which produces some cleaning water); boning; and rendering to produce tallow and meal (Australian Meat Processors Corporation, 2010b). Because of strict hygiene standards, meat processing uses a large quantity of hot and cold washing and sanitizing water, and this water would carry some meat residues and blood which could have been considered edible, and producing a wastewater.

Wastewater from different processing areas may be pre-treated before being lumped to produce a combined wastewater which typically undergoes pond-based biological treatment (Jensen, P. et al., 2014) (Figure 4) and is irrigated onto agricultural land to harness its nutrient value or in cases is instead discharged to sewer (Australian Meat Processors Corporation, 2010b; Liu and Haynes, 2011).



**Figure 4** A flow diagram illustrating generic RMP and the wastewater and organic wastes (“Screenings” and “Sludge”) that it produces. The wastewater contains potentially edible components (e.g. meat components, fat and blood) which rapidly become contaminated to variable extents with inedible components (e.g. manure and paunch contents). The crusty pond image on the right was adapted from (McCabe et al., 2014). RMP facility images were adapted from Google Earth Pro.

If potentially edible components entrained in the wastewater (e.g. red stream from the slaughter floor) can be recovered early-on by primary treatment before becoming significantly contaminated with inedibles (e.g. with manure or paunch contents), then it may be possible to save food waste (Section 1.4). This is often done via rendering. However, many meat processors struggle with aged legacy primary treatment systems, which are neither properly designed for closed-loop recovery nor optimal for closed-loop recovery.

Moreover, an increasing number of facilities are implementing covered anaerobic ponds to convert organic matter entrained in the wastewater into biogas to displace onsite boiler fuel. Whether or not organic matter is then recovered for reprocessing or whether it is instead allowed to progress with the wastewater onto subsequent covered pond treatment, would depend on the relative value of energy extractable as biogas vs. the value of extracted and reprocessed co-products (e.g. lower grade tallow) (Fredheim, 2018).

Biological sludge is produced by the onsite biological treatment of combined wastewater from RMP. This sludge consists of microbial biomass formed during treatment, non-biodegradable organic matter and other inerts. This sludge has been of emerging importance in recent years, with increasingly stringent environmental regulations requiring more intensive biological treatment of wastewater, leading to larger quantities of sludge (Yerman et al., 2020). This can add significant handling and disposal costs.

### 3.1.2 Energy consumption and organic waste (liquid and solid) production

The ACC meat processing facility in Cannon Hill Brisbane follows a similar processing chain to other RMP facilities, also producing organic wastes as described in the previous section. Whilst the Cannon Hill facility is strategically located from a business operability perspective, from a waste management perspective the facility is influenced by its locality in three important ways:

1. ACC considers it of utmost importance that their meat processing would minimise negative amenity impacts by operating in a manner to NOT be seen (e.g. no negative visual amenity impacts), heard (e.g. no noise) nor smelt (e.g. no odour);
2. The ACC processing facility has minimal footprint, with minimal-to-no ability to expand to utilise large relatively low-cost covered anaerobic ponds to recover biogas energy; and
3. The ACC processing facility has minimal-to-no land available to irrigate wastewater or spread solid organic wastes for agronomic purposes to recover value from nutrients, organic matter and water.

These influence potentially feasible closed-loop technology options for ACC Cannon Hill. In addition, whilst the facility is located in the port of Brisbane precinct, materials transported to and from the facility for closed-loop options were to be via road.

ACC provided data for the Cannon Hill facility to use in this project. These included:

1. Natural resource intensity (water and energy inputs); and
2. Wastewater and solid organic wastes amounts and costs.

For confidentiality, these data are not explicitly stated in this report, but instead are implicitly compared with available literature data to contextualise closed-loop options for ACC, including options potentially transferable to other Australian RMP facilities.

**Wastewater production by ACC RMP:** Industry data suggest site wastewater production to be on average 8.5 kL per tonne Hot Standard Carcass Weight (HSCW) as per an Environmental Performance Review published by AMPC (Ridoutt et al., 2015) (i.e. essentially 8.5 times as much wastewater as meat product produced). Around the time that this project report was being prepared, AMPC was in the process of conducting the next Environmental Performance Review for the RMP sector. The industry-average wastewater production amount in the 2015 Environmental Performance Review was reasonably representative of ACC Cannon Hill.

**Energy consumption and energy use type used by ACC RMP:** Available data suggest that meat processing is reasonably energy intensive, consuming on average, about 3,005 MJ per tonne HSCW, including thermal energy demand for onsite rendering (Ridoutt et al., 2015). ACC Cannon Hill has onsite rendering and the industry-average energy consumption was reasonably representative of ACC Cannon Hill.

On average, the majority energy form used by Australian red meat processors is electricity (35.6%), followed by natural gas (30.2%), coal (18.3%), fuel oil (1.4%), liquefied petroleum gas (LPG; 0.6%) and others (which include biomass and biogas) (Ridoutt et al., 2015). When typical thermal energy types (including coal, natural gas, biomass and biogas) are combined, the relative proportions of energy usage types in terms of thermal vs. electricity vs. LPG and diesel oil, were reasonably representative of ACC Cannon Hill, except that the Cannon Hill facility did not utilise biogas, biomass or natural gas.

**Organic waste production by ACC RMP:** Data on the availability of organic wastes from Australian RMP in general are scarce. Table 1 shows estimated organic waste amounts based on the minimal data available in the public domain. Estimates of total waste amounts for RMP across Australia are also given in Table 1 based on ~3 million tonnes HSCW per annum processed in 2018 (total sum of beef, veal, lamb and mutton production as per (Meat & Livestock Australia, 2019)). Data are also included in the table for inedible organic wastes because waste transformation technologies have been increasingly targeting these wastes to also be converted into food and fibre (see Sections 3.1.3 and 3.1.4).

The estimate of “solids from primary treatment” in Table 1 (potentially with a food waste component) is much higher than the National Food Waste Baseline estimate of 123,000 tonnes of food waste generated by beef, lamb, pork and chicken processing in 2016/17 (Arcadis, 2019). Moreover, indicative estimates using a recently published Aggregated Waste to Energy Tool developed by an AMPC project (All Energy Pty Ltd et al., 2020), indicated that the amount of organic waste potentially with a food waste component that is produced by Australian RMP could be:

- as little as 129,000 tonnes per annum (if only including “DAF Sludge” and “Red Stream Screenings” in the Aggregated Waste to Energy Tool); or
- as much as 715,000 tonnes per annum (if only including “DAF Sludge”, “Red Stream Screenings” and “Aerobic Wastewater Sludge/Waste activated sludge” in the Aggregated Waste to Energy Tool).

This highlighted a notable and important uncertainty in actual quantities of internal organic wastes with food waste components from Australian RMP, which affects the evaluation of closed-loop concepts.

**Table 1** Estimated amounts of organic wastes produced by Australian meat processing

Waste type	Amount (kg per tonne HSCW)	Reference	Comment	Estimated total amount (tonnes per annum)*
Manure (cattle yards)	4-13	(Australian Meat Processors Corporation, 2010a)	Not food waste	12,000 – 39,000
Paunch contents (paunch emptying & washing)	25-70	(Australian Meat Processors Corporation, 2010a)	Not food waste	75,000 – 210,000
Solids from primary treatment (screenings, dissolved air floatation float, bottom solids)	150-300	(Australian Meat Processors Corporation, 2010a)	Partially food waste	450,000 – 900,000
Biological sludges from wastewater treatment (waste activated sludge at 10-15% solids)	70-200	(Australian Meat Processors Corporation, 2010a)	Partially derived from food waste component	210,000 – 600,000

The combined estimates of manure and paunch contents in Table 1 were found to be representative of green stream screenings amounts reported by ACC Cannon Hill. The combined estimates of “solids from primary treatment” and “biological sludges from wastewater treatment” in Table 1 were much higher than wastewater treatment sludge amounts reported by ACC Cannon Hill which included both these wastes. This could indicate that the extent of recovery to onsite rendering at ACC Cannon Hill was high. This could be preferable from a closed-loop perspective. Note that none of the organic wastes produced by ACC Cannon Hill are sent to landfill, but instead are sent to offsite composting.

**Summary:** Overall, the ACC processing facility operations appeared to be average or better-than-average in terms of organic waste amounts produced, and average in terms of amounts of wastewater produced and energy consumed. A lack of reliable Australian RMP industry data on the quantities of organic wastes generated within the industry was identified as a key knowledge gap to be addressed in future work.

### 3.1.3 Past closed-loop investigations by ACC meat processing

The intended purpose and function of closed-loop technologies at ACC's facility (and similarly at other facilities) would be to:

1. enable energy recovery to offset onsite energy costs;
2. maximise conversion of inputs into products;
3. minimise solid organic wastes sent offsite; and
4. reduce costs associated with water (purchase, treatment, disposal) and solids handling and disposal.

ACC has a significant past-history of investigations of closed-loop options for their Cannon Hill facility. For example, as early as 2002, ACC was the winner of a Queensland Primary Industries Environment Award and a Queensland Red Meat Innovation Environment Award, for their eco-efficiency initiatives. These initiatives were documented in an early showcase study (Environmental Protection Agency Queensland, 2002).

Recent investigations included a comprehensive Organic Waste to Energy study carried out in 2017.

**Closed-loop water-related initiatives:** For meat processors like ACC that discharge their final treated wastewater to sewer, water is a triple-cost, including the cost of:

1. purchasing or extracting/pre-treating fresh water used for processing;
2. treating wastewater onsite prior to sewer discharge; and
3. discharging final treated wastewater to sewer.

Wastewater treatment and recovery is also relevant to food waste from RMP, because of the formerly edible components in the wastewater (Section 3.1.1). For these reasons, closed-loop solutions in RMP should also consider water/wastewater.

Past initiatives at ACC Cannon Hill have sought to reduce water use, and to recycle water to non-contact areas of the facility (Environmental Protection Agency Queensland, 2002). However, in general the quantity of water required in external non-contact areas of a meat processing facility is typically much less than that used for contact hygienisation purposes within the facility. This can severely limit opportunities for water recycling, because in some international jurisdictions, such as the USA, direct potable reuse is prohibited for contact in food production areas regardless of water quality; albeit that in other jurisdictions, such as EU, direct potable reuse is permitted if the water is of an appropriate potable quality (Prasad et al., 2017). This then affects closed-loop options for water of Australian RMP businesses that must meet the requirements of their respective export jurisdictions.

In past investigations, water recycling options did not appear to be limited by business case, and if the demand for water was available and water recycling was permissible, then typical analyses indicated that water recycling could be profitable, likely due to the triple-cost of water to ACC Cannon Hill.

Direct potable reuse also did not appear to be constrained by available technical or engineering solutions, because commercial technologies and food safe methods were established (HACCP principles; multi-barrier protection) to enable preparation of high-quality and safe direct potable reuse water; albeit that further work could explore future-proofing solutions against recalcitrant agents if they arise.

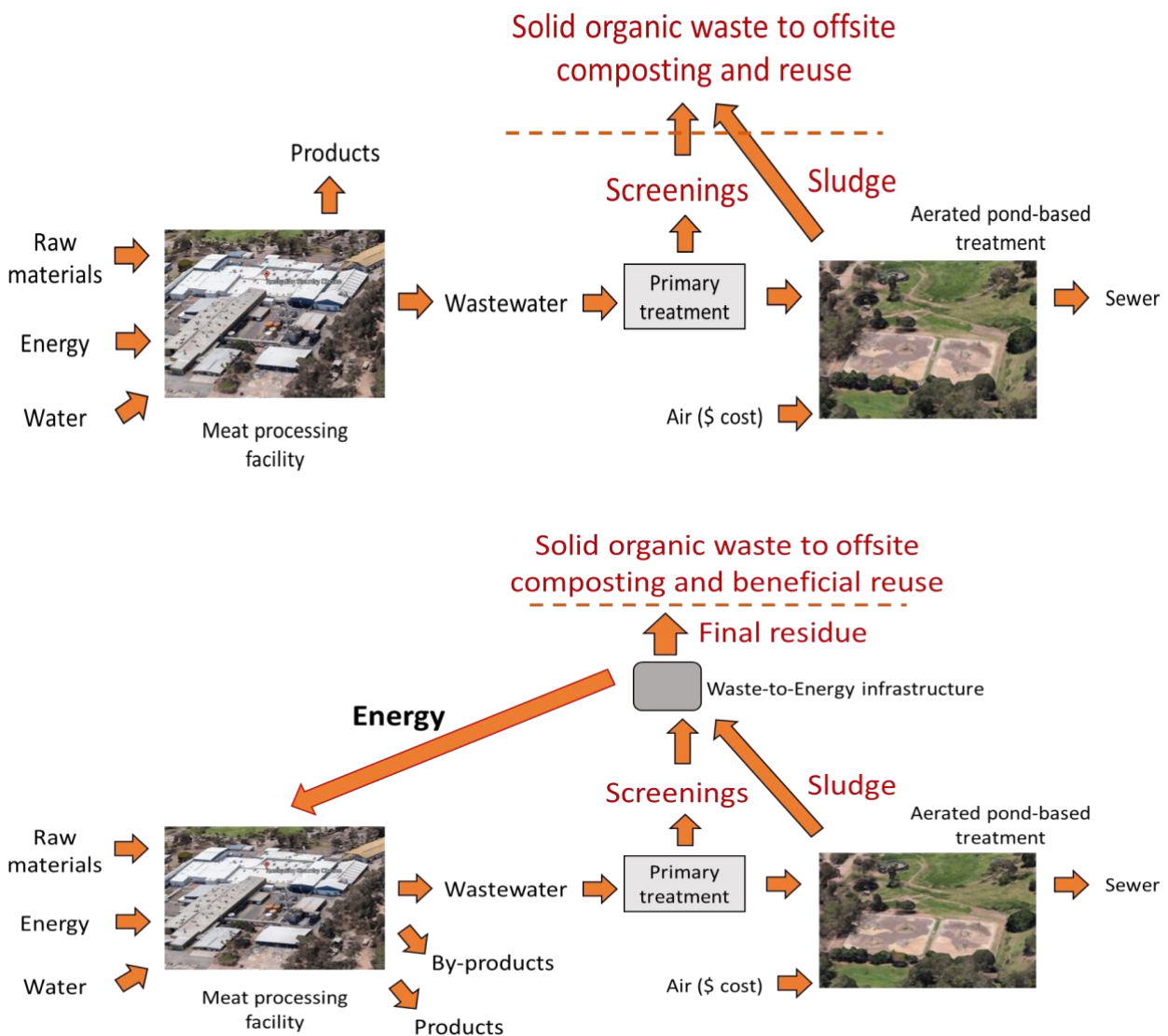
**Closed-loop energy-related initiatives:** Meat processing, including the operations of ACC, is energy intensive and organic wastes offer a potential closed-loop waste-to-energy solution. Past projects had explored the business case of organic waste-to-energy solutions for ACC. These had considered:

1. Drying and pelletising of solid organic wastes (paunch contents, manure and wastewater treatment sludge) before being used as a boiler fuel; and
2. Anaerobic co-digestion of solid organic wastes to produce biogas for use in a combined heat and power (CHP) generator to offset "behind the meter" baseload electricity demand.

These had investigated “end-of-pipe” waste to energy solutions (e.g. anaerobic co-digestion) for transforming solid organic wastes from ACC processing, before it left the site boundary (Figure 5).

Past studies showed moderate profitability for anaerobic co-digestion (~6 years simple payback period) and marginal profitability (>7 years simple payback period) for thermal options. These were sensitive to moderate-to-high capital costs.

Past investigations for ACC had only explored waste-to-energy as an end-of-pipe solution for solid organic wastes and had not considered integrated anaerobic treatment of wastewater. This may have been due to the space constraints of ACC Cannon Hill (Section 3.1.2).



**Figure 5** A generic flow diagram illustrating how past studies for ACC investigated “end-of-pipe” waste-to-energy technologies to transform solid organic wastes before they leave the site boundary to go to offsite composting and beneficial reuse. ACC facility images were adapted from Google Earth Pro.

Past investigations for ACC did not appear to define feasible and profitable reuse pathways for the final digestate from anaerobic co-digestion, and this could represent a significant cost risk for prospective anaerobic co-digestion projects. ACC's Cannon Hill facility appeared to have little-to-no option for beneficial reuse of digestate onsite or on nearby agricultural land. As a result, if digestate must be disposed of at additional cost, this would erode the economic benefit of a biogas project.

Recent policy initiatives in Queensland are enabling wastes to be classified as a resource to encourage beneficial reuse by reducing regulatory burden (Queensland Government Department of Environment and Science, 2020). However, this policy does not currently appear to cover beneficial reuse of digestate from anaerobic digestion.

**Closed-loop organic waste-to-feed initiatives:** Past projects for ACC Cannon Hill had explored novel options for "end-of-pipe" transformation of solid organic wastes and digestate into animal feed products. These included the production of black soldier fly larvae (BSFL) at a small to large size, with a small facility providing brood stock/strain optimisation for a larger commercial facility producing meal and oil, and the larger facility focussing on meal production via rendering. Mushrooms were also explored as a direct horticultural route for digestate. Early analyses indicated moderate-to-good business case for some of these options ( $\leq 5$  years payback), but also highlighted significant commercial and technology risk due to the infancy of markets and largely unknown technical and financial viability. Moreover, a more recent analysis for ACC indicated a less feasible business case for BSFL (All Energy Pty Ltd, 2019).

**Summary:** Findings from past ACC investigations reviewed in this project can be summarised as follows:

- Water is a critical resource and a major cost to all red meat processors including ACC, and significant business opportunities exist for potable reuse at meat processing plants. However, some international jurisdictions impose strict requirements, preventing direct potable reuse in direct contact areas of the processing facility where there tends to be the greatest potable water demand.
- Organic waste-to-energy options had been investigated as end-of-pipe solutions for solid organic wastes just before they leave the ACC processing facility to composting and beneficial reuse. Marginal profitability was observed, largely due to moderate-to-high capital costs.
- Past investigations on anaerobic co-digestion of solid organic wastes from ACC Cannon Hill showed moderate profitability but had not appeared to define feasible and profitable reuse pathways for digestate, and this represented a cost risk to a prospective digestion project.
- Organic waste-to-feed options had been explored for ACC Cannon Hill, including black soldier fly larvae and mushroom production, but were found to be *not* economically viable at this stage and/or were subject to significant technical and business risk.
- Integrated waste-to-energy or waste-to-feed options had not been previously explored for the wastewater component of ACC Cannon Hill. This may have been due to space constraints at ACC Cannon Hill likely preventing the use of relatively low-cost covered anaerobic ponds.

### 3.1.4 Closed-loop concepts or options explored from the general literature

With the assistance of a visiting PhD student Dr. Lisandra Marina Da Rocha Meneses from the Estonian University of Life Sciences, the project team reviewed scientific and peer reviewed literature, to more broadly identify a range of closed-loop technologies and concepts that could be considered and screened at a high level. Literature selected for review included:

1. Scientific and technical project reports in the public domain and published by reputable sources such as Meat and Livestock Australia (MLA) and the Australian Meat Processor Corporation (AMPC); and
2. Peer-reviewed international journals.

The outcomes of the review were summarised in Rocha Meneses et al. (2020). The technologies that were explored included:

1. Technologies suited to wastewater and technologies suited to solid organic wastes;
2. Biological, chemical and thermal technologies;
3. Technologies aimed at nutrient and organic matter recovery, albeit that technologies aimed at nutrient and organic matter dissipation/destruction were excluded;
4. Technologies aimed at energy and water extraction and recovery; and
5. Technologies aimed at upgrading of organic matter and nutrients into higher-value products, such as solid organic wastes into animal feeds and/or organic fertilisers.

In general, closed-loop technologies have previously been broadly classified as accumulation, release or extraction-type technologies (Mehta et al., 2015). Accumulation technologies aim to up-concentrate or capture waste resources from dilute waste streams into more concentrated processable forms (Mehta et al., 2015). Accumulation technologies often require a subsequent processing step to produce marketable products. Release technologies aim to mobilise nutrients or energy from an organic waste for subsequent use or extraction (Mehta et al., 2015) (e.g. biological or thermal processing to produce a gaseous or liquid fuel). Extraction technologies aim to recover marketable nutrient or animal feed products from organic wastes or wastewaters (Mehta et al., 2015). Note that some accumulation technologies could also be extraction technologies if the products that they produce are near market ready.

### **3.1.5 Initial screening and short-listing of closed-loop options**

The various technologies that were identified from the literature review and past ACC investigations were then screened as summarised in Table 2. This evaluation considered;

1. whether the technologies could *economically* reduce or transform food waste;
2. whether the technologies offered other significant industry profitability benefits;
3. respective technology readiness levels; and
4. significant secondary impacts (e.g. environmental impacts such as gaseous emissions during waste processing).

The short-listing evaluation is summarised in Table 2, showing a colour coding, being specifically;

- shading as green, meaning Yes – a short listed option selected for further evaluation;
- shading as red, meaning No – *not* a short listed or selected option; or
- shading as amber, meaning “Maybe” – indicating technologies that were not explicitly short-listed but showed great potential with significant anticipated future benefits to the RMP sector. These usually were attracting significant on-going research and development attention. Some of these technologies were integrated together with short-listed technologies in the subsequent more in-depth evaluation (Section 3.2).

Table 2 also provides a summary of the reasoning or justification for why a particular technology was short-listed or not. Based on this short-listing, a more in-depth scenario analyses of the short-listed options followed, as described in Section 3.2.

**Table 2** Screening and short-listing of potential closed-loop technology options during the desktop review.

Class	Technology	Short-listed (Yes/No/Maybe) - Reasoning	Key references
Accumulation	Activated sludge treatment	Red - No – High sludge production. Energy for aeration. Low-value sludge.	(The Ecoefficiency Group et al., 2017)
	Drying of solid organic wastes (removes moisture and thus reduces bulk) – Solar or Belt	Green - Yes – Can significantly reduce bulk of solid organic waste, removing moisture. Can prepare solids as feedstock for thermal processes.	(Bridle, 2011a, c; Spence et al., 2018)
	Electrocoagulation	Red - No – Produces salty residues; Need for research on cost feasibility.	(Price et al., 2018)
	Pre-fermentation and subsequent biological phosphorus removal	Red - No – Complex process. Requires readily biodegradable carbon. Not common in RMP. Low-value sludge.	(The Ecoefficiency Group et al., 2017)
	Primary treatment such as screening, settling or floatation	Green - Yes – Accumulates float and screenings, a part of common RMP wastewater treatment. Screenings from red stream can be part food waste.	(Bridle and Hickey, 2013; Fredheim, 2018)
	Uncovered anaerobic ponds	Red - No – Very common, but significant fugitive gaseous emissions. Low-value sludge.	(Jensen, P.D. et al., 2014; McCabe et al., 2014)
Release	Anaerobic (co-) digestion of solid organic wastes (also a Recovery technology if used to produce marketable digestate)	Amber – Maybe – Produces biogas for renewable energy. Produces digestate with mineralised nutrients for beneficial reuse. Shown to be marginally economically viable, but on-going costing and opportunity scoping initiatives are significant, and will likely identify a suitable economic fit within the red meat sector.	(All Energy Pty Ltd, 2017b; Heussner, 2017; Jensen and Tait, 2014; Jensen et al., 2016)
	Anaerobic treatment of liquid meat processing wastewater	Green - Yes - Covered ponds increasingly used. Fugitive emissions reduced by capturing and burning off-gases. Captures biogas as renewable fuel. High-rate engineered digesters provide low-footprint options. Can provide multiple benefits (see Section 3.2.1).	(Harris et al., 2018; Jensen, 2014; Jensen, 2016; Jensen et al., 2015; Johns Environmental Pty Ltd, 2016; McCabe et al., 2014; McCabe et al., 2020)
	Co-combustion of solid organic wastes with biomass or coal	Red - No – Economics unattractive, even if existing biogas boilers are being used. High costs for drying of moist solid organic wastes.	(Bridle, 2011a, b)
	Gasification of solid organic wastes (also Recovery* if used to produce marketable products)	Amber – Maybe – Can provide co-processing option for solid organic wastes. Can provide net positive return. Can reduce bulk. Potential for electricity generation from syngas. Sensitive to biochar sales.	(Bridle, 2011a, c)
	Pyrolysis of solid organic wastes (also Recovery* if used to produce marketable products)	Amber – Maybe – Can provide co-processing option for solid organic wastes. Can provide net positive return. Can reduce bulk. Sensitive to biochar sales.	(Bridle, 2011a, c)
	Smouldering (also Recovery* if used to produce marketable products)	Amber – Maybe – Able to handle higher moisture content, typical of solid organic wastes, but scale-up from lab to pilot scale not yet successful.	(Yerman et al., 2020)
	Torrefaction (also Recovery* if used to produce marketable products)	Red - No – Cost uncertainty. Marginal profitability. Economics sensitive to biochar sales, with unknown market value.	(Lycopodium Process Industries Pty Ltd, 2015)

Class	Technology	Short-listed (Yes/No/Maybe) - Reasoning	Key references
Extraction/ recovery	Black soldier fly larvae cultivation	Amber – Maybe – Whilst suggested not economically viable for ACC, Australian commercial entities with operational systems exist and service existing markets. Animal feed opportunities.	(All Energy Pty Ltd, 2017a)
	Composting	Amber – Maybe – Can reduce bulk. Conventional and common solution for biofertiliser production. Potential long-term soil organic matter benefits.	(Antille et al., 2018)
	Fibre extraction/ Biocomposites	Amber – Maybe – Technology readiness level is low for waste applications, but high for conventional commercial fibre composite products. Chemical digestion required.	(Jensen et al., 2017)
	Hydroponics or aeroponics for horticultural crops, including vertical gardens, cycling of waste nutrients, water and energy	Amber – Maybe – Commercial suppliers are emerging. Aligns with food production which is the core focus of the meat processing industry. Potential to value-add to nutrients, water and energy extracted from wastewater.	(Lal, 2016)
	Mushrooms	Red - No – Cost uncertainties. May require pre-sterilisation. Low technology readiness level.	(All Energy Pty Ltd, 2017a; Jensen et al., 2017)
	Micro-algae cultivation	Amber – Maybe – Medium technology readiness level. Moderate value end use for algal products possible. Limited by moderate production costs. Able to utilise waste resources (e.g. nutrients). Separation can be a challenge. Could produce range of products.	(Fornarelli et al., 2017)
	Membrane filtration and tertiary treatment for potable water recycling	Green - Yes – Commercial solutions are available. Profitability indicators are strong. The main barrier is international jurisdiction for some important export markets.	(All Energy Pty Ltd, 2017a; Prasad et al., 2017; Pype et al., 2017)
	Organo-mineral fertilisers production	Amber – Maybe – Solid organic wastes already typically land-applied, including after composting. Requires targeted research on fertiliser replacement value, organic matter benefits, and to formulate marketable products.	(Antille et al., 2018; McCabe et al., 2020)
	Purple phototrophic bacteria	Amber – Maybe – Can produce high protein content animal feed directly from wastewater. Moderate technology readiness level. Can grow in moderate strength wastewaters.	(Hulsen et al., 2018; Hülsen et al., 2017; Jensen et al., 2017)
	Pre-fermentation and biopolymer production	Red - No – Technology in early stages of development. Yields typically low and recovery costs are high.	(Jensen et al., 2017)
	Struvite precipitation for phosphorus recovery	Red - No - Solely focussed on phosphorus recovery rather than addressing a lumped food waste source.	(Butler, 2018)
	Three-phase decanter centrifuge	Amber – Maybe – Provides a means to recover additional low-grade tallow, thereby recovering additional food waste component. Can have short payback periods for particular facilities. Requires a hot feed stream, with potential opportunities to utilise waste heat.	(Olmstead, 2015)
	Transesterification and biodiesel production	Amber – Maybe – Continued interest from commercial entities. Challenged by costs, moisture content of organic wastes, purity and fuel properties and competitive uses of tallow feedstock.	(Meat & Livestock Australia Limited, 2011)

### 3.2 Further in-depth evaluation of closed-loop technology options

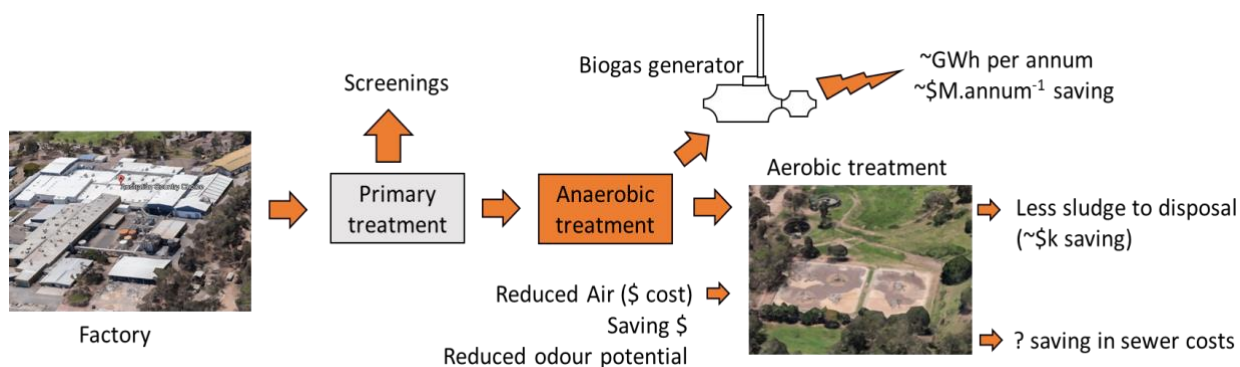
Short-listed technologies (Table 2) were further evaluated in terms of specific opportunities if integrated into ACC Cannon Hill or more broadly into other Australian RMP facilities. The outcomes of this analysis are described in the sections that follow.

#### 3.2.1 Integration of an organic matter transformation step for wastewater

Prior studies for ACC had not explored integration of a transformation step (e.g. anaerobic treatment) for wastewater upstream of the existing aerobic treatment step. Such a treatment step could reduce the organic loading to the subsequent aerobic treatment system, which could:

1. decrease the demand and cost for aeration energy;
2. reduce the amount of waste activated sludge produced; and
3. decrease the risk of odour from the aerobic treatment system.

One option is anaerobic treatment (Figure 6) which also provides biogas as a renewable energy source. This has the potential to offset onsite electricity and fossil fuel use, reduce costs and increase profitability. For ACC, electricity is a logical first energy source to offset with biogas, because electricity is clean, versatile and a well-known energy type in significant demand at ACC Cannon Hill. Moreover, natural gas is not currently used as a boiler fuel at ACC Cannon Hill.



**Figure 6** A generic flow diagram illustrating a potential option to integrate anaerobic treatment of wastewater at a RMP facility, also indicating the additional benefits such treatment could provide at a facility such as ACC Cannon Hill. RMP facility images were adapted from Google Earth Pro.

Biogas can be used to fuel a generator to continuously supply the baseload “behind the meter” electricity used by a facility. In Australia, the general experience to date has been that connection of a biogas generator to the electricity supply network to export excess electricity can be costly and/or difficult to negotiate, and the tariff received for exported electricity is generally low. For these reasons, it may not be as profitable to size a larger biogas generator to provide the peak electricity demand of a facility, because such a generator would have to export excess electricity generated during the trough usage periods.

As noted earlier, covered anaerobic ponds are becoming increasingly popular for biogas recovery from wastewater at Australian RMP facilities, due to their relatively low cost and simplicity. However, covered ponds typically have large footprints, and would unlikely be an option for ACC Cannon Hill due to space constraints (Section 3.1.2).

High-rate anaerobic treatment is an alternative option with a small compact footprint. Two types of high-rate anaerobic treatment systems may be suitable for RMP wastewater, namely:

1. Anaerobic membrane bioreactors (AnMBRs), which are commercially available and have been previously tested at pilot scale in Australian RMP (Jensen, 2014; Jensen et al., 2015). The technology uses a membrane to retain microbial biomass, organic solids and fats, allowing a high spatial loading; and
2. Anaerobic floatation reactors (AFRs) (Jensen, P.D. et al., 2014), which are commercially available and operate with biomass, solids and fat, oil and grease being separated out using a biogas sparged floatation chamber, and being returned to the reactor for further treatment. As with the AnMBR, the AFR decouples the treatment times for the water and retained solids components to allow a high spatial loading (<https://en.pagues.nl/products/featured/biopag/biopagafr>).

High-rate anaerobic systems preferably operate at elevated temperatures of about 35-38°C for mesophilic systems, or even at thermophilic conditions (Jensen, 2014; Jensen et al., 2015). An energy balance would need to be performed for a site to determine if waste heat is available that could be used to preheat the wastewater prior to anaerobic treatment (e.g. using hot water recovered from an generator engine, or hot streams exiting rendering).

A high-level business case analysis in the current project indicated that anaerobic treatment could be reasonably profitable for ACC Cannon Hill. A future, more detailed investigation is recommended to further investigate and clarify economic and technical feasibility of this technology option.

Into the future, as emerging wastewater treatment technologies such as purple phototrophic bacteria (Hulsen et al., 2018; Hülßen et al., 2017; Jensen et al., 2017) and microalgal photobioreactors (Fornarelli et al., 2017) become increasingly mature, these could be considered in the place of an anaerobic treatment step. Such technologies would instead recover organic matter and nutrients as a protein-rich microbial biomass or as other higher-value products. This would have the same benefits as listed above for anaerobic treatment, also reducing the organic loading to a subsequent aerobic biological treatment step.

Although not further explored in the current project (because biogas energy is not typically available in excess at meat processing facilities), the upgrading of biogas to produce biomethane may provide future opportunities, because biomethane is nearly identical to commercial natural gas and can be an excellent substitute for natural gas.

### **3.2.2 Integration of an end-of-pipe valorisation approach for solid organic wastes**

Prior studies for ACC had explored end-of-pipe conversion technologies for solid organic wastes (Section 3.1.3). Such end-of-pipe conversion technologies can be biological (e.g. anaerobic digestion) or thermal.

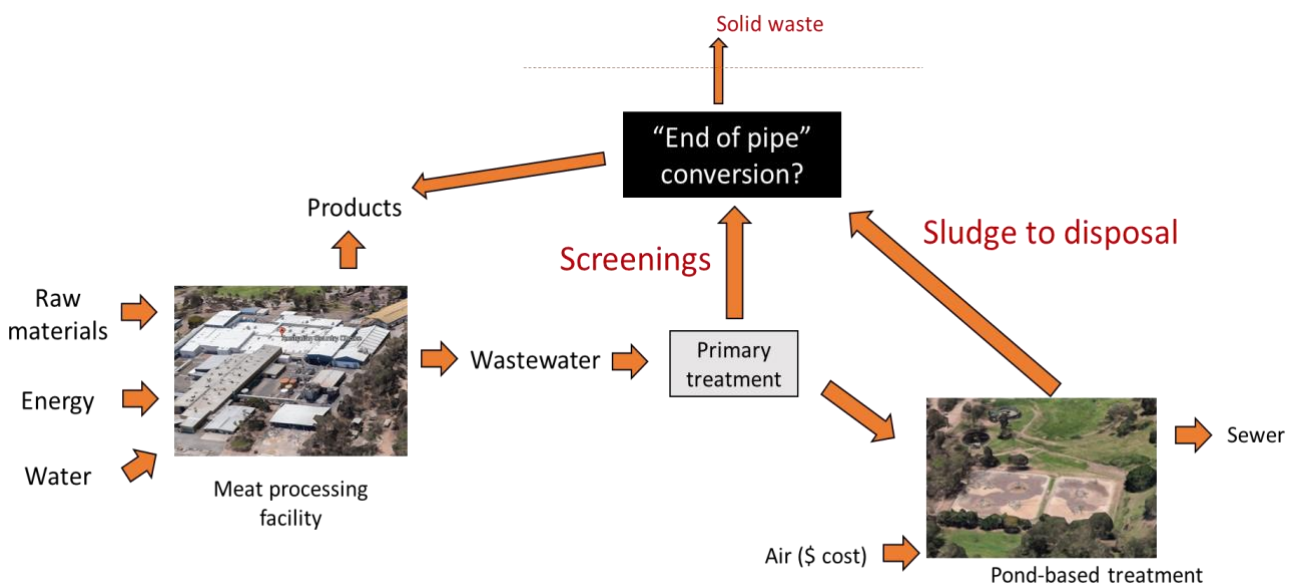
Anaerobic digestion should aim to minimise digestate tonnages for final offsite processing. Alternatively, digestate should be beneficially reused or converted into marketable products that could minimise disposal costs and/or generate additional revenue. Anaerobic digestion technologies are commercially available that tolerate high solids feedstocks, and this may be beneficial to minimise the amount of dilution water used for feedstock preparation, and thus minimise digestate tonnages to subsequently dewater and/or process.

Thermal conversion technologies aim for volume/mass reduction of paunch contents and wastewater treatment sludge to substantially reduce final disposal costs, by instead converting wastes into products and energy. Examples include gasification and pyrolysis (Bridle, 2011c), which involve conditions with limited to no oxygen, and produce biochar, biocrude, syngas and ash, in proportions depending on the operating conditions and the waste feedstock composition. Syngas, biochar and biocrude are also potential energy sources if further combusted (Bridle, 2011c).

A high moisture content of solid organic wastes from meat processing has been a consistent challenge for thermal processing options and minimises or even eliminates the net energy benefit from processing of RMP organic wastes (Bridle, 2011c), but interesting drying options have been previously considered in investigations (Bridle, 2011a, c; Spence et al., 2018). This could significantly value-add by reducing bulk tonnages of solid organic waste prior to thermal processing to enable a net positive energy balance. These should be further explored in future work.

As also highlighted in Section 3.1.3, the near-complete conversion of solid organic wastes into marketable products is important to minimise final residues requiring disposal (Figure 7), because post-processing and final disposal costs could erode the economic benefits of conversion. This was especially noted for thermal processing technologies, where economic feasibility was very sensitive to the sale of novel final products such as biochar. Markets for biochar are yet to become known and established.

The same applies for biological conversion processes (e.g. anaerobic (co-)digestion and composting) for which outputs should be valorised into products that match the requirements of suitable reuse markets. For example, granulation of digestate or compost incorporating, blending or coating with additives such as synthetic fertilisers, may supply a more physically and chemically balanced fertiliser for crop growth. New formulation approaches should also consider the form of products being produced, to make them suitable for end-use in existing farm machinery. For example, granulated biofertiliser products can be more amenable to spreading with conventional fertiliser spreaders, and this could facilitate market penetration.



**Figure 7** A generic flow diagram illustrating how integration of end-of-pipe conversion and processing technologies should maximise conversion into marketable products to minimise final waste for disposal. RMP facility images were adapted from Google Earth Pro.

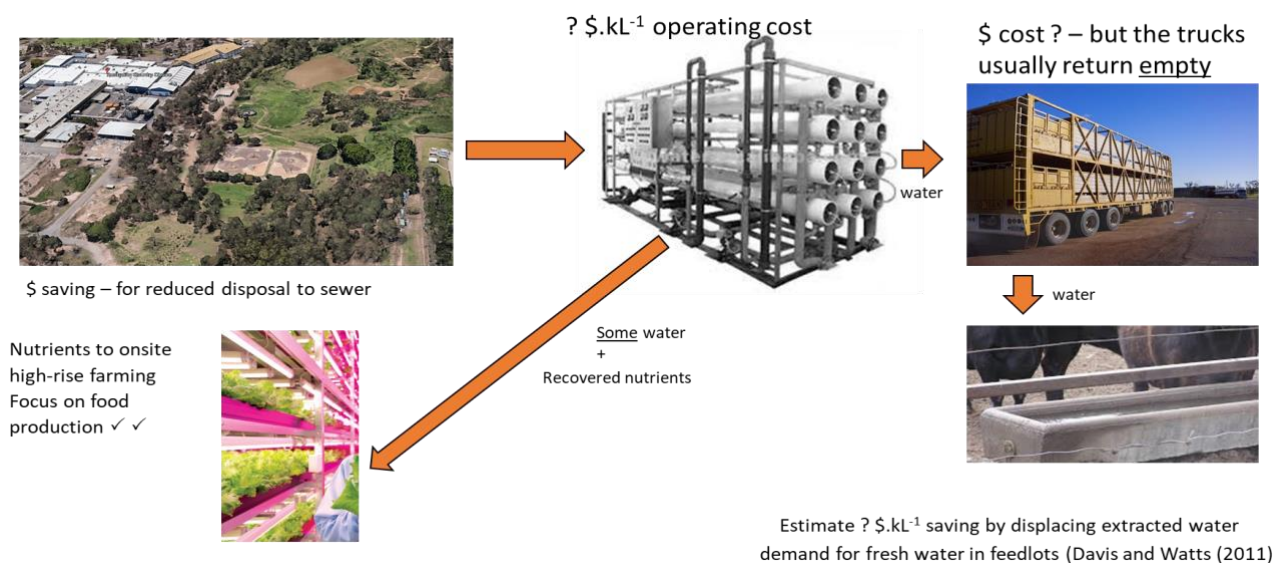
From the literature review it was clear that future research is needed to validate the value of carbon in products from conversion processes (e.g. in biochar, or in compost, or in a separated solid fraction of digestate). This would be important to understand realistic markets for the conversion products, and thus the true business case for conversion technologies. It will be important to consider the incremental value-proposition of all conversion and processing steps being added to produce such products from organic wastes. This is important to ensure that costs of conversion and processing are justified by the incremental value-add of processing to achieve reasonable market expectations.

### 3.2.3 Options for recycling of water across the livestock supply chain

Section 3.1.3 highlighted how direct potable reuse water within a meat processing facility was restricted by some international jurisdictions. As a result, only a limited demand for recycled water existed in external non-contact plant areas. Profitability and technical feasibility were typically strong in cases where there was a significant water demand and use of high-quality recycled water would be permitted (Section 3.1.3). This is important because:

1. advanced water treatment and recycling technologies are commercially mature and readily available in Australia;
2. meat processing is water-intensive (Section 3.1.2); and
3. sites that discharge final treated wastewater to sewer (such as ACC) pay for water three times (i.e. to purchase, to treat, and to dispose to sewer).

Water is a critical resource consumed across the entire livestock supply chain, not just at the processing stage. In fact, consumption of water on farms and feedlots has been estimated to be more than 90% of the total water used across the red meat industry (O'Hara et al., 2016). Beef feedlots are estimated to use 30-104 kL per tonne HSCW gain (75-90% for drinking) (Davis et al., 2008) as compared to meat processing which uses ~8.5 kL per tonne HSCW processed (Ridoutt et al., 2015). If treatment barriers were in place to produce safe potable recycled water and if logistical challenges of transport up the supply chain could be overcome, there may be significant opportunities to meet water demands further up the livestock supply chain. This potential opportunity was discussed during project workshops because trucks that carry cattle to a meat processing facility leave empty when they return to a farm or feedlot. It may be possible to backload such trucks with high-quality potable recycled water (Figure 8).



**Figure 8** A generic flow diagram illustrating potential potable water recycling opportunities across a livestock supply chain, specifically from meat processing to beef feedlots. Advanced water treatment could also enhance nutrient and water recovery for other food production purposes, such as horticultural crop production via hydroponics or aeroponics, or for microalgal systems. Source: Adapted from Australian Country Choice (2019), Alibaba.com, Watts et al. (2016), Google Earth Pro., Bosworth (2016), copyright retained by source.

Potential benefits of integrated water recycling at ACC Cannon Hill could include:

1. Decreased volume-based sewer discharge costs (would need approvals to discharge higher nutrient concentration or would need to recover nutrients for other applications);
2. More efficient recovery of nutrients, with a higher nutrient concentration in the reject water from a membrane water treatment plant. Such nutrients may provide novel future opportunities, such as to grow horticultural crops (Figure 8) or to produce microalgal products;
3. Making high quality potable recycled water available across the livestock supply chain. This could displace extracted bore water used at a feedlot and thereby save on extraction costs. This could also improve reliability of water supply to a feedlot; and
4. The implementation of water treatment equipment could ready a meat processing facility for a future where international jurisdictions may permit direct potable reuse across the facility.

The vertically integrated supply chain of ACC (Section 1.5) could facilitate the implementation of such water recycling initiatives. Moreover, the concept of nutrient recovery for novel agronomic concepts, such as integrated horticulture (Figure 8), appeared to align well with ACC's goals to maximise food production from inputs and was also consistent with ACC's view that their Cannon Hill facility is a "food facility", not an abattoir (Australian Country Choice, 2019).

The economic and technical feasibility of an integrated water recycling and nutrient recovery and reuse option was unknown. Future work is required to explore these feasibility aspects, including a consideration of the logistics and costs of preparing and backloading potable recycled water onto trucks for transport to a feedlot. Integration options for novel horticultural or other agronomic production systems should be further analysed.

Note that the most suitable feedwater for a water recycling plant would likely be aerobically pre-treated final wastewater, such as is available from the aerated treatment pond at ACC Cannon Hill, rather than upstream primary treated wastewater. This is because a membrane filtration plant is unlikely to be tolerant of a high organic loading which could exacerbate biofouling.

### **3.3 Similarities between meat processing and milk processing, implications for closed-loop options**

To further the reach of the FFW -CRC by identifying future research opportunities, the project compared organic waste streams of meat processing with that of other food processing sectors. This was to identify similarities and therefore synergistic opportunities to transfer closed-loop concepts from meat processing to the other sectors. A sector that showed close alignment with RMP in this regard was milk processing, because both milk processing and meat processing:

1. use significant quantities of water for cleaning, which carries product losses as potential food waste;
2. are energy-intensive, including having a significant thermal energy demand, and this highlighted potential opportunities for anaerobic treatment of wastewater. Moreover, milk processing sources significant amounts of thermal energy from natural gas (Prasad, 2006), which can be readily displaced with biogas;
3. use primary treatment and often pond treatment of wastewater, especially prior to sewer discharge; and
4. produce sludges from wastewater treatment as a significant organic waste type (Arcadis, 2019; Australian Meat Processors Corporation, 2010a).

In fact, an Australian university lumped the organic waste streams and possible treatment options for milk processing and RMP into a single review paper under the title "Origin, Nature, and Treatment of Effluents From Dairy and Meat Processing Factories...." (Liu and Haynes, 2011), reflecting the similarities between these two processing sectors.

Whey is a key liquid organic waste unique to milk processing (Arcadis, 2019; Fernandez-Gutierrez et al., 2017). However, because of a highly fermentable lactose content (Prazeres et al., 2012), whey could be amenable to high-rate anaerobic treatment (Prazeres et al., 2012) as suggested for RMP wastewater in Section 3.2.1.

In general, variants of the closed-loop concepts analysed for RMP above may be transferable to organic waste streams from milk processing. There are seemingly similar opportunities for water and energy recovery in both sectors, albeit that indirect potable reuse may be less restricted in milk processing.

### **3.4 Identified knowledge gaps, opportunities for further research and prospective future projects**

This project was a scoping project, intended to identify key knowledge gaps and opportunities for further research pertaining to closed-loop concepts. This aims to progress Australian RMP towards a profitable circular economy.

To scope out prospective project concepts, a collaborative workshop was held as part of the project, with key CRC researchers from QUT, USQ and UQ members of the FFW -CRC's Transform Program. The discussion led to the outcomes described in this section.

The literature review and project scoping workshop highlighted key knowledge gaps and research opportunities in three important areas:

1. Quantification and characterisation of resource intensity and organic waste streams within meat processing and across the livestock supply chain;
2. Testing and validation of closed-loop technologies within the Australian RMP context; and
3. Validation of business models, products and markets for closed-loop technologies and concepts.

#### **3.4.1 Quantification of resource intensity and internal organic waste streams**

With vertically integrated companies potentially offering opportunities to cycle natural resources further up the supply chain (Section 3.2.3), there is a need to better track resource use intensity (energy, water and nutrient inputs) and wastage across supply chains. This will help to highlight opportunities for circularity and reduced wastage. Future work could consider producing a resource map for the red meat supply chain, and possibly a valorisation roadmap as a decision support tool.

The desktop review of the project highlighted how RMP produced significant quantities of solid organic waste and wastewater, both of which can contain food waste components (e.g. blood and fat). The review further indicated a potential substantial discrepancy (approximately 2-3 fold) between estimates of meat processing food waste in the National Food Waste Baseline vs. estimates in the current project using the minimal publicly-available industry data (Section 3.1.2). There is a need to better understand quantities and characteristics of organic waste streams across the livestock supply chain, and especially for meat processing.

For the purposes of identifying and targeting food waste reduction, it may be important for future analyses to try and clarify which internal organic waste streams have a significant food waste fraction (Section 3.1.2).

### 3.4.2 Testing and validation of closed-loop technologies within Australian red meat processing

A few pertinent studies of closed-loop technologies applied to Australian RMP wastes have been reviewed in the current project. Many of these studies tested technologies up to pilot scale, providing invaluable data to evaluate high-level suitability of particular technologies for sites like ACC Cannon Hill. Similar validation studies should continue into the future, especially for promising technologies that are subject to significant cost, performance or product uncertainty. An example was thermal processing, being sensitive to moisture and ash contents of the solid organic waste being processed, and being heavily reliant on the value of co-products such as biochar for which established markets may not yet exist. Such future work should also seek to guide policy and regulatory developments (e.g. to facilitate direct potable reuse, or to promote beneficial reuse of anaerobic digestion digestate).

Pilot testing can be costly and consume significant project resources but would provide very important testing and validation data at a relevant scale. Several of the closed-loop technologies identified and analysed in the review were ranked as “Maybe” technologies, because of significant on-going R&D interest and/or significant potential benefits for RMP if matured to a commercial scale. Testing and development of such technologies should continue and is a priority to ensure that a pipeline of relevant concepts is available into the future.

The importance of further testing and development has already been highlighted by key initiatives exploring various waste conversion technologies for livestock sectors, such as the large MLA-led Waste to Profits program (<https://research.qut.edu.au/biorefining/projects/wastes-to-profits/>). In addition, MLA donor-funded partner-initiated projects and AMPC site-specific projects (See References) have to date provided invaluable seed funding for pilot testing and technology validation in meat processing at a relevant scale. There is a strong need and opportunity for such initiatives to continue via strategic future projects, including via the FFW -CRC Transform Program.

Performance and development testing could assist in providing confidence in technology solutions, including to help overcome international (e.g. water recycling) and national (e.g. digestate management) regulatory barriers, and to future-proof closed-loop concepts.

The analysis in the project also highlighted how the combined integration of various closed-loop technologies may provide greater benefits, working together to maximise resource recovery and to minimise wastage. The examples above included:

1. Anaerobic treatment of RMP wastewater, allowing energy recovery in the form of biogas for onsite electricity or heat production, whilst facilitating downstream aerobic biological treatment and reducing aeration energy and waste activated sludge disposal costs (Section 3.2.1); and
2. Potable water recycling, which could enhance nutrient recovery opportunities for novel agronomic purposes and may make water available across a broader supply chain. This could consider integrating novel nutrient recovery systems together with innovative horticultural production systems (e.g. hydroponics) (Section 3.2.3).

Proof of concept testing of the integration of various technologies could provide evidence for the interactive benefits, strengthening the future business case for implementation of closed-loop concepts.

### 3.4.3 Validation of business models and product markets for closed-loop technologies and concepts

Some closed-loop technologies reviewed in the project were commercially available and had already been tested at pilot scale within the RMP sector. However, more detailed feasibility analyses are needed to clarify full-scale applications. Such feasibility assessments could draw on data from on-going testing and development projects (Section 3.4.2). The aim will be to identify suitable fits for various closed-loop technologies across the Australian RMP sector to progress the sector towards circularity. This would build momentum as more sites implement closed-loop technologies, providing demonstrations and case studies for other processing facilities considering the same technologies, and building evidence for the benefits.

Case study data can be used to validate industry economic assessment tools being developed to assist the evaluation of a business case for new projects. An example is the aggregated waste to energy (W2E) concept calculator recently developed with funding from AMPC (All Energy Pty Ltd et al., 2020), which helps RMP facilities to quickly assess aggregated waste to energy options for their facility. A similar tool is in development via MLA Rural R&D for Profits Waste to Profits called ADAAdvisor ([https://www.youtube.com/watch?time\\_continue=3&v=dI6fEcF\\_BcM&feature=emb\\_logo](https://www.youtube.com/watch?time_continue=3&v=dI6fEcF_BcM&feature=emb_logo)). ADAAdvisor expands the scope of feasibility evaluation across organic wastes from various Australian livestock sectors, specifically for anaerobic co-digestion. Tools like these will likely enable future business case development and evaluation, to assist decision making and to encourage the uptake of closed-loop technologies.

End-of-pipe thermal processing technologies appeared to show a strong potential to reduce waste quantities via valorisation into energy and products. However, the economic feasibility of such technologies appeared to be very sensitive to the sale value of co-products, especially biochar. Past research activity on biochar has been significant. For example, there have been large initiatives such as the National Biochar Initiative (DAFF, 2012) and past research conducted via CSIRO's Sustainable Agriculture Flagship (<https://biochar-international.org/csiro/>). This past research had indicated that biochar could enhance soil fertility, increase soil carbon and decrease greenhouse gas emissions under particular circumstances (Cowie et al., 2013). However, there is still considerable uncertainty around the anticipated benefits of a proposed biochar product for a proposed agricultural application. There is a need for future work to fully characterise such co-products together with their market credentials to enable uptake of closed-loop technologies.

Digestate from anaerobic digestion and compost are both established products. However, regulations around the beneficial reuse of digestate is still under development in Australia, largely because anaerobic digestion technology is still in its early stages of adoption in Australia. There is a need for agronomic performance testing on digestate to clarify the benefits, including nutrient and soil carbon benefits. Further, market penetration and beneficial reuse of digestate could be facilitated by better product formulations, including of physical properties that would ideally match the mechanical handling and spreading capabilities of existing broadacre cropping equipment. In this regard, formulation methods such as granulation or pelletisation could greatly assist by increasing particle size and strength of a product to make it more favourable for use. However, future work should also clarify the cost-benefit of such further processing steps.

### 3.5 Short, medium and long-term strategies to transition ACC towards increasing circularity

The project investigations were centred around ACC as an important Australian red meat processor. To value-add to ACC's business profitability and to assist ACC in their progress towards a circular economy, the project developed a set of possible short, medium and long-term strategies that ACC could consider for implementation. These are documented in this section. Implementation of these strategies by ACC would be voluntary.

#### 3.5.1 Short-term strategies (0 - 3 years)

1. To better understand inputs and natural resource intensity across ACC's supply chain, it is proposed that a "walk the chain" style project be conducted looking at the amount and cost of water, the amount, type and cost of energy, and feed inputs across ACC's whole supply chain. This can then be used to develop a resource map for ACC's supply chain and to clarify waste resource cycling opportunities across the supply chain.
2. To better understand meat processing organic waste streams as a potential resource for transformation into products, it is proposed that ACC carry out a detailed organic waste quantification and characterisation exercise for the Cannon Hill facility. This could include metering, sampling and analysis of red stream wastewater (which can contain a significant food waste component), as well as the internal solid organic wastes at the point immediately following initial separation from the wastewater.

With these short-term strategies implemented, it is proposed that ACC sets clear and achievable targets in the form of a revised Cleaner Production Implementation Plan. The results from the studies in (1.) and (2.) could enable ACC to confidently assess the business case for closed-loop options in the mid-term.

3. To understand the true benefits of high-rate anaerobic treatment of wastewater to ACC's Cannon Hill facility, it is proposed that a feasibility/process options study be commissioned, specifically exploring the cost-benefit of a commercial anaerobic treatment high-rate system applied to the primary treated wastewater at the site. The study should consider electricity from biogas, together with other potential ancillary benefits highlighted in this report, such as reduced sludge production, reduced aeration costs, and potentially reduced load-based sewer discharge costs.

Pending the outcome of the high-rate anaerobic treatment options study (3. above), a detailed feasibility study would be a logical next step to progress the technology towards implementation.

#### 3.5.2 Mid-term strategies (3 - 10 years)

Pending the outcomes of the resource map from (1.) and waste characterisation study from (2.) it is proposed that:

4. ACC explores the logistics of and business case for backloading empty cattle trucks with potable recycled water prepared at the processing plant for transport to ACC's upstream operations;
5. ACC conducts an options and feasibility assessment of an integrated closed-loop concept that includes nutrient and water recovery, and innovative horticultural production systems; and
6. ACC considers the logistics of and business case for dewatering and/or drying options for solid organic waste at Cannon Hill. These could significantly reduce the tonnages of solid organic waste sent offsite and could improve the future business case for thermal processing options.

Pending the outcome of the investigations in (4.), (5.) and (6.), the logical next step for ACC would be to progress some or all of the closed-loop concepts towards detailed feasibility assessment and implementation.

7. Because the regulatory context for digestate as a beneficial reuse product is progressively evolving, it is proposed that ACC revisits the business case for anaerobic (co-)digestion in 5-10 years' time. Digestate may have a significant market value by then and this could make the business case for the technology attractive to ACC into the future.

### **3.5.3 Long-term strategies (10 - 20 years)**

8. To continue to progress ACC towards carbon neutrality and zero waste into the long-term, it is proposed that ACC keeps a watching brief on closed-loop technologies for feed and fibre production from organic waste. This could include alignment with on-going MLA, AMPC and other funding initiatives in terms of progressing technology prospects from bench to pilot to commercial scale, potentially including for Cannon Hill and upstream production sites.
9. Whilst this report and project focussed largely within the bounds of the Cannon Hill facility (because of the relative importance of meat processing to food waste production, Section 1.4), it is proposed that ACC in the longer term promotes circularity across its entire supply chain from on-farm through to processing. This should benefit from ACC's fully vertically integrated supply chain, providing greater control in terms of cycling of waste resources, for example, with potential cycling of fertiliser nutrients and/or water from processing to upstream on-farm operations, to benefit ACC's broader supply chain.

## 4 Impact and ongoing monitoring

### 4.1 FFW -CRC Project Impact Tool assessment

Potential project impacts in terms of relevant FFW -CRC metrics were quantified using the FFW -CRC Project Impact Tool Version 2.1.4 (the Impact Tool). The following were assumed or considered during the analysis by the Impact Tool:

1. analysis of a scenario where the RMP industry had actually implemented technologies and practices as identified and scoped out in the current project. This is important to note, because the current project was a scoping project, not an implementation project.
2. Impact area = processing (for livestock), specifically food waste from meat processing.
3. Estimates of where food waste ends up were taken from the National Food Waste Baseline report specifically being anaerobic treatment (assumed to be in uncovered ponds) (8%), biomaterials/bioprocessing (60%), composting or aerobic processes (30%) and landfill (2%) (Arcadis, 2019).
4. Likelihood of technical success = medium (50%)<sup>1</sup>
5. Estimated number of years to full impact = 10 years
6. Number of years the solution will be utilised = 10 years <sup>1</sup>
7. Likelihood of adoption = medium (50%)<sup>1</sup>
8. Target potential food waste nominally set at the Table 1 estimate of primary treatment solids (Section 3.1.1, 675,000 tonnes per annum across Australia red meat sector). However, as highlighted in Section 3.1.1, the amount of actual food waste from RMP is very uncertain due to a lack of publicly available data on internal organic waste streams, and a lack of knowledge about the fraction of various organic waste streams that is actually food waste.
9. Assumed 25% of food waste produced could be saved by implementing closed-loop concepts.
10. Assumed conservatively 2 industry people trainer per year for 10 years in the field of closed-loop concepts because of implementation of research and/or circular technologies in the report.

The results from this assessment using the Impact Tool are summarised in Table 3.

**Table 3** Summary of project impacts estimated by the FFW -CRC Project Impact Tool Version 2.1.4

Impact area	FFW -CRC Target	Estimated project impact (from the Impact Tool)*
Reduction in food waste	30 million tonnes reduction	191,762 tonnes per annum reduction
Industry profitability	\$2 billion increase	\$2 million per annum
Food rescue	20 million kg	Not applicable
Job creation	5200 circular economy jobs	16 circular economy jobs
Training future leaders	40 future leaders graduated	Not applicable. No FFW CRC students were involved in this project.
Training industry people	250 industry people trained p.a.	10
Greenhouse gas emissions	44 Mtonnes co2-eq	0.05 Mtonnes co2-eq

\*Estimated project impacts as directly given by the Impact Tool. These were not independently estimated, assessed, or verified.

It is anticipated it will take a significant amount of time to achieve full circularity within the red meat sector. However, within a 10 years' time frame, the current project is expected to assist by pointing towards short to medium-term projects that could be realistically initiated/progressed to clarify the business case for circular technologies and in this way to drive adoption. For ACC specifically, closed-loop concepts were analysed during the project which could also allow cycling of waste resources further up ACC's broader supply chain.

<sup>1</sup> This would be expected to depend on the technology solution selected and being adopted and its respective readiness level. It was noted that technologies could improve over time. Actual impacts of the project in the mid to long term would depend on the extent of adoption of circular technologies within a nominated 10-year time frame. Systems currently considered as state-of-the-art commercially may become aged and legacy in 10 years' time.

Due to the similarities between RMP and milk processing (Section 3.3), the transference of closed-loop technologies between these industries may be possible with likely additional impacts.

#### **4.2 On-going monitoring**

Because data on waste amounts were very scarce, an initial step of any follow-on project should be to investigate and refine food waste estimates from RMP. This can engage with Research Development Corporations (RDCs) (e.g. AMPC, MLA) who will likely have an interest in this work.

Impact can be measured into the future by tracking implementation over the next 10 years of project concepts as proposed in this scoping study report, including for ACC specifically, as well as for the broader red meat industry. For example, this report included definition of measurable short and mid-term strategies for ACC to increasingly transition towards a circular economy.

One aspect that was uncertain during the impact assessment, due to data gaps identified by the current project (Section 3.4), was the forecasted industry profitability gains which would result from circular concepts implemented in the RMP sector. This is partly due to diversity in the industry (e.g. some sites are house-locked, whilst others are remote regional). Ongoing initiatives should aim to quantify these profitability gains, which could include reduced input costs (e.g. energy and water) as well as reduced disposal costs for those facilities that currently pay for their solid or liquid waste to be processed and/or disposed offsite. The quantification of benefits can help clarify and calibrate business evaluation tools in development for circular technologies and projects (Section 3.4.3). It is recommended that the FFW -CRC impact tool also be rerun in the future, using updated and calibrated data.

## 5 Conclusions and Recommendations

This was a scoping project. The aim was to screen closed-loop technologies and practices for RMP to define important knowledge gaps, and to define future project concepts that can promote adoption of closed-loop technologies across the RMP sector. The project structured its investigations around an important red meat processor, namely ACC. An in-depth desktop review and analysis was carried out. The investigation led to the following conclusions:

- As much as 675,000 tonnes of organic waste with a significant food waste component is produced annually by red meat processing (RMP) across Australia.
- A significant amount of organic waste ends up in relatively low-value end uses, providing opportunities for valorisation using closed-loop technologies that cycle waste resources such as energy, water, organic matter and nutrients.
- The food waste is often combined with wastewater, which affects closed-loop technology options;
- Several closed-loop technologies showed merit for RMP wastes, but many of these are still under development and, because of significant anticipated benefits, justify further research;
- Integration of closed-loop technologies can provide multiple benefits, such as reduction in waste, recovery of energy and water, reduction in energy consumption, and reduction in greenhouse gas emissions. These multiple benefits should be considered in future business case assessments;
- Important data gaps identified by the project included waste availability data, technology performance testing and scaling up to full-scale commercial systems, business case development for circular concepts, and a need to confirm market credentials for products of closed-loop technologies; and
- There are synergies and opportunities for translation of closed-loop concepts between RMP and milk processing.

A set of specific voluntary short, medium and long-term strategies were defined for ACC specifically, to help increasingly transition towards circularity. In addition, with the implementation of closed-loop technologies across the RMP sector, significant recycling of food waste resources could occur. This could also increase the profitability of the sector. It is recommended that the project concepts described in this project report be progressed towards definition of a strategic set of research projects under the FFW -CRC Transform Program. This could occur in collaboration with other funding agencies that have an interest in the profitability and environmental stewardship of the Australian red meat sector (e.g. AMPC and MLA).

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