Australian Government
Department of Agriculture and Water Resources

AUSTRALIAN Pork

Closing the Loop to Reduce Waste Roadmap for the Australian Pork Industry 2025

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Research Organisation

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1. Introduction

"Closing the Loop" sets out the pork industries' ambitious aim to move to zero waste and contribute to the circular economy by reducing waste throughout the agri-food sector.

The pig industry is a leader in "Closing the Loop" on waste; both as a user of by-products from other sectors, and as an efficient user of all the resources on the farm to maximise pork production and generating energy and nutrients. This roadmap provides guidance for pork producers, regardless of size, to participate in effective waste management methods to 'Close the Loop'. The pig industry is a 'solutions' industry that can provide services in waste management to other sectors of the economy. The implementation of commercially viable waste management strategies could see piggeries setting a new standard in low waste food production.

There is growing expectation by Australian consumers for all sectors of the economy to demonstrate and report a high standard of environmental, social and governance (ESG) outcomes.

Waste minimisation is of significance across all Australian jurisdictions, with ambitious targets in place at national, state and regional levels, including a federal government commitment to a 50% reduction in food waste by 2030. In addition to government policies, major retailers have also developed programs with the aim of reducing waste.

APL's closing the loop on waste by 2025 policy position is consistent with other parts of the food supply chain and broader public policy.

1.1 What is Closing the Loop?

Circular systems are the key to closing the loop. Figure 1 shows a transition from a traditional linear economy where materials are used as input to production then waste disposed of at the end of the process; through a recycling economy where a portion of the materials are recycled; through to a truly circular system, where waste products are converted into marketable and useful products.

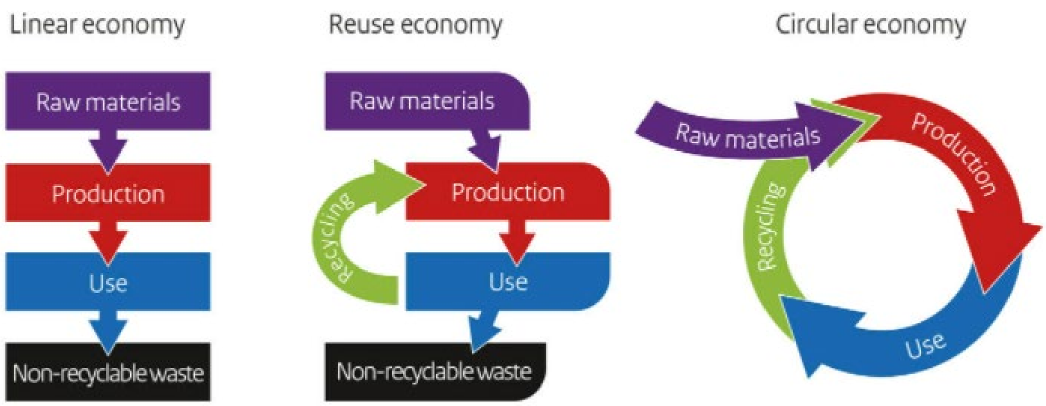

Figure 1. The transition from linear to circular economy (Government of the Netherlands 2017)

Achieving a circular economy requires a change of thinking: all inputs should be considered to ensure that any waste they generate can be used, and all waste material generated must be considered a potential resource. In the agri-food sector, the pig industry can improve circularity by utilising other "waste" products from the human food supply chain as feed sources for pigs and can also move to circular agricultural systems at the piggery itself.

The waste hierarchy (Figure 2) shows that the primary focus should be on waste avoidance and prevention, followed by waste reuse, then recycling and resource recovery of generated waste streams. Waste disposal should be the last alternative, and in an ideal circular system, the aim is for zero waste to require disposal.

2. What is 'Closing the Loop' for Piggeries?

The pig industry is a leader in circularity in the food sector, but more can be done to harness the opportunities to use by-products from other parts of the economy, and to reduce waste from pig production. While this is obvious to pig farmers, outside the industry there are many competing industries and technologies moving to gain an edge in this field. Some of these are complementary, and some are competitive with the pig industries' goals.

The nature of pig production provides an opportunity to divert food waste for use as feed, which is a preferred option for reuse compared with other competitive processes such as anaerobic digestion for energy recovery or composting. Figure 2 shows the different tiers of the food waste recovery hierarchy based on the benefits gained from waste diversion to the environment, society and the economy. Feeding animals ranks higher than competitive resource recovery alternatives for food waste.

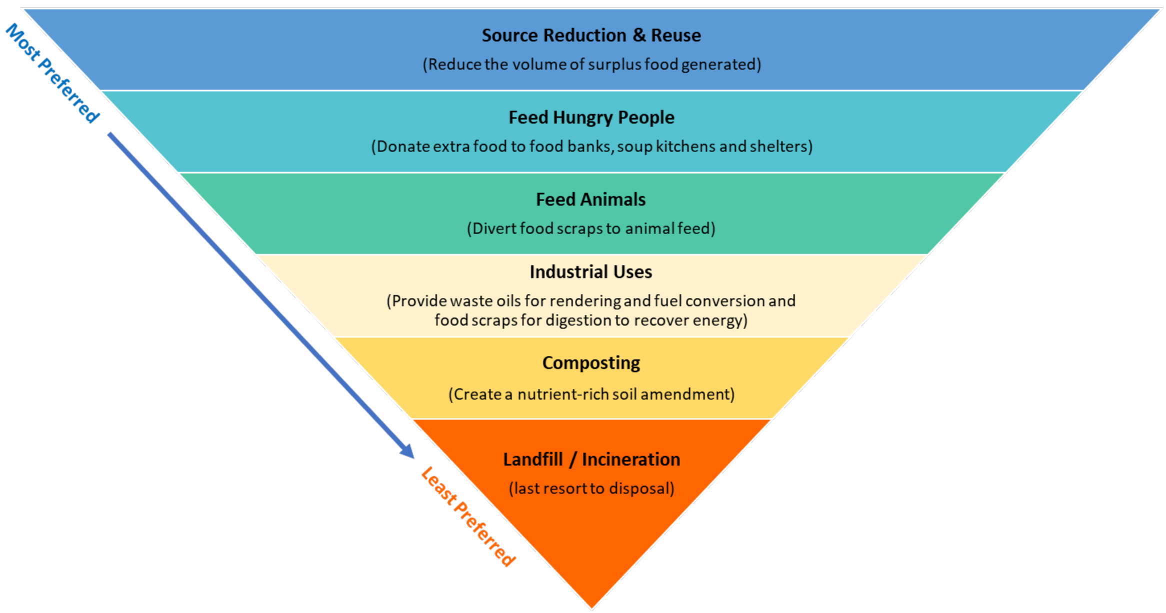

Figure 2. Food waste recovery hierarchy (U.S. EPA 2021)

This roadmap is divided into five key areas. In each area the guide shows the process of closing the loop, following steps in the waste hierarchy (Reduce > Reuse > Recycle >Recover). These five areas are:

- **Feed** – minimising inputs, improving production efficiency to minimise wastage, substituting third party food waste products into piggery feed, alternative feed sources
- **Energy** – recovery of residual energy in the effluent system through methane capture from anaerobic digestion, co-digestion of third party waste products to increase methane generation, biomethane production
- **Nutrients** – utilising manure nutrients, nitrogen (N). phosphorus (P) and potassium (K), in raw form, nutrient recovery to create high-value products
- **Water** – minimising water usage through waste reduction and reuse, on-site recycling
- **Solid waste** – minimising consumption and using the highest proportion of recyclable materials on-site, including plastic, cardboard and metal

2.1 Waste Measurement Indicators

To measure progress towards the goal of closing the loop, it is important to measure waste generation rates over time to assess change. Table 1 provides a range of waste indicators for different production systems, allowing an operation to benchmark their current position regarding waste generation and monitor progress towards reducing their waste footprint.

Table 1. Waste indicators for the Australian pork industry

Resource	Description	Units	Indicator	Purpose
Feed	% of ration sourced from residues and by-products	%	Ration ingredients	On-farm/supply chain benchmarking
	Estimated % feed waste in piggery	%	/kg LWG	On farm benchmarking
	Decrease in FCR/HFC in last 12 months		Change in FCR/HFC	On-farm/supply chain benchmarking
	Ration ingredients	%	% of ration using imported ingredients	On-farm/supply chain benchmarking
	Ration ingredients	%	% of ration using locally grown ingredients	On-farm/supply chain benchmarking
Energy	% of energy in manure beneficially used*	%	% of energy in manure beneficially used*	On-farm/supply chain benchmarking
	CO_2 utilisation	%	% CO_2 utilised in a beneficial way*	On-farm/supply chain benchmarking
Nutrients	Effluent / manure utilisation	%	% of N utilised for beneficial purposes*	On-farm/supply chain benchmarking
	Effluent / manure utilisation	%	% of P utilised for beneficial purposes*	On-farm/supply chain benchmarking
	Effluent / manure utilisation	%	% of K utilised for beneficial purposes*	On-farm/supply chain benchmarking
Water	% of effluent water utilised for beneficial purposes*	%	% of effluent water utilised for beneficial purposes*	On-farm/supply chain benchmarking
Solid Waste	kg solid waste excluding manure	kg	/kg LW produced or exported	On-farm benchmarking
	kg of plastic waste	kg	/kg LW produced or exported	On-farm benchmarking

**Beneficial is defined as a positive, good, or advantageous result by the indicated practice. This may be in relation to pasture or crop application of solid waste products or effluent water reuse, where a beneficial application would imply meeting the requirements of the plants in question as to limit nutrient build-up above requirements or possibilities of nutrient leaching or runoff.*

2.2 Baselining and Benchmarking

Collection of reliable waste data across a range of relevant indicators would provide an improved understanding of the current waste generation rates. Understanding the waste volume and streams would then allow opportunities for industry wide recycling to be identified and improve the sharing of knowledge on best practice waste minimisation.

Data collection also allows progress toward waste minimisation targets to be measured and tracked overtime. Accurate measurement would allow the businesses and industry to promote achievements towards national, state, regional and operational targets.

3. Feed

Feed is the largest input for a piggery operation. Because of this, there are opportunities for closing the loop through minimising the requirements of traditional inputs and by utilising waste from other industries as pig feed, such as pre-consumer human food chain wastes. This section outlines options to reduce the waste footprint from feed for a producer.

3.1 Improving FCR

Reducing waste starts with optimising inputs to reduce wastage out of the system. To improve current grain-fed feeding systems requires reduced feed wastage and feed lost into the manure management system. Reducing feed wastage makes economic and environmental sense as it improves productivity and reduces waste nutrients from the manure stream.

Feed waste can be reduced by over 50% in response to better feed management and feeding systems. Major changes which can reduce wastage include:

- Changing feed type (changing from mash to pellets or liquid food),
- Feed presentation (feeder type), and
- Feed processing (optimising feed particle size for pig growth stage).

Most feeders are manufactured to reduce feed wastage, e.g. creep feeder separations and rounded rims on stainless steel troughs. Minor changes that can greatly reduce feed wastage include optimised feeder adjustment, cleanliness, auger monitoring and feeder pan coverage to reduce spills and overfeeding. For new installations that deliver dry feed, electronic feeding systems that use electronic identification to provide the individual with the pre-set allocated portion will provide the greatest reduction in feed wastage. Liquid feeding systems allow for an even greater reduction in feed wastage, as do wet/dry feeders compared to using conventional dry feeders.

3.2 Utilising Commercial Food Waste

The ability for pigs to digest a diverse range of food without impacting performance makes them the animal most able to consume and subsequently recycle food waste. Pigs are one part of the solution to closing the loop on an estimated 7.3 million tonnes of food wasted in Australia each year (Commonwealth of Australia 2017). Under current laws, swill (food that has been offered for human consumption) and waste meat products are not allowed to be fed to pigs, meaning wastes from primary production and manufacture are the most suitable to be included in pig diets.

Primary production waste includes product loss along the supply chain which is damaged or discarded during production, packaging or handling. Surplus product may be a result of a fall in market prices or the inability of the product to meet quality or size specifications. This includes fruit and vegetables, nuts, wine grapes, crops, fisheries, eggs, livestock and milk.

Manufacturing waste is produced from fruit, vegetable and seafood processing and the manufacturing of oil and fat, grain mill and cereal, bakery product, sugar and confectionary, meat and meat product and dairy product.

Around 4 million tonnes of food waste from primary production and manufacturing are generated annually (Table 2).

Table 2. Waste volumes from primary production and manufacturing in Australian (ABARES 2019; ARCADIS 2019)

Food supply chain sector	Product	Volume (t/yr)
Primary production	Fruit (citrus, apples, pears and bananas)	228 200
	Vegetables	816 000
	Egg waste	5 000
Manufacturing	Grain	882 000
	Fruit and vegetable packing houses	422 000
	Dairy processing	630 000
	Nuts	82 500
	Wine grapes	224 000
	Seafood	50 080
	Dairy	630 000
Total		**3 969 780**

Currently only 10-20% of commercial pig herds divert food waste from primary production and manufacturing (Torok *et al.* 2021) utilising a very small portion of the potentially available 4 million tonnes.

3.3 Utilising By-products

Loss of quality by- and co-products occurs during the production, processing and distribution of food through the supply chain. For example, bran, germ and hulls are by-products wasted in the milling of wheat to flour and the processing of certain crops. The incorporation of these losses utilises waste of unusable products otherwise disposed. The two categories of feed products, based on the production system they are sourced from are:

- Co-products: generated from another production system as a secondary product attributed a proportion of the 'environmental burden' of the production system where they arose e.g. canola meal, meat meal and tallow.
- By-products: low or high value by-products from other production systems e.g. whey and some yeast products. Where the value is negligible and demand is low, it is reasonable to assume that no environmental burden is associated with these products.

By-products and co-products suitable for use in pig diets are summarised in Table 3. Utilisation of high-quality by-products is done successfully at some smaller scale operations in Australia, and at more commercial levels internationally.

Table 3. By-products and co-products suitable for formulating into pig diets

Dairy	**Grain milling**	**Animal**	**Vegetable**	**Sugar production**
Whey	Millrun	Animal fat	Dried potato meal, slices, flakes	Cane molasses
Dried buttermilk	Wheat bran	Blood meal		Bagasse
Dried skim milk	Wheat pollard	Meat and bone meal		
	Rice hulls	Hydrolysed hog hair		
	Rice bran			
	Rice pollard			
	Biscuit meal			
	Brewers grain			

Dried Distillers Grain	
Hominy meal	

3.4 Alternative Feed Sources

The use of alternative feed sources in pig diets can utilise waste from one system and reduce the use of grains/protein sources and associated waste along the supply chain. There is a large amount of research underway across the world investigating insect protein meal. One challenge is that any system that involves feeding material to another organism rather than feeding the pig directly has the biological disadvantage of a direct efficiency loss equivalent to the FCR of the organism being fed. Consequently, these systems will only work efficiently where they are fed products that can't be fed directly to pigs.

Having noted this, insect meal has been recognised as a cost-effective and sustainable alternative to reducing protein meals in pig diets, with black soldier fly larvae (BSFL) the most promising candidate in place of high-protein feeds.

Although currently in Australia all insect farmers are of small scale or in the startup phase, the sector is receiving significant interest and investment due to the potential of closing the loop on waste whilst producing protein for use in livestock feed. The prospect of insect meal being used in pig diets is still not clear, although State-wide regulations indicate growing insects on plant material does meet swill feeding legislation, further policies are required to finalise regulations (Nolet 2020). There is ongoing Government and private research investigating the development of insect farming to service the pork industry.

Alternative waste utilisation includes duckweed and algae. Whilst these options have promise for utilisation of pig feed, foundational research and development of guidelines and legal frameworks is required prior to on farm trials being implemented.

3.5 Considerations when Introducing Feed Substitutes

Before introducing new dietary ingredients to a commercial piggery operation, the following considerations should be addressed:

1. Check state government guidelines with regard to regulations for alternative feed for pigs.
2. Is it considered swill? Meat or meat products or any food that has been in contact with meat is prohibited. Do not use food waste from households or restaurants. For more information go to farmbiosecurity.com.au.
3. Check the supply for continuity considering swine digestive processes need time to adjust.
4. Are there storage and packaging requirements to consider and what is the shelf life?
5. What is the cost benefit, are there added costs associated with transportation and storage?
6. What is the moisture content e.g. brewers grains and vegetable by-products must be stored to minimise leaching.
7. Conduct a nutrient analysis and check variation in the nutrient content.
8. Consider contamination and toxins as feeding excess phosphorus must comply with nutrient management and waste plans while cottonseed and grain screenings can harbour mycotoxins.

Due to current biosecurity regulations in Australia, utilising by-products and waste for pig feed is restricted to pre-consumer products. Across all states and cities, there is an increase in post-consumer organic waste via kerbside collection. This has resulted in a highly consistent supply of post-consumer food waste. This waste stream is not permitted to be utilised in the piggery waste stream. To be used the waste must undergo an intermediate processing, such as the utilising the organic waste first as an insect feed source, then using insects to produce pig feed. Heat treatment of post-consumer waste is not currently an approved method of treatment in Australia, and this is an area of significant potential. Thermal processing of waste is commonly used internationally and proven effective in countries like Japan to utilise 35 – 43% of food waste through animal feed.

4. Energy

4.1 Methane Capture

Regardless of how efficient a piggery is at minimising feed waste and improving FCR, a proportion of the energy in feed will pass through the pig into the effluent treatment system. In traditional effluent treatment systems, this is converted through a biological process in the anaerobic effluent ponds, and energy is released to the atmosphere as methane gas. Methane has an energy density of 55.65 MJ per kilogram, and enough is generally released at most piggeries to power the whole piggery and sell excess power to the electricity grid. This is closing the energy loop at the piggery. Capture and reuse of methane for energy production a viable process at conventional piggery sites, and it is a common practice in many parts of the world, utilising the inherent energy value contained within the piggery effluent stream. The process for all systems works by capturing the biogas resource generated from the anerobic digestion of effluent which can be burnt to generate electricity and/or heat. If this methane was not captured, the gas is lost to the atmosphere, which is considered a wasted resource as well as contributing to the greenhouse emissions from the operation. An additional benefit from biogas capture systems is potential odour reduction. Australian Pork have developed a Code of Practice for On-farm Biogas Production and Use (Piggeries) (APL 2015) which provides guidance for the establishment an on-farm biogas system and is important reference when considering for the safe design, construction, operation and maintenance of biogas systems.

Several options exist to utilise captured biogas, with each described below.

- **Heat Utilisation**: Boiler efficiency is approximately 90%.
- **Electricity Generation**: Generator efficiencies is approximately 25-40%.
- **Combined Heat and Power (CHP):** CHP conversion of methane gas into electrical energy is approximately 25-40%; while an additional 45-55% can be recovered as heat energy.
- **Biomethane Production:** Produce a high quality renewable methane gas and carbon dioxide. to either sell to a commercial processer.

4.2 Co-digestion

The capital investment associated with the construction of a methane capture and reuse system is significant for a piggery operation, and one method which assists in maximising the return on investment as well as assisting in closing the loop on waste is co-digestion. Anaerobic co-digestions is the treatment of two (or more) separate waste streams through an anerobic digestor in order to increase the methane generation from a system. A comprehensive review of the opportunities associated with co-digestion in the pig industry was undertaken by in CRC 4C-109 *Enhanced methane production from pig manure in covered lagoons and digesters* (Tait *et al.* 2017). The key outcomes of this report and relevant updates are provided in the below section.

There are two methods that can be used to increase methane production from anaerobic digestion including:

- Digesting pig manure simultaneously with of waste products of higher biochemical methane potential; and/or
- Increasing the total amount of waste digested, therefore increasing methane production.

A range of waste products, by-products and co-products products from agricultural, industrial and municipal sources are potentially suitable for co-digestion including:

- Apple pulp, apple waste
- Alcohol
- Banana Peels
- Beef feedlot manure (fresh)
- Brewers spent grains
- Fruit wastes

- Fish Waste
- Glucose
- Stomach intestinal content, Cattle
- Stomach intestinal content, Pigs
- Concentrated whey protein (20-25%)

The biochemical methane potential of a material is a measure of the methane and carbon dioxide produced during anaerobic digestion and varies significantly between products. Anaerobic co-digestion is successful when the organic loading rates of solid material does not exceed the capacity of the digester. Although the use of anaerobic co-digestion can successfully reuse, reduce and recover waste, implementation requires careful consideration and consultation with experienced professionals. Co-digestion in a covered anaerobic pond is generally suitable for wastes with low solids content, while a mixed liquid digester is more suitable for wastes with higher solids.

4.3 Relevant Funding Opportunities

The use of methane for energy generation has the co-benefit of reducing greenhouse gas emissions associated with the loss of methane to the environment. As a result, methane capture projects can generate revenue through the carbon market. The carbon market is regulated by the Clean Energy Regulator (CER) which administers national carbon markets for:

- The Emissions Reduction Fund (ERF), which supplies Australian carbon credit units (ACCUs) – including the Animal Effluent Method and the Biomethane Method.
- The Renewable Energy Target, which creates tradable large-scale renewable energy certificates (LGCs) and small-scale technology certificates (STCs).

5. Nutrients

5.1 Manure By-products

Piggery by-products contain significant quantities of nitrogen, phosphorus, potassium, trace elements and carbon which are valuable commodities in agricultural production. Due to the intensive nature of the most piggery operations, the management of manure is a significant factor in production. Depending on the production system, nutrient rich manure by-product streams may include:

- Effluent
- Separated Solids
- Sludge
- Spent Litter

Typical nutrient and carbon generation from two common production systems for a 1,000 sow farrow to finish operations with a wheat and barley based diet are shown in Table 4. The Piggery Manure and Effluent Reuse Guideline (Tucker 2015) details the steps involved with determining the value contained within the nutrient in effluent and solid waste. As shown in Table 4, significant commercial value is contained within the manure by-products.

Table 4. Nutrient excretion rates for 1,000 sow farrow to finish piggery (Source: Pigbal v4, 2015)

	Total Nitrogen#	**Total Phosphorus**	**Total Potassium**	**Total Organic Carbon**
Conventional	259 kg/day	90 kg/day	88 kg/day	2,190 kg/day
	94 tonnes/year	33 tonnes/year	32 tonnes/year	800 tonnes/year
- Value*	$147,000	$129,000	$46,000	
Conventional bred and deep litter grown	254 kg/day	107 kg/day	107 kg/day	3,330 kg/day
	93 tonnes/year	39 tonnes/year	39 tonnes/year	1,210 tonnes/year
- Value*	$146,000	$152,000	$57,000	

 # Assumes 30% loss of nitrogen through volatilisation

**Based on fertiliser values of $720/tonne of urea, $780/tonne of triple superphosphate and $710/tonne of muriate of potash. (prices at October 2021)*

Based on typical fertiliser application rates for broadacre farming of 100kg of nitrogen and 20kg of phosphorus, a 1,000 sow conventional operation could provide enough nitrogen for 945 ha and phosphorus for 1,650 ha of broadacre farmland each year.

5.2 Current Nutrient Usage

Current nutrient usage in the Australian pig industry varies from farm to farm, with a high level of use of piggery manure by-products through irrigation or for land application occurring at some sites, while others operate closed systems where effluent is lost through evaporation, and nutrient either lost to the atmosphere or retained in the sludge in effluent ponds. Accurate data is not currently available on the level of nutrient usage across the Australian pig industry.

On-site manure use leads to a reduction in waste, particularly if crops (grain/straw) produced on-site can be utilised back through the piggery production cycle.

Although the nutrients in effluent are a valuable resource, regulatory and operational issues associated with the transport and spreading of high volume, low strength effluent can make the cost and process onerous for some piggery operators. While on-site treatment and storage of effluent and manure solids improves the operational management of application, the process does result in a loss of significant amounts of nitrogen to the atmosphere which could be considered a wasted resource. Opportunities exist for the recovery and reuse of the maximum amount of nutrients (further discussed in Section 5.4).

5.3 Mortalities Use

Management of mortalities is a part of all piggery operations, with the preferred methods for disposal as recommended by Tucker (2015) shown in Figure 3.

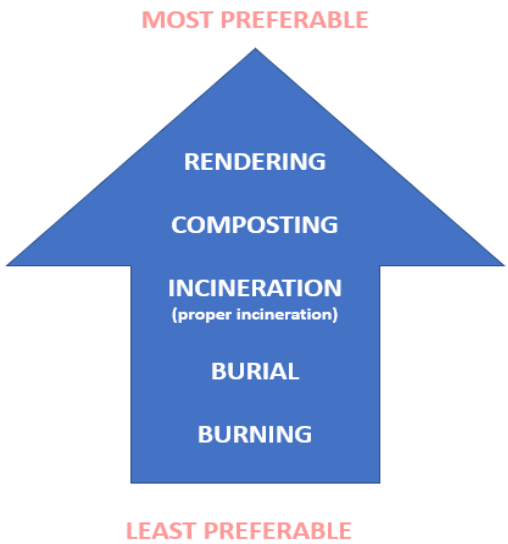

Figure 3. Mortalities management hierarchy (modified from Tucker, 2015)

Based on average mortality rates, a total mass of mortalities expected from a 1000 sow farrow to finish piggery is 85 tonnes. Contained within the 85 tonnes is 2.18 tonnes of nitrogen, 0.4 tonnes of phosphorus, 0.2 tonnes of potassium and 13.3 tonnes of total organic carbon.

Both rendering and composting of mortalities assists in closing the loop on waste, as a significant portion of the nutrient and material contained within the pigs is recovered and can then be reused. Incineration, burial and burning are not preferred as they result in a loss of almost all resources contained within the bodies to the environment.

An alternation method of resource recovery for mortalities is to utilise dead pigs through co-digestion. Anaerobic co-digestion of pig carcasses and effluent can increase biogas and methane yields by 6% (Tápparo *et al.* 2020). For carcass co-digestion to be effective, the system must be designed and constructed to specifically to manage mortalities, and bodies processed as required by the system prior to digestion.

5.4 Nutrient Recovery Technologies

While some piggery by-products are utilised through agriculture, a significant portion of the nutrients are wasted through loss to the atmosphere (nitrogen) and/or retained indefinitely in closed system wastewater treatment systems. Opportunities exist to improve recovery of the resources contained in manure by-products through the production of high nutrient value added products. These would provide an alternative to commercial fertiliser products. These options are likely to increase in financial viability as the price of synthetic fertiliser increases.

Nutrient recovery technologies can be divided into three categories:

- Nutrient accumulation - includes biological mechanisms such as enhanced biological phosphorus removal (EBPR) and physiochemical mechanisms such as adsorption/ion exchange.
- Nutrient release - occurs through anaerobic digestion in anaerobic pond or engineered digesters
- Nutrient extraction - liquid-gas stripping, crystallization and chemical precipitation.

Details of the available nutrient reduction technology are provided in the Closing the Loop to Reduce Waste – Manual (APL 2020/00087). The advantages and disadvantages of a range of nutrient recovery methods that are suitable for piggery effluent are summarised in Table 5. 2021 has seen significant increases in the price of fertiliser products, and continued increases will only increase the economic viability of nutrient recovery projects.

Table 5. Advantages and disadvantages of nutrient removal technologies

Nutrient Removal Technology	Process Description	Advantages	Disadvantages
Enhanced Biological Phosphorus Removal	• Activated sludge process for nutrient removal	• Can be cost effective for agricultural waste streams (Mehta et al. 2015) • Phosphorus recovery 95-98% and nitrogen recovery up to 83-99% (Obaja *et al.* 2005). • High reduction in oxygen demand also achieved during the process	• End-product is a wet sludge (5-7% P) which has operationally can be difficult to use as fertiliser replacement.
Chemical coagulation/flocculation	• Coagulation and flocculation where nutrients precipitate as solids.	• Nitrogen and phosphorus recovery greater than 90% • Pathogens, viruses, arsenic, fluoride and organic matter also removed. • Low capital costs • Ease of operation • Flexibility to varying conditions	• High operational costs • Increased salinity in the treated effluent (due to Cl^-, SO_4^{2-}), an • Increase in the volume of sludge produced, • Reduction in the bioavailability of the chemically bound P in the sludge, and • Inhibitory effects on anaerobic digestion following coagulation
Chemical Precipitation/Crystallisation	• Precipitation of phosphorus (and to some extent nitrogen) as struvite crystals	• Currently the most commercially adopted method of phosphorus recovery • Produces a high stability nutrient dense product • Suitable for nutrient recovery post anaerobic digestion	• Operating costs can be high due to magnesium salt inputs
Liquid-Gas Stripping	• Ammonia stripped from liquid to gas phase	• 96% ammonia recovery • Relatively low management cost requirements	• High capital and annual input chemical costs. • No removal of phosphorus
Adsorption/Ion-Exchange	• Adsorption of ions (nitrogen, phosphorus and potassium) to charges surface of sorbent material	• Ability to generate high P accumulation and low P concentrations in the treated effluent. • No additional sludge apart from the spent adsorptive media is created, and the • pH is not affected by the process.	• Not suitable for effluent with total solds greater than 2,000mg/L • Relatively high cost of the adsorptive media • High volume required for complete adsorption (Mehta *et al.* 2015)
Settling systems	• Physical settlement of solids into sludge	• Low capital and operating costs. • Proven technology	• Nitrogen remains largely remains dissolved in solution. • End-product is a wet sludge which has operationally can be difficult to remove from ponds and use as fertiliser replacement. • Periodic removal of nutrient sludge does not allow for ongoing supply. • Large area footprint required for long on-site retention time of liquid.

6. Water

6.1 Minimising Potable Water Use

Water is both the most important nutrient for pigs and the most valuable natural resource (after land) in Australia. Clean water at piggeries is required not only for drinking but also shed cleaning and summer cooling. Direct water consumption (freshwater used within the piggery operations) ranged from 4.1 to 56.2 L/kg LW. The significant differences in water usage were influenced by:

- Production type
- Climate
- Shed design (sheds with evaporative cooling used much higher quantities of water and deep litter sheds used less water than conventional sheds)
- Drinker system maintenance and wastage rates
- Proportion of freshwater used in recycling in conventional sheds

Total direct freshwater consumption has reduced from over 90L/kg LW to less than 20L/kg LW between 1980 to 2020 for conventional piggery operations, see Figure 4 (Watson *et al.* 2018)..

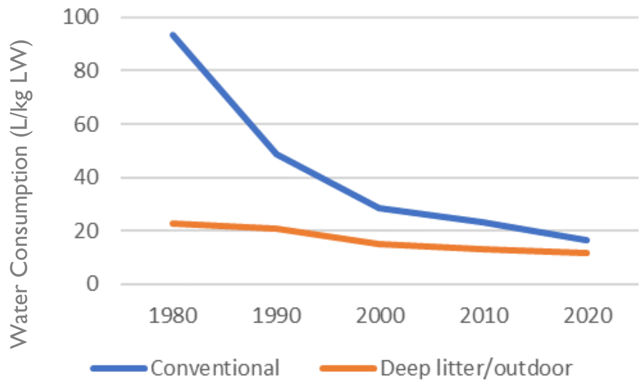

Figure 4. Trends in direct freshwater consumption for Australian pork production (Watson *et al.* 2018)

It is common for effluent treated through a pond system to be used for flushing through a conventional piggery. This is an effective way to minimise the potable water. It should be noted that ongoing, very high recycling rates can negatively impact on the effectiveness of wastewater treatment ponds due to the escalation of certain contaminants (ie. Ammonia, salts and volatile fatty acids) which can inhibit biological wastewater treatment processes.

Although there is some scope to further reduce direct freshwater usage through improvements in efficiency, maintenance and FCR, the most promising opportunities come from water treatment.

The extended water cycle for piggeries includes water use in cropping. Reducing demand on irrigated crops and conducting a more thorough analysis of water for feed grain would be beneficial to reduce demand. Depending on the origin of piggery feed ingredients, the water embedded in feed products can vary significantly with northern regions (ie. Qld) having higher contribution of irrigated ingredients in crops than southern and western regions

6.2 Water Recycling

Advanced water treatment plants (AWTPs) are becoming more common in Australian meat supply chains. However, there is low uptake at a farm-scale compared with processing plants. Technologies available within AWTP that are relevant to on-farm piggeries include:

- Membrane Filtration – including microfiltration, ultrafiltration, nanofiltration and reverse osmosis
- Disinfection treatments- including ultraviolet (UV) light and oxidative disinfection

Different technologies are available for the treatment and recycling of effluent, with the method adopted highly dependent on the intended final use of the treated wastewater. The sections summarise available treatment methodologies applicable to the treatment of piggery effluent. At present, there are knowledge gaps around the commercial viability at the farm scale of these technologies.

6.2.1 Membrane filtration

Membrane filtration is a physical separation method with the ability to separate contaminants in a waste stream based on the different sizes and characteristics of the molecules. . Membrane filtration technologies such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) are suitable for heavy metal removal due to their high efficiency, ease of operation and limited space requirements. Toxic heavy metals of particular concern in treatment of wastewaters include lead, zinc, copper, mercury, nickel, cadmium, and chromium, as these limit the reuse opportunities within a piggery (Fu and Wang 2011)

UF is the considered the most suitable technology for heavy metal removal, and has a pore size range of 0.001-0.05µm (Masse *et al.* 2007). A review of heavy metal removal efficiencies from UF suggested a high level of removal can be achieved (Fu and Wang 2011). In addition to heavy metals, UF can remove bacteria, protozoa, endotoxins, proteins and carbohydrates very efficiently.

Reverse osmosis technology can also be successfully used for the reduction of heavy metal, pathogen and virus concentrations. RO is an established desalination technology. Pre-treatment before RO is an important step because of the sensitivity of RO membranes to suspended solids and organics in natural waters which are present in piggery effluent. RO systems also generate a brine waste stream, which is concentrated in salts, and required environmentally responsible management for disposal.

6.2.2 Disinfection treatments

Piggery effluent contains a range of pathogens, including bacteria, viruses, and protozoa. Disinfection treatments such as oxidative and ultraviolet (UV) light disinfection are used to remove pathogens from water, following extensive pre-treatment.

Oxidative disinfection reacts with the organic structure of the pathogen. Typical oxidants such as chlorine gas or hypochlorite salts are used, however ozone can be used. Chlorination is very effective against enteric bacteria, such as E.Coli, however is not as effective for other bacterial species.

UV treatments disrupt the pathogen's genetic material and restricts replication. Some of the major advantages of UV disinfection are that it does not add to the toxicity of the wastewater, it is rapid and it is a cost effective process. In addition, it is highly effective for protozoa, bacteria and most viruses.

The disinfection of effluent using chlorine and ozone can result in the formation of by-products that negatively affect the environment. Therefore, it may be advantageous to use processes which do not increase effluent discharge toxicity, such as UV. However, it is important to ensure that the wastewater is treated with UV immediately prior to use in the piggery, as UV does not have any residual disinfection capabilities.

6.3 Regulatory Requirements

Different water quality standards, regulatory approvals and monitoring requirements are applicable for different uses. Potential use options for recycled water include:

- Hose down and cleaning water
- High volume irrigation water
- Cooling water
- Stock drinking water

Depending on the end use of the recycled water and the relevant State government regulations, a water recycling scheme may require approval from the state government agency. Generally, approval is required if there is an opportunity for human contact (ie. hose down water) to ensure protection of the environment and the occupational health of employees.

7. Solid Waste

Solid waste generation is an important and easily measurable waste stream and is often an important key metric in supply chain waste assessments. Solid waste can be categorised as:

- Recyclable – recycling is the process of converting waste into a reusable material.
- Compostable – composting natural materials into a nutrient-rich substrate.
- Biodegradable – any material that can be decomposed by bacteria and micro-organisms

Almost all waste generated from a piggery site can be recycled if the correct method of disposal is followed (Table 6). Typically, agricultural waste has a relatively low recycling rate. As shown in Table 6, almost all of the waste streams from a piggery have the capacity for recycling. Some operational changes, such as bundling of like wastes together, allows for a greater range of products to be recycled.

Table 6. Correct method of waste disposal for solid waste

Category	Recyclable	Method of disposal
Metal (e.g. feeders, gates, crates)	☑	Scrap metal company offers collection or use of a collection bin free of charge. The dealer pays for the scrap metal (copper, aluminium, stainless steel, lead, steel, brass) by weight
Concrete (e.g. slatted flooring)	☑	Can be disposed of to a concrete recycling facility, free of charge
Expanded polystyrene (e.g. eskies)	☑	Dropoff at an EPS collection facility
Rigid plastic (e.g. penguin feeders, slatted flooring, feeders)	☑	Plastics recyclers offer pickup, drop-off or a collection bin
Rubber (e.g. matting)	☑	Rubber tyre recycling and disposal service offer pickup
PVC (e.g. polypipe)	☑	Needs to be free from contamination and in sufficient, ongoing quantities to warrant feeding offcuts into production processes. Alternatively, use a construction waste company for disposal.
Paper and cardboard	☑	Recycle in curb side or industrial specific recycling bin
Glass (e.g. medicine & vaccination bottles, coffee jars/tins)	☑	Remove the plastic or metal lids and dispose of in general waste. Bottles can then be disposed of in the recycling bin. No need to remove paper labels.
Chemical drums	☑	Cleaned containers recycled through the drumMUSTER program
Plastic AI straws	☑	AI straws may be recycled if they are collected and tied into bundles or packaged into containers of the same type of plastic. Once repackaged, the straws can be processed through the normal plastics recycling.
Feed bags (woven polypropylene)	☑	Feed bags may either be returned to the producer for reuse, or recycled through the REDcycle system. The REDcycle system does require bags to be cut into A3 sized pieces which will require additional processing by producer.
Cling film pallet wrapping	☑	Pallet wrap can be recycled if bundled. Once bundled then the wrap can be recycled through the REDcycle system.

Baling twine	☑	Baling twine can be recycled if bundled together into clean bundles. Once bundled, the straws can be processed through the normal plastics recycling.
Sharps bin	☒	*Place all needles and syringes in a sharps disposal container. Syringes are not recyclable. Collection company will dispose of in a thermal treatment facility.*

Long-term options to reduce wastes include:

- Going paperless – utilising electronic data recording
- Removing the single-use of eskies - businesses are using thick cardboard as an alternative which is strong enough to protect the product and costs the same to use. For thermal insulation, leak proof hard plastic tubs can be used and returned at each collection time to be reused e.g. veterinary industry.

8. Partnerships and Funding

Considering the proliferation of policies and targets in waste management, significant resources have been allocated to assist industry in achieving the waste reduction goals. The following sections outlines a number funding sources that are available to the pig industry to assist with the innovation and implementation of on-ground waste reduction strategies.

8.1 Government Funding

ARENA is a federal government agency that operates a number of programs to support projects that advance renewable energy technology along the innovation chain. ARENA projects are generally large in scale and APL may be best placed to develop an industry wide project scope to maximise renewable energy from the pig industry which would assist in meeting both the GHG and waste minimisation objected of the industry. Further information can be found at https://arena.gov.au/funding/

Each state government has funding available to support projects that will assist in achieving waste reduction targets.

8.2 Cooperative Research Centres (CRCs)

The Fight Food Waste Cooperative Research Centre has funding until 2022 for small to medium-sized enterprises to focus on (1) testing new and novel food processing, packaging and agricultural technologies, (2) identifying valuable products and transform into new commercial opportunities, and (3) identify technology opportunities and processes to enhance food and agricultural waste reduction. The CRC is representative of widespread interest in waste management and the funding available to conduct research, development, and extension in this area.

8.3 Retailers

Major retailers in the food sector have defined strategies in waste management. Because of their scale and the fact that they deal with pre-consumer waste, the supermarkets are a key, relevant stakeholder.

Woolworths - Woolworths Stock Feed for Farmers Program

- The Woolworths website explains they donate food (surplus fruit and veg, produce off-cuts, and surplus bakery items) to farmers (including commercial farmers) for animal feed or composting. They partner with 600 farmers and are seeking to expand this program. Donating food to farmers is prioritised behind donating feed to people in need.
- The default unit of food waste is a 240 L bin, so special arrangements may be required to obtain commercial quantities of food waste. The website includes a link to an application form that is submitted to the State Administration Manager, and respondents are encouraged to speak to a store manager for access to surplus food regularly.

9. Closed Loop Farm

Technology currently exists to develop a wholistic and large scale demonstration site to show how food waste, pig systems and energy recovery can function effectively. The demonstration farm was proposed as part of the Low Carbon Emission report (APL 2020/0086) but is repeated and expanded here as it is highly relevant to the Closing the Loop on Waste project.

A closed loop farm could be established with the ambition of demonstrating positive energy production (export of energy), low-cost pork production, with feed totally supplied via by-products and/or alternative feed sources.

The full cascading system of food waste recovery could be demonstrated, as per the hierarchy shown in Figure 5.

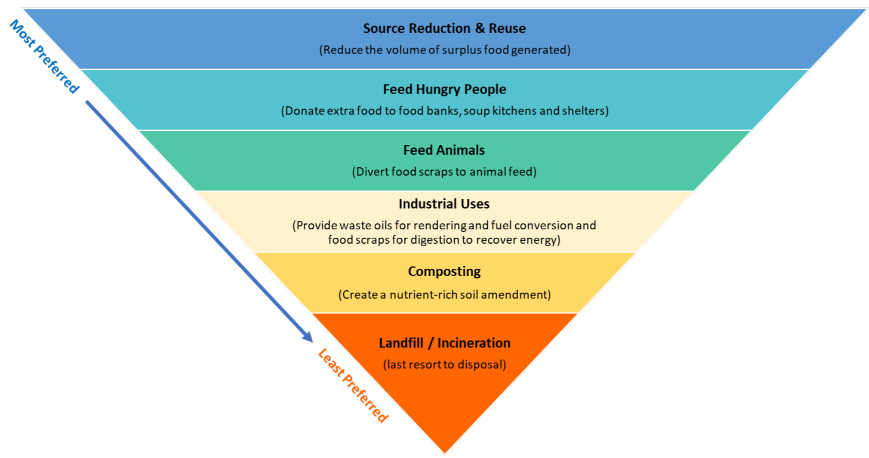

Figure 5. Food recovery hierarchy triangle (U.S. EPA 2021)

This site would:

1. Conduct research on maximising value from waste food from manufacturers, retailers and municipalities via:
    a. Developing new processes for handling of difficult waste streams (mixed) and how to separate these to maximise value as feed.
    b. Developing heat treatment for products that currently can't be fed legally, and developing the regulatory processes to legally feed these products.
    c. Develop ideal feeding strategies and diet formulation.

2. Demonstrate alternative options for residual waste food – insect production for animal feed.
    a. This field is expanding, and the site could act as a demonstration and proof-of-concept testing ground for new options as they become available. Integrating this into a system which already maximises waste food and manure would be more insightful that operating in isolation.

3. Demonstrate energy recovery technology.
    a. Optimising biogas yield and quality
    b. Value recovery from CO_2
    c. Biomethane generation
    d. Energy recovery from manure and mixed biomass (i.e. energy generation with all biomass not suitable for feeding to pigs)
    e. Heat recovery and utilisation (for example, rendering)

4. Demonstrate nutrient recovery technology.
    a. Bolt-on technologies for P removal (i.e. based on struvite)
    b. Bolt-on technologies for N removal (i.e. ammonia stripping).
    c. System optimisation and cost reduction of nutrient removal.

With these core aspects in place, a system to evaluate environmental and economic potential for new technologies could be established to provide guidance for research and adoption. This would be a strategic investment for the industry. Provided a suitable, existing piggery was available, development of this type of facility may require $25M funding. It would suit a university or possibly a large scale private enterprise.

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