Final Report

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Assessing the value of soil conditioner derived from red meat processing AD digestate

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1.0 Abstract

Project 2024-1091 explores the market potential of biofertiliser derived from anaerobic digestion (AD) digestate of red meat processing by-products. This innovative product improves soil properties while promoting circular economy principles by repurposing organic by-products.

Conducted by Tessele Consultants, the project reviews existing research, evaluates the quality of the biofertiliser compared to current market options, and examines Australian regulations for its potential application along with its economic feasibility. Key stakeholders include a WA meat processor, a WA renowned fertiliser company, and the University of Western Australia (UWA).

The WA meat processor, is collaborating with Tessele Consultants to analyse a bioresource recovery facility on-site, incorporating wastewater treatment, biogas, and biofertiliser production. The WA fertiliser company is a national garden product manufacturer and operates a biogas plant on their site, with digestate currently unused but holding potential for a combined biofertiliser production.

UWA's School of Agriculture and Environment conducted an online survey to assess social license perceptions and consumer preferences for biofertiliser from AD digestate.

This project paves the way for a sustainable and innovative product, outlining the feasibility of a biofertiliser plant and fostering environmental and economic benefits for the industry.

2.0 Executive Summary

This report evaluates the feasibility of commercialising a digestate-derived biofertiliser incorporating red meat by-products in Australia. A key objective of this study was to assess the market value of the recovered resource by evaluating various dewatering technologies and processing routes. Among these, pelletised biofertiliser emerged as the most advantageous option due to its ease of handling, storage, and transportation, as well as its reduced odour and pathogen levels. Furthermore, it retains more nutrients than other biofertiliser alternatives, such as biochar, making it a more effective soil conditioner.

A survey conducted under AMPC Project 2022-1081 by Tessele Consultants assessed market demand and the potential adoption of digestate-derived biofertilisers across various sectors, including forestry, commercial off-takers, landcare, natural resource management, mining, and municipal applications. The findings highlighted that product quality, pricing, and regulatory compliance are critical factors for successful commercialisation in Australia.

To evaluate the quality of digestate from red meat processing facilities, a comprehensive analysis was conducted using existing literature and data from previous Tessele Consultants projects with the Australian Meat Processor Corporation (AMPC). In addition, digestate quality from other industries, such as food waste digesters, was considered, as these sources represent additional stakeholders that could contribute to the biofertiliser plant's feedstock, such as the WA fertiliser company.

Regulatory frameworks for bio-based fertilisers in Australia were also reviewed. Given the absence of specific national regulations for digestate-derived biofertilisers, the national biosolids regulations were used as a benchmark for establishing quality standards. The characterisation of red meat by-products, such as anaerobic pond sludge and pasteurised digestate, revealed lower contaminant levels compared to conventional biosolids, meeting safety criteria for land application.

For further regulatory comparison, international guidelines from Canada and the UK were examined. In Canada, digestate falls under the National Fertilizers Act, and producers may choose to market it as a fertiliser, requiring adherence to national and provincial regulations. The UK regulatory framework sets upper limits for various quality parameters, including odour emissions, pathogens, potentially toxic elements, stability, physical contaminants, and physicochemical properties. However, it does not regulate organic contaminants such as PFAS and PAHs. In Australia, the state of Victoria has introduced digestate management guidelines, covering feedstock controls, pasteurisation requirements, and contamination thresholds.

Ensuring regulatory compliance for this innovative biofertiliser presents an opportunity to divert significant volumes of red meat processing by-products from disposal. This adds value to the recovered resource and supports circular economy principles by repurposing organic waste into a sustainable agricultural input.

A consumer purchasing behaviour survey conducted by UWA provided insights into economic feasibility. Results indicated that consumers are willing to pay AU$12 more for Certified Organic fertilisers and AU$8 more for digestate-derived fertilisers, assuming nutrient value remains unchanged. Among digestate-derived options, fertilisers sourced from food waste were preferred, whereas those made from meat processing waste or biosolids were expected to sell for AU$1 less than food waste-derived alternatives.

Economic scenario analyses were performed to evaluate different biofertiliser plant locations, including the WA meat processor and the WA fertiliser company sites, as well as an independent biofertiliser plant in Bunbury, Western Australia. Variations in nutrient levels in the final product were also considered. A detailed assessment of feedstock from the WA meat processor and the WA fertiliser company production to the biofertiliser plant was undertaken. The most well-presented and realistic economic scenario simulated a product sales distribution of 20% in retail, 30% in direct sales, and 50% in horticulture and agriculture—along with enhanced nutrient levels, resulting in a projected payback period of 7 years, confirming the financial viability of the project. However, refining assumptions and conducting internal discussions with stakeholders to review feedstock characteristics and product specifications, as well as assess operational approval in the selected location, is recommended.

3.0 Introduction

This project assesses the market feasibility of a red meat digestate-derived biofertiliser in Australia by identifying target segments, consumer acceptance, and economic viability. Given the abundance of by-products from the red meat and other industries in Australia, a circular economy approach was explored by proposing a biofertiliser produced from combined digestates—organic residues remaining after anaerobic digestion.

A comprehensive market survey, conducted as part of Project 2022-1081 by Tessele Consultants was included, which evaluated opportunities for this innovative biofertiliser in the Australian market. The present study also examines the quality of red meat and food waste digestate, along with the necessary technologies to convert them into a market-ready product. Additionally, national and international regulatory frameworks governing biofertiliser applications were reviewed to ensure compliance and commercial viability.

Further insights were gathered through a purchasing behaviour survey conducted by UWA, providing valuable data on consumer perception and willingness to pay for this innovative product. Validating the commercial potential of this biofertiliser will promote sustainable resource recovery in Australia, diverting industry by-products from waste streams and repurposing them for agricultural and horticultural use.

4.0 Project Objectives

This project aims to assess the market feasibility of a red meat digestate-derived biofertiliser within the Australian retail sector by identifying target segments, consumer behaviour, and economic viability. The project objectives include:

- Summarising the literature review on red meat digestate-derived biofertiliser technologies and opportunities in the Australian market.
- Conducting a detailed review of the quality of red meat digestate-derived biofertiliser compared to those currently available in the market, as well as examining current regulations related to its potential application in the Australian market.

- Implementing a comprehensive online survey targeting 1,000 Australian fertiliser consumers to gather data on socio-demographic and purchasing behaviour, consumer preferences, and pricing for red meat digestate-derived biofertiliser, while assessing the impact of pro-environmental messaging on sales.
- Evaluating the economic feasibility of red meat digestate-derived biofertiliser and highlighting the collaboration between the WA meat processor and the WA fertiliser company in promoting sustainable resource recovery practices.

5.0 Methodology

The project methodology was structured into the following key steps:

Literature Review: An extensive review of existing research and previous work conducted by Tessele Consultants on biofertiliser production from digestate of red meat processing waste. This included an evaluation of preferred digestate dewatering technologies, biofertiliser processing routes, and market opportunities for this innovative product in Australia.

Digestate Characterisation: Analysis of red meat industry by-products and food waste digestate qualities to establish reference benchmarks for the biofertiliser feasibility assessment, as the digestate qualities for the WA meat processor and the WA fertiliser company digestates, respectively.

Regulatory Review: A comprehensive desktop review of regulations governing the application of digestate-derived biofertilisers, including national and international regulatory frameworks.

Consumer Perception Survey: Conducted by UWA, an online survey evaluated public perceptions of fertilisers derived from red meat processing by-products and concepts toward the meat processing industry. The survey examined key factors such as fertiliser purchasing habits, consumer acceptance of different waste sources for fertiliser production, and comparisons between digestate-derived fertilisers, chemical fertilisers, and organic-certified alternatives. Additionally, it assessed consumers' willingness to pay for the innovative red meat digestate-derived biofertiliser.

Economic Assessment: A detailed economic assessment establishing a biofertiliser facility using combined feedstocks from the WA meat processor and the WA fertiliser company digestate under different scenarios, varying location and final product nutrient content. This involved gathering detailed operational and technical information from the WA meat processor and the WA fertiliser company, supplemented by well-informed assumptions based on literature and previous studies. It is important to note that, for this stage of the project, expenses and revenues were assessed under the assumption of a single-party operation. A more detailed economic framework can be developed to establish clear financial boundaries between the WA meat processor and the WA fertiliser company, ensuring a precise allocation of costs and revenues for each stakeholder involved.

6.0 Results

6.1 Literature Review

6.1.1 AD digestate from Red Meat Processing Waste Characteristics and Dewatering Technologies

The characteristics of a digestate are dependent on the type of substrate feeding the biogas plant, as well as the operational parameters of the process. The average total solids (TS) content in a digestate is 5%. It is known that for transporting and disposing of digestate, regulatory authorities require a minimum solid content of 15%. Geo bags are currently the most common technology applied for dewatering in the red meat industry in Australia. Despite this being a relatively cheap technique, it demands a large area, long time frame and dry weather to work properly. Therefore, many facilities are searching for alternative dewatering methods which require less space and are more efficient.

Table 1 shows the benefits, disadvantages, technology readiness level (TRL) as well as cost, energy use and footprint of preferred dewatering technologies in the market. It is relevant to mention that the solid content of a biofertiliser is approximately 90%, thus efficient dewatering technologies are necessary to convert AD digestate from red meat processing waste to biofertiliser. A complete summary of all available dewatering technologies can be found in Appendix 1.

Table 1. Analysis of preferred dewatering technologies in the market.

Technologies	Benefits	Disadvantages	TRL	Cost	Energy Use	Footprint	Combined Rating
Decanter Centrifuge	• High dewatering level (up to 30% TS). • Handles varied sludges. • Can dewater small volumes without chemicals. • Large processing range.	• High CAPEX and OPEX. • High power consumption.	9	High	High	Low	10
Rotary Press	• Low maintenance. • Low OPEX, power and process water requirements. • Low odour. • Simple operation and low labour. • High product %TS. • Large processing range (1-60kL/hr).	• Polymer required.	8	Low	Low	Low	10
KDS Multidisc Roller System	• Low noise and vibration. • No wash water is required • Self-cleaning; handles oily and fibrous material. • High solids capture in solids stream. • Very low energy use. • Low operator and maintenance attention. • Small footprint.	• Designed for smaller to medium-sized applications, throughput of 1kL-15.5kL/hour at 2%TS.	8	Medium	Low	Low	10
Screw Press (Variations of traditional)	• High dewatering level (15-70%TS). • Low energy use. • Handles varied sludges and high fibre content. • Large capacity, 1kg to 1326kg DS/h. • Reduced CAPEX and OPEX.	• Flocculant usage is recommended. • Process water required. • May have issues handling small particles.	9	Medium	Low	Low	8

Converting digestate into biofertiliser avoids digestate disposal costs, brings additional revenue and increases the facility's carbon credits, offsetting the use of synthetic fertilisers in the market. Depending on the final characteristics of the digestate, it can be used in certain applications without further processing. However, the physical and chemical properties of the sludge cake can change with the feedstock and may contain pathogens. Therefore, it is advised to process the sludge cake further, to stabilise and transform it into a marketable product with a consistent quality.

6.1.2 Processing technology options to produce bio-based fertiliser

The below schematic (Figure 1) summarises high-level processing technology options to produce bio-based fertiliser.

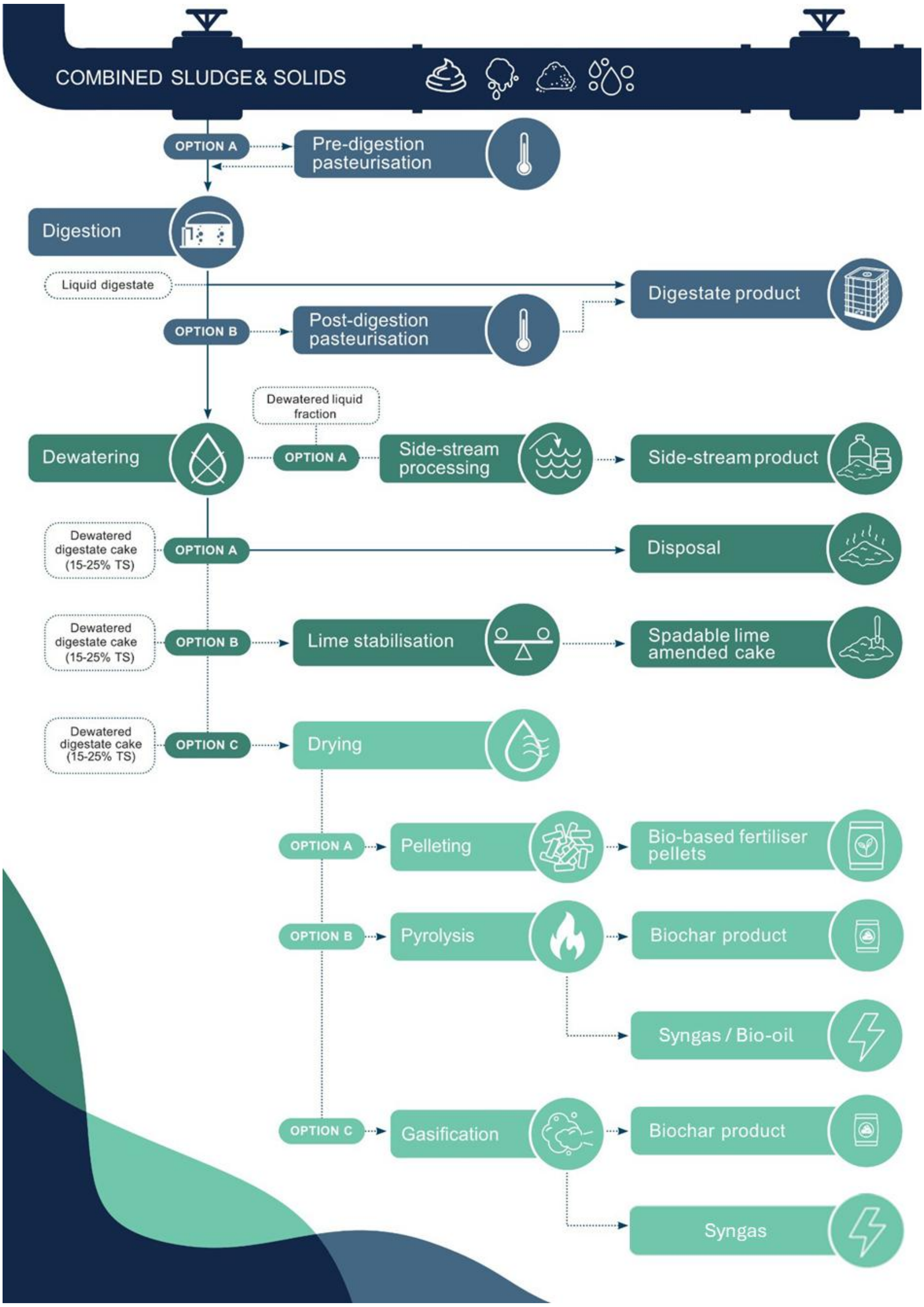


Figure 1. Digestate processing options for bio-based fertiliser production.

Some regulatory frameworks (such as the NSW) allow liquid digestate to be utilised either pasteurised or unpasteurised. However, pasteurising the digestate broadens the range of permitted uses, resulting in a higher grade of biosolids. Additionally, potential modifications to AQIS (Australian Quarantine and Inspection Service) or environmental regulations specifically for the outcomes of this innovative project may mandate pasteurisation to allow the spreading of digestate on land used for livestock grazing, as a measure to reduce disease transmission.

The recommendation to implement a hygienisation step after, rather than before, is primarily motivated by the goal of reducing energy costs associated with heating. The system designed for this process is not only compact but also encompasses a complete package. This package includes all the necessary equipment such as heat exchangers, hot water connections, and pumps. It is usually provided by the anaerobic digestor supplier.

After pasteurising and dewatering the digestate, there is the possibility of using it with less moist content (option A), executing lime stabilisation (option B) or proceed with drying technologies to increase the recovered resource value (option C).

Lime stabilisation of digestate involves adding lime to raise the pH, which kills pathogens, controls odours, and stabilises nutrients. This process makes the digestate safer and more effective as a fertiliser or soil amendment by improving its handling properties and ensuring nutrient availability for plants. The high pH environment also prevents pathogen regrowth, making it suitable for agricultural use and land reclamation.

The drying of dewatered digestate will reduce the digestate volume and convert it into a dryness that is appropriate and more efficient for further processing systems such as pelleting, pyrolysis or gasification. The dryer is usually an indirect dryer and utilises a shell and tube heat exchanger, so the heat source and feedstock do not mix.

Pelletising digestate involves processing it into small, dry pellets, which simplifies handling, storage, and application. This process enhances nutrient concentration and stability, making the pellets an efficient and convenient biofertiliser. The pellets are easier to transport and apply uniformly across fields, providing a consistent release of nutrients to crops. Additionally, pelletised digestate has reduced odour and pathogen levels, improving its safety and suitability for agricultural use and land reclamation. Figure 2 bellow illustrates the benefits of pelletising AD digestate from red meat processing waste.

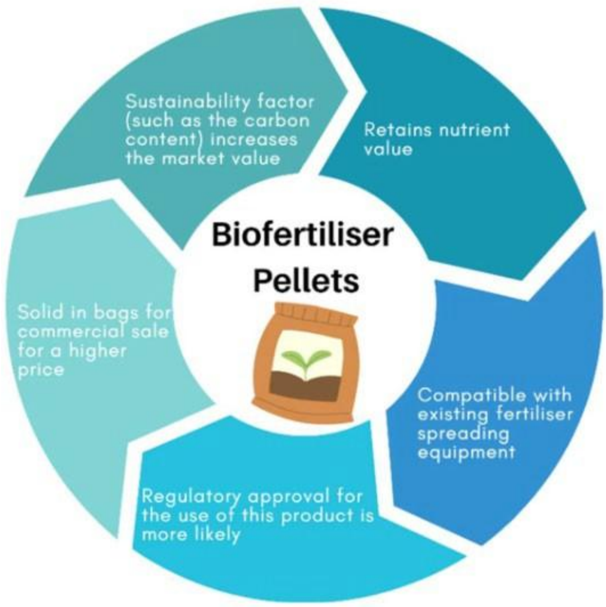


Figure 2. Pelletised bio-fertiliser advantages.

It is known that by using heat exchangers or waste heat recovery units, the pelletising system can repurpose heat generated during pellet production. This not only reduces energy costs but also aligns with principles of a circular economy.

Regarding the outlined technologies used for producing biochar, there are pyrolysis and gasification. Pyrolysis occurs in high temperatures (400-800°C) and the absence of air while gasification happens at very high temperatures (800-1000°C) and the presence of air. The decision to choose a specific biochar process primarily depends on factors such as operation conditions, final product requirement and the scale of the individual red meat processing plant. It is relevant to mention that pyrolysis requires significant flue gas scrubbing equipment, making it more economically viable for large-scale operations. While gasification requires more energy than pyrolysis due to the higher temperatures involved and produces a product with fewer nutrients compared to pyrolysis. However, gasification generates more syngas, resulting in greater energy production. If biochar with higher nutrient content is desired, pyrolysis should be chosen despite producing less syngas and, consequently, less energy. On the other hand, pyrolysis can generate bio-oil, which requires further refinement during wastewater treatment.

Both technologies can implement energy efficiency strategies such as heat integration, where excess heat from the reaction is recirculated to preheat incoming feedstock. They can also be combined with other energy systems, such as combined heat and power (CHP) to optimise energy balance and improve operational sustainability.

The two biochar technologies excel in eliminating pathogens and potential contaminants, potentially receiving broad regulatory approval for various uses. In contrast, while still sufficiently pasteurised for numerous reuse opportunities, bio-based fertiliser pellets will preserve more nutrients, making them particularly valuable to certain end-users.

Biochar can be sold at a significantly higher value than other bio-based fertiliser options such as pellets due to its various uses, including soil amendment for improved moisture and nutrient retention, as a carbon feed for livestock, for soil remediation, pollutant capture, and carbon sequestration. However, due to retaining fewer nutrients and requiring energy-intensive processes, it may be less preferable compared to other types of biofertiliser.

Table 2 shows the benefits, disadvantages, technology readiness level (TRL) as well as cost, energy use and footprint of the studied digestate processing options. Benefits, disadvantages and TRL of alternative technologies such as struvite precipitation can be found in Appendix 2.

Table 2. Analysis of the studied digestate processing options.

Option	Technology	Benefits	Disadvantages	TRL	Cost	Energy Use	Footprint	Combined Rating
Pelletised biofertiliser	Pellets from Drying Systems	• Heat recoverable. • Low volume of product for transport and reuse. • Product retains nutrients.	• High energy requirement. • Relatively high OPEX. • Relatively high CAPEX.	9	High	High	Medium	9
Biochar from Pyrolysis (Absence of Air)	Biochar from Pyrolysis	• Volume reduction. • High-quality final product well accepted by buyers, with potential for a variety of end uses.	• High heat and energy requirement (500 – 800 ºC). • High CAPEX and OPEX. • Liquid by-product which needs treatment, re-use or disposal options.	8	High	High	Medium	8

		• Produces gas, which can recycle heat and electricity, and produce biochar.	• More scrubbing of flue gas is required.					
Biochar from Gasification (Presence of Air)	Biochar from Gasification	• Volume reduction. • High-quality final product well accepted by buyers, with potential for a variety of end uses. • Produces gas, which can recycle heat and electricity, and produce biochar. • No liquid by-product produced.	• Very high heat and energy requirement (800-1200ºC). • High CAPEX and OPEX. • Reduced nutrient content in end product. • A less common technology with suppliers.	8	High	High	Medium	8

Choosing the most appropriate digestate processing technology involves considering a variety of factors beyond the technology itself, such as the scale of the operation in the facility, characteristics of the digestate, local demand for bio-based fertiliser, logistics, as well as environmental regulations.

It was shown that the digestate derived from anaerobic digestion can be used in various forms. There is a direct relationship between the value added to the bio-based fertiliser and the level of technology and complexity required to produce it. Figure 3 depicts the different uses and levels of complexity of the assessed technologies.

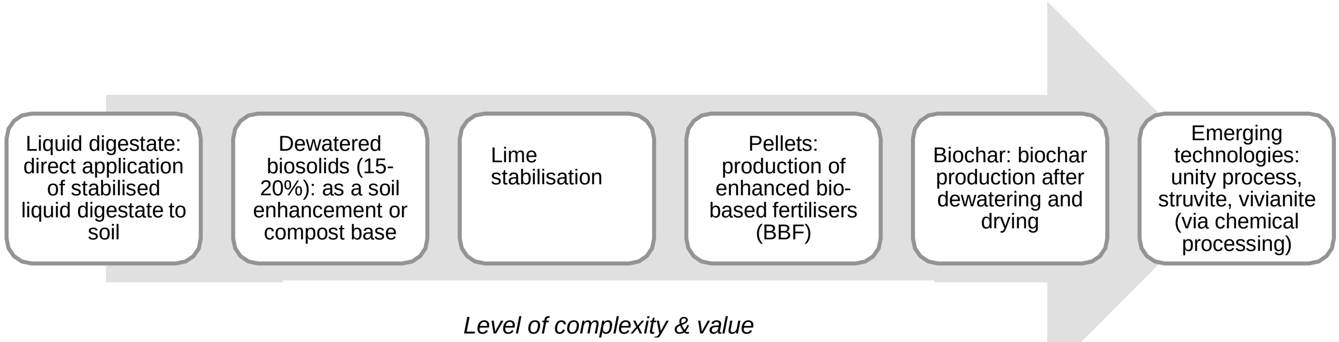


Figure 3. Different uses and levels of complexity of the assessed technologies.

It is important to note that despite the potential for utilising pasteurised digestate directly on agricultural land, several factors need careful consideration. Primarily, there could be a significant social concern regarding the odour emanation impacting adjacent facilities and residences. It is also critical to underscore the significance of transforming by-products into an environmentally sustainable, socio-economically beneficial product. Rather than disposing of the digestate in its untreated form, the strategy involves enhancing its value by converting it into a durable bio-based fertiliser, characterised by reduced volume and ease of handling.

Should the WA meat processor develop an on-site anaerobic digester, their estimated digestate product would be 6,500 tonnes/year (assuming a capacity of 73,921 t.HSCW/yr), which can be converted to 2,028 tonnes of pellets (90% TS) or to 1,862 tonnes of biochar (98% TS). When combined with the digestate output from the WA fertiliser company (estimated at 50,000 tonnes/year), the available digestate quantity may result in a favourable supply-demand scenario for the digestate-derived biofertiliser commercialisation. Addressing the demand not only in Western Australia but also nationwide.

6.1.2 Industry Drivers and Opportunities

According to AMPC database, there are 129 facilities registered as active members across Australia. The potential digestate, and subsequently bio-based fertiliser production quantities, were estimated for each AMPC member facility in project 2022-1081 executed by Tessele Consultants.

It was concluded that despite having fewer facilities, the larger facilities have the capacity to collectively produce 64% of the total red meat-derived bio-based fertiliser production in Australia, if biobased fertiliser production plants were implemented at all AMPC member red meat processors. This is because the larger facilities can produce more than twice as many pelletised biofertiliser as their small and medium-sized counterparts, making them the most industrially significant players in this sector. Figure 4 below shows the AMPC members across Australia.

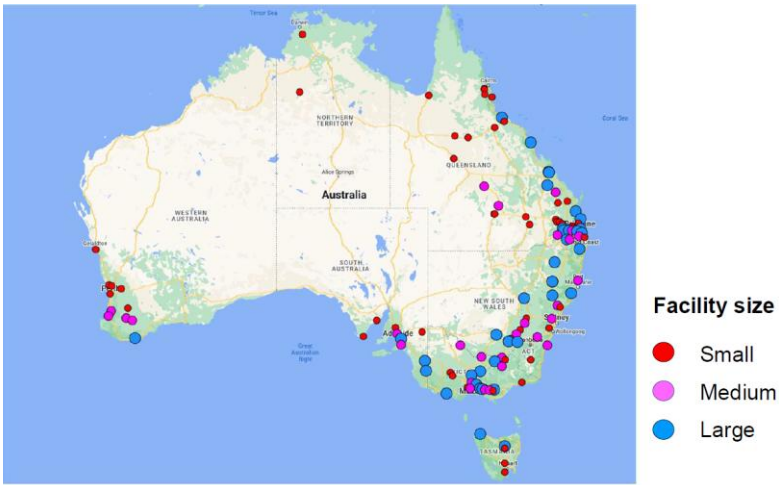


Figure 4. AMPC member facilities map.

A Geographic Information System (GIS) analysis was undertaken of the composition and area of land use in a 50km radius surrounding various AMPC establishments, with additional analysis of the broad, non-food demand sectors of forestry, commercial off-takers, landcare, natural resource management (NCM), mining and municipal to identify segments providing potential opportunities for the use of bio-based fertilisers. These segments are depicted in Figure 5 below.

Figure 5. Industry sectors for bio-based fertiliser use.

A map displaying the location of AMPC establishments, associated demand catchments and land use across Australia is shown in Figure 6.

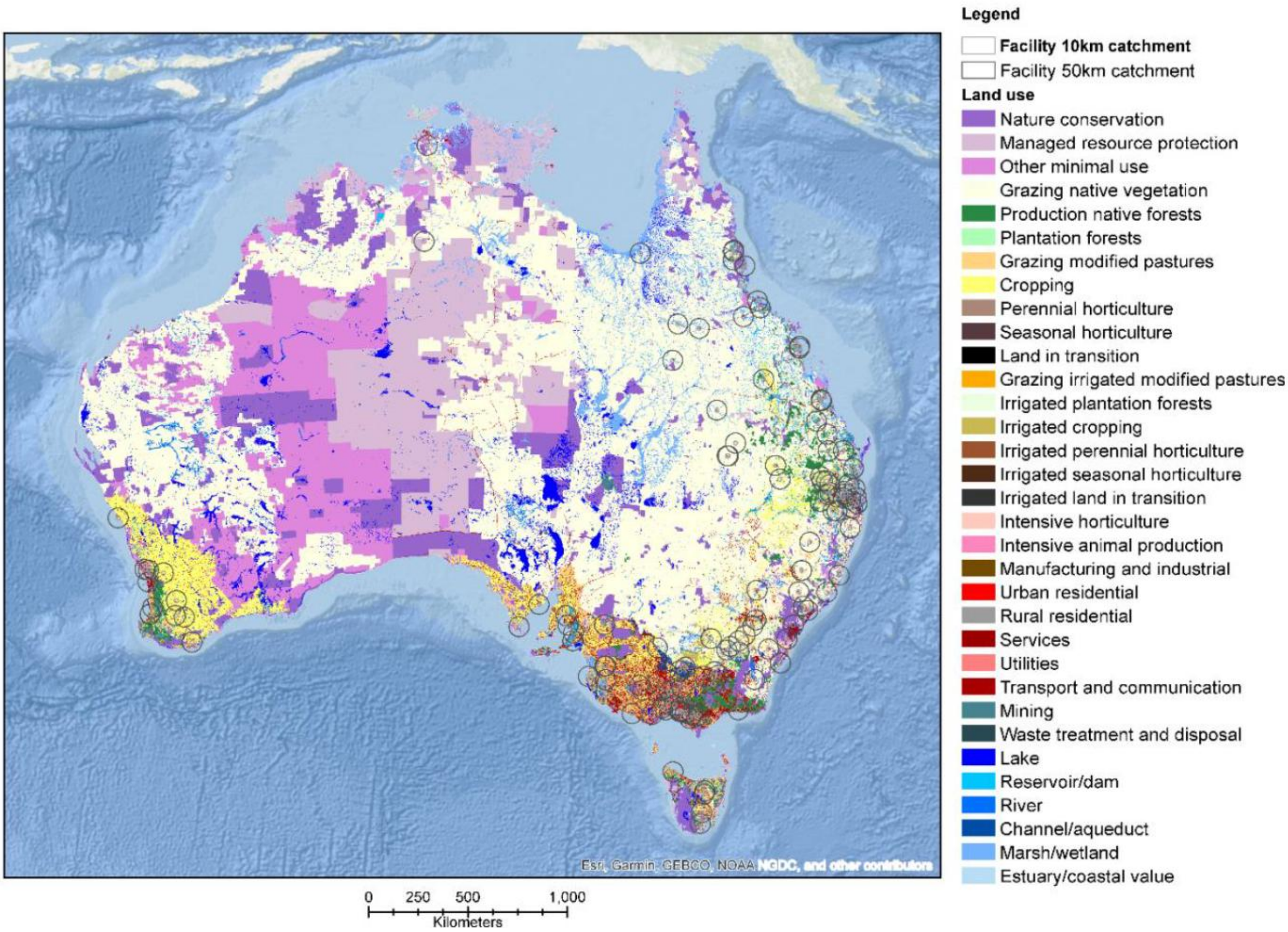


Figure 6. Location of AMPC establishments, demand catchments and land use.

The potential production quantities, in conjunction with other criteria such as the location of the facilities, were used to establish 11 red meat processing facilities as case studies. These case studies were used to determine potential market industries and local off-takers for the red meat digestate-derived biofertiliser. The estimated production quantity and quality of product were compared to the potential demand for using bio-based fertilisers in surrounding areas. Figure 7 depicts the 11 case study facilities, where implementing a Bio-Resource Recovery Facility (including a bio-based fertiliser plant) could be beneficial.

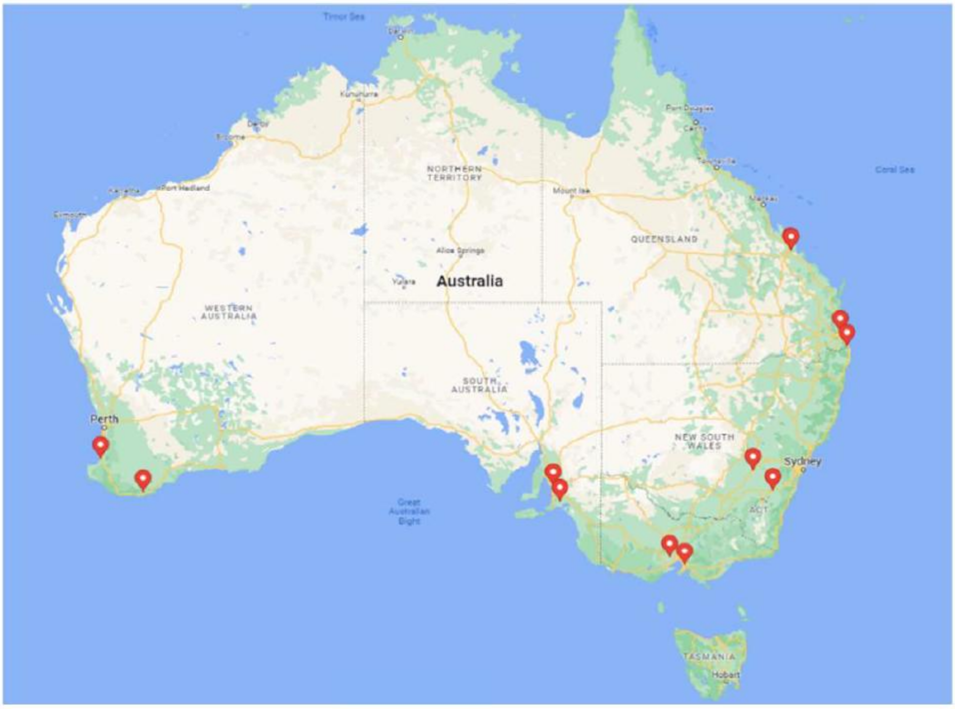


Figure 7. Map of 11 case study facilities for bio-based fertiliser plant implementation.

Demand for bio-based fertilisers is influenced by end-user application rates and surrounding land use. The ability to sell the entire supply depends on the demand relative to the production capacity (the demand/supply ratio). In the market research encompassing the 11 case study facility locations, potential demand for bio-based fertilisers across forestry, commercial off-takers, landcare, natural resource management (NCM), mining, and municipal sectors was assessed. Table 3 provides a summary of the survey results for these sectors adjacent to the case study facilities.

Table 3. Summary of the survey results for the mentioned sectors adjacent to the case study facilities.

Industry Sector	Sub-sector	Overall Survey Outcomes
Forestry	Softwood Plantations	• Strong potential for local bio-based fertiliser use, with a significantly increasing demand forecast.
	Environmental Plantations	• Little to no requirement for bio-based fertiliser traditionally. • Increasing plantations in sandy soil, and a motivation of offset carbon, increases the forecast bio-based fertiliser demand.
	Nurseries	• Little to no requirement for bio-based fertiliser. • Low appetite to trail bio-based fertilisers.
Commercial Off-takers	Commercial off-takers	• Keen interest to obtain additional and alternative feedstocks for existing pelletisation and biochar production plants.
Landcare	Regenerative Agriculture	• High product quality demand. • Specific product quality requirements.
Natural Resource Management	Carbon Farming	• Strong interest and demand. • Implementation not well established.

	Water Erosion and Sedimentation	• Strong opportunity in Queensland. • Basin case study area in addition to other bio-based fertiliser uses.
	Salinity	• Limited opportunity or demand.
	Acidity	• Strong interest and demand in South Australia. • Specific product quality requirements.
Mining	Mine and Quarry Rehabilitation	• Strong Opportunity in Western Australia. • Dependent on the type of land needing rehabilitation.
Municipal	Recreational Land	• Medium opportunity Australia-wide. • Medium product quality demand.
	Urban Cooling	• Strong opportunity in Victoria. • Low product quality demand.
General/All	General/All	• Strong industry-wide motivation to replace synthetic fertilisers with organics for ESG outcomes. • Cost and quality need to be comparable to existing fertiliser options. • Nutrient content is important.

Focusing on the Western Australia survey results, three WA-based companies (two in the forestry sector and one in the mining sector) were interviewed and contributed to the following findings:

These companies experience similar topsoil issues, including drought tolerance, nutrient availability, and soil carbon content. Additionally, they had similar concerns regarding the switch to bio-based fertilisers, such as product quality, price, and alignment with regulations. The price and amount of fertilisers currently used by the companies vary greatly, depending on their specific needs. Two out of the three companies showed great willingness to switch to a bio-based fertiliser.

All WA-based companies had similar requirements regarding the quality of the bio-based fertiliser, focusing on nutrient value, specifically nitrogen, phosphorous and potassium. One of the companies in the forestry sector specified that a high antibiotic pathogen tolerance would be desirable, and the mining company had additional concerns regarding livestock treatment residuals in the bio-based fertiliser.

The desired product form varied between each company, dependant on their spreading method. Two companies specified granules or pellet form rather than liquid form, and the remaining one requested any form that could be distributed with a mechanical spreader.

Further information regarding Project 2022-1081 and the undertaken survey can be found in the Bio-solids upgrade (Stage 1) Final report available on the AMPC website.

6.2 Desktop Review of Soil Conditioner Quality Standards

6.2.1 Characterisation of Red Meat By-products

In order to estimate the quality standard for red meat digestate-derived biofertilisers, this report section presents the characterisation of different red meat facility by-products. For instance, anaerobic pond sludge from a red meat facility in the Australian Southwest. This specific assessment involved quantifying nutrients and potential contaminants in the pond product. It is relevant to mention that the studied anaerobic pond sludge was dewatered using bench-scale tests. Samples of the dewatered cake and filtrate were analysed for nutrients, organics, metals, pathogens and contaminants. The results determined the need for side-stream treatment for the filtrate and assigned financial value to the solid by-product. Table 4 shows the anaerobic pond sludge characteristics.

Table 4. Anaerobic pond sludge characteristics.

Parameter	UOM	Quality
As	mg/kg	<1
Cd	mg/kg	<0.3
Cr	mg/kg	36
Cu	mg/kg	160
Pb	mg/kg	13
Ni	mg/kg	15
Se	mg/kg	7.0
Zn	mg/kg	960
Hg	mg/kg	<0.05
E. coli	MPN/g	<100
Faecal Coliforms	MPN/g	240,000
TN	mg/kg	33,000
TP	mg/kg	17,000
K	mg/kg	870
Organic Matter	%w/w	49
TOC	%w/w	28
VSS	g/kg	570
Al	mg/kg	3,900
BOD5	mg/kg	300
Ca	mg/kg	36,000

Fe	mg/kg	31,000
Mg	mg/kg	1,800
Mg	mg/kg	<0.05
FOG	mg/kg	27,000
Na	mg/kg	1,800
Alkalinity	mg/kg	190
TDS	mg/kg	11,000
Total Fluoride	mg/kg	460
NH_3	mg/kg	350
NO_3	mg/kg	1.3
NO_2	mg/kg	1.4

Figure 8 below represents the typical NPK (nitrogen, phosphorus, potassium) ratios of a range of commercial slow-release and general fertilisers, compared with the NPK ratio of the dewatered anaerobic sludge derived from the Australia Southwest red meat facility.

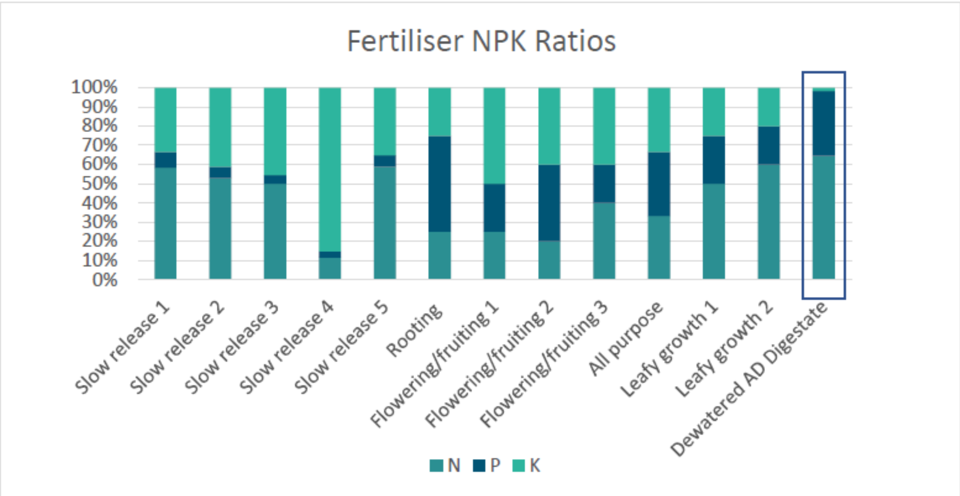


Figure 8. NPK ratios of synthetic fertilisers vs dewatered anaerobic pond sludge. Ratios derived from: Bunnings Australia (2023) and Montreal Space for Life (2023).

The dewatered anaerobic pond sludge showed elevated levels of nitrogen and phosphorus. However, its potassium content was notably lower compared to the selected synthetic fertilisers. Regarding the low potassium content, additional potassium sources can be added to optimise its nutrient composition. However, it is known that should the WA meat processor develop an on-site anaerobic digester, its feedstock will include not only sludge but also other nutrient-rich organic solids. The planned addition of nutrient-rich solid organic by-product streams to the anaerobic digestion process is expected to naturally increase the digestate's nutrient composition.

Tessele Consultants has been involved in various projects focusing on the recovery of red meat by-products. Consequently, Tables 6 and 6 below present the physicochemical characterisation of beef and lamb offal digestates from a red meat facility in the Australian Southwest and the averaged values of digestates from eleven red meat facilities across Australia, respectively.

Table 5. Characterisation of beef and lamb offal digestates from a red meat facility in the Australian Southwest.

Parameter	UOM	Beef Offal	Lamb Offal	Beef/ Lamb Offal	Beef/ Lamb Offal & Grain
Cl	mg/L	725	744	795	709
NO_2	mg/L	<0.1	<0.1	<0.1	<0.1
NO_3	mg/L	7.58	3.81	3.57	2.94
PO_4	mg/L	157.2	68.9	124.4	56.7
SO_4	mg/L	21.5	24.9	37.6	30.5
Na	mg/L	544	733	990	541
K	mg/L	2,258	2,487	3,949	2,485
Ca	mg/L	112	160	199	195
Mg	mg/L	15.5	14.6	26.5	32.5
TKN	mg/L	15,000	15,000	11,000	12,000
Total Ca	mg/L	2,700	2,600	2,700	2,800
Total K	mg/L	2,500	2,400	2,500	2,400
Total Mg	mg/L	2,600	2,500	2,800	2,700
Total Na	mg/L	400	470	430	410
Total P	mg/L	4,000	3,900	4,300	4,100

Table 6. Characterisation of 11 samples of red meat digestates in Australia.

Parameter	UOM	Result (mean ± SD)
TS	%w/w	2.28 ± 0.05
VS	%w/w	1.19 ± 0.10
TN	mg/kgFM	3,026 ± 478
TON	mg/kgFM	1,326 ± 906
TIN	mg/kgFM	2,162 ± 1191
TKN	mg/kgFM	2,888 ± 485
Protein	g/kgFM	18.19 ± 2.99

NH4-N	mg/L	2,229 ± 1,004
Free NH3	mg/L	141.27 ± 58.41
pH		7.8 ± 0.08
TVFA	mg/L	16.70 ± 2.79
Free acetate	mg/L	0.01 ± 0.01
Free propionate	mg/L	0.0029 ± 0.0013

It is relevant to note that the digestate characterisations in Tables 5 and 6 were undertaken post-biomethane potential analysis. Additionally, the experimental methodology encompassed dewatering the solid by-products which may transfer some nutrients from the solid portion to the filtrate. Despite this, the parameters presented remain a reliable estimate of the components present in red meat digestate.

To verify the characterisation of red meat by-products previously presented in the literature, Table 7 shows the physicochemical characteristics of untreated, sterilised, and pasteurised red meat waste at the end of an anaerobic digestion process. The data represent means ± standard deviation of 20 digested samples categorised as untreated, sterilised, and pasteurised red meat digestate.

Table 7. Physicochemical characteristics of untreated, sterilised, and pasteurised red meat waste at the end of an anaerobic digestion process (Matjuda et al., 2023).

Parameter	Unit	Untreated	Sterilised	Pasteurised
pH		7.86 ± 0.11	8.01 ± 0.03	8.11 ± 0.09
VS	%	4.67 ± 0.58	3.88 ± 0.49	3.12 ± 0.26
VS/TS		0.56 ± 0.08	0.55 ± 0.01	0.38 ± 0.03
Moisture	%	91.61 ± 0.56	92.95 ± 0.48	92.05 ± 0.85
TS	%	8.37 ± 0.61	7.05 ± 0.48	7.9 ± 0.58
COD	mg/L	3,724.61 ± 301.75	2,048.71 ± 282.65	1,441.35 ± 178.08
NH_4^+-N	% TKN	51.33 ± 2.01	63.41 ± 3.51	67.09 ± 2.94
TKN	g/kg DM	47.32 ± 2.03	53.26 ± 3.56	57.33 ± 2.36
EC	µS/cm	2,260 ± 65.91	1,977 ± 71.33	1,759 ± 83.33
TVFA	mg/L COD	2,872.57 ± 531.89	2,359.12 ± 498.15	2,102.27 ± 398.21
Ca	g/Kg	30.9 ± 0.92	27.4 ± 0.73	25.7 ± 0.90
Mg	g/Kg	2.41 ± 0.16	1.95 ± 0.22	1.75 ± 0.09
K	g/Kg	57.7 ± 0.65	49.6 ± 1.09	35.5 ± 0.77
Na	g/Kg	14.8 ± 0.29	13.0 ± 0.38	8.86 ± 0.17

S	mg/Kg	600.37 ± 5.56	412.33 ± 4.96	409.67 ± 3.49
P	g/Kg	27.1 ± 0.38	20.7 ± 0.49	19.2 ± 0.31
Fe	g/Kg	7.67 ± 0.34	5.20 ± 0.24	4.66 ± 0.19
Mn	mg/Kg	128.11 ± 1.82	96.07 ± 1.23	93.41 ± 0.83
B	mg/Kg	35.3 ± 0.78	29.0 ± 0.64	28.6 ± 0.52
Mo	mg/Kg	1.26 ± 0.03	0.47 ± 0.04	0.44 ± 0.06
Al	mg/Kg	232.09 ± 0.35	127.72 ± 0.84	124.86 ± 0.53
N-org	%TKN	3.23 ± 0.07	2.89 ± 0.05	2.47 ± 0.09
C-org	%	34.1 ± 0.43	33.1 ± 0.21	33.4 ± 0.18
C/N		8.06 ± 0.13	11.45 ± 0.08	13.52 ± 0.12
E.coli	cfu/mL	1,023 ± 35	873 ± 22	715 ± 31
Salmonella	25g of fresh sample	Not detected	Not detected	Not detected
Listeria	25g of fresh sample	Not detected	Not detected	Not detected
Zn	mg/Kg	273 ± 7.21	196 ± 4.36	162.26 ± 5.51
Cu	mg/Kg	48.5 ± 1.90	36.72 ± 1.09	35.8 ± 0.99
Cd	mg/Kg	0.89 ± 0.04	0.61 ± 0.06	0.57 ± 0.03
Cr	mg/Kg	43.59 ± 2.69	29.33 ± 1.66	19.05 ± 1.14
Pb	mg/Kg	10.23 ± 0.71	4.63 ± 0.45	3.97 ± 0.31
Ni	mg/Kg	3.08 ± 0.04	1.39 ± 0.07	1.30 ± 0.04
Hg	mg/Kg	0.08 ± 0.01	0.00 ± 0.00	0.00 ± 0.00
As	mg/Kg	4.93 ± 0.30	2.47 ± 0.19	1.99 ± 0.34

It is known that Project 2024-1091 intends to assess the feasibility of red meat digestate-derived biofertiliser from the WA meat processor and the WA fertiliser company digestates. Thus, Table 8 below shows the physicochemical characteristics of the WA fertiliser company digestate. The data represent the means ± standard deviation of 5 digested samples.

Table 8. Physicochemical characteristics of the WA fertiliser company digestate.

Parameter	Unit	Results (mean ± SD)
Ammonia - N	mg/L	3,020 ± 577.58
Chloride	mg/L	1,580 ± 116.61

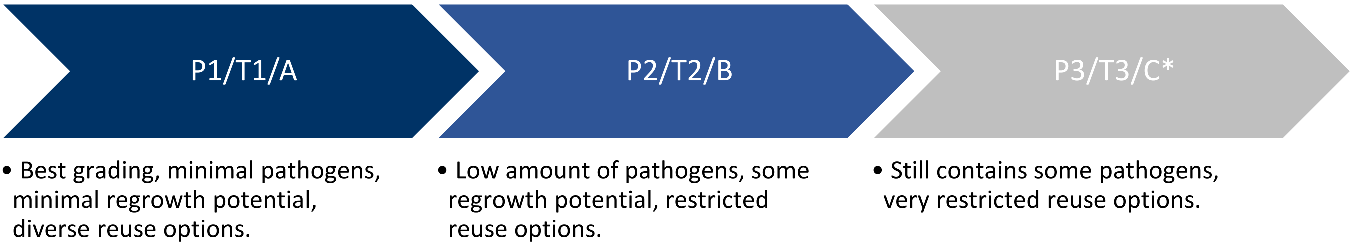
Conductivity	uS/cm	22,000 ± 0.00
Filterable Reactive Phosphorous	mg/L	26.00 ± 0.00
Nitrate - N	mg/L	10.83 ± 17.99
Nitrite - N	mg/L	0.01 ± 0.00
NOx - N	mg/L	11.07 ± 17.85
pH	pH Units	8.00 ± 0.00
Total Kjeldahl Nitrogen	mg/L	3,625 ± 294.74
Total Nitrogen	mg/L	4,060 ± 909.06
Total Phosphorous	mg/L	253 ± 94.95
Sulfur - Total	mg/L	90.2 ± 41.23
Cobalt	mg/L	0.076 ± 0.03
Copper	mg/L	1.66 ± 0.74
Iron	mg/L	68.4 ± 31.51
Manganese	mg/L	23.42 ± 37.84
Nickel	mg/L	0.15 ± 0.05
Zinc	mg/L	11.28 ± 4.22
Calcium	mg/L	1,020 ± 798.12
Magnesium	mg/L	113.8 ± 60.06
Potassium	mg/L	1,118 ± 149.98
Sodium	mg/L	954 91.56

6.2.2 Biosolids

Biosolids are defined as sludge from a wastewater treatment plant that has undergone further treatment to significantly reduce disease-causing pathogens and volatile organic matter, resulting in stabilised material suitable for beneficial use. However, this definition excludes industrial and food processing sludges, meaning that red meat processing facility-derived sludge is not currently considered biosolid and is not governed by state and national guidelines for biosolids management.

Biosolids Stabilisation Grades

The Australian stabilisation grades also known as the pathogen grade, assigned to produced biosolids depends on pathogen levels presented in the material. This is typically measured by the presence of salmonella, E.coli, faecal coliforms, and certain parasites. Additionally, there are specific vector attraction reduction criteria and land management controls associated with each stabilisation grade. The Australian stabilisation grades are presented in Figure 9, where P and T stand for pathogen reduction and treatment process, respectively.



* P3/T3/C is equivalent to Class B for Tasmania.

Figure 9. Australian biosolids stabilisation grades.

Biosolids Contamination Grades

The contaminant grade assigned to produced biosolids is determined by the levels of heavy metals and other contaminants, such as pesticides. The most conservative grading, C1/A, is designed to protect human health and preserve the environment. Subsequent classifications – C2/B, C3/C, and C4/D – indicate increasing concentrations of contaminants.

Characterisation of by-products from the red meat industry vs sewerage biosolids

Although the definition of biosolids excludes by-products from the red meat processing industry, comparing the characteristics of biosolids with red meat by-products can indicate suitable regulations for red meat digestate-derived biofertilisers. Table 9 provides a comparison of biosolids classification limits and typical nutrient contents with a preliminary analysis of red meat by-products presented in the previous section of this report such as dewatered anaerobic pond sludge from a RMF (red meat facility) located in the Australian Southwest and pasteurised red meat digestate (Matjuda et al., 2023).

Table 9. Comparison of biosolids and red meat by-products characteristics.

Parameter	UOM	Biosolids grade P1/T1/A and C1/A	Biosolids grade P2/T2/B and C2/B	Dewatered Anaerobic Pond Sludge	Pasteurised Red Meat Digestate (Matjuda et al., 2023)
Total solids	%w/w	>15%TS	>15%TS	25.7	7.9
Total Kjeldahl Nitrogen	mg/kg	75,000*	75,000*	33,000	57,330
Total Phosphorus	mg/kg	28,000*	28,000*	17,000	19,200
Arsenic, As	mg/kg	20	60	<1	1.9
Cadmium, Cd	mg/kg	2	20	<0.3	0.5
Chromium, Cr	mg/kg	100-400 (for Cr III)	500- 3000 (for Cr III)	36.0	19
Copper, Cu	mg/kg	100-200	2500	160.0	35.8
Lead, Pb	mg/kg	150 - 300	420	13.0	3.9
Nickel, Ni	mg/kg	60	270	15.0	1.3
Selenium, Se	mg/kg	3	50	7.0**	Not assessed
Zinc, Zn	mg/kg	200 - 250	2500	960.0	162.2
Mercury	mg/kg	1	15	<0.05	0
E. coli	MPN/g	<100	<1000	<100	<1000
Faecal Coliforms	MPN/g	<1,000	<2,000,000	240,000	Not assessed

**These are 'normal values' based on averaged data from two municipal wastewater treatment plants in WA for select biosolids which are typically classified as P3 and C2. Nutrients are not specifically limited in the biosolids guidelines and nutrient concentration does not change the stabilisation or contamination grade of biosolids. However, biosolids producers do put limits on their nutrient components to comply with specific end-use biosolids application rates.*

***Selenium deficiency, as well as copper, cobalt and phosphorus, is common in cattle and sheep in Australia. Having a higher selenium concentration may not be an issue if the use of the biofertiliser is for livestock grazing pastures (MLA, 2021).*

Table 9 has only compared red meat by-products to P1/C1 and P2/C2 biosolids. Typical biosolids spread on agricultural land, after anaerobic digestion processes or lime stabilisation processes, are typically classed as P3 and C2, which are of even poorer quality. The national biosolids guideline compared in Table 9 is stricter in terms of stabilisation and contamination grading limits than the USA (and therefore also stricter than NSW and QLD, which closely follow the USA EPA).

Comparison of red meat by-products characteristics vs biosolids

The red meat by-products may contain fewer contaminants and pathogens compared to municipal biosolids. Typically, municipal biosolids that have been anaerobically digested or treated with lime are classified as P3/C2 in terms of pathogens (Stabilisation Grade) and heavy metal contaminants (Contaminant Grade). In contrast, using the Australian Biosolids Guideline as a conservative benchmark, the red meat by-products anaerobic pond sludge and pasteurised red meat digestate could be classified as P2/C2 and P2/C1, respectively. Regarding the anaerobic pond sludge, there is potential for a higher classification, such as P1 if only E.coli levels were considered, rather than overall faecal coliforms and C1, if selenium and zinc levels were not an issue. The pasteurised red meat digestate meets P1 limits and could be considered as C1 if E. coli values were lower than 100 MPN/g.

Assuming a conservative P2/C2 classification, the red meat by-products could be used for nearly unrestricted applications, including crops that come into direct contact with the product and grazing/fodder crops. This usage scope is broader than what is permitted for municipal biosolids. Therefore, until specific regulations for red meat digestate-derived biofertiliser are established, the biosolids guidelines can serve as a provisional guide. The comparison of characteristics and adherence to biosolids guidelines indicates a wide range of potential uses for the biofertiliser derived from red meat digestate, supporting confidence in investing in re-processing technologies.

6.2.3 Organic Fertilisers Available in the Market

Based on the information provided in the previous section of this report, the biofertiliser derived from the WA meat processor and the WA fertiliser company digestates aims to meet high-quality standards of organic fertilisers currently available in the market. Figures 10 and 11 depict the nutrient compositions of established organic fertiliser brands in Australia.

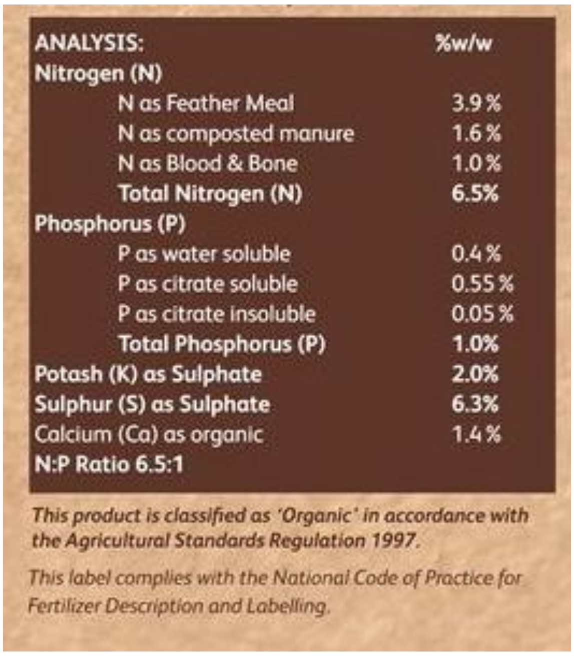
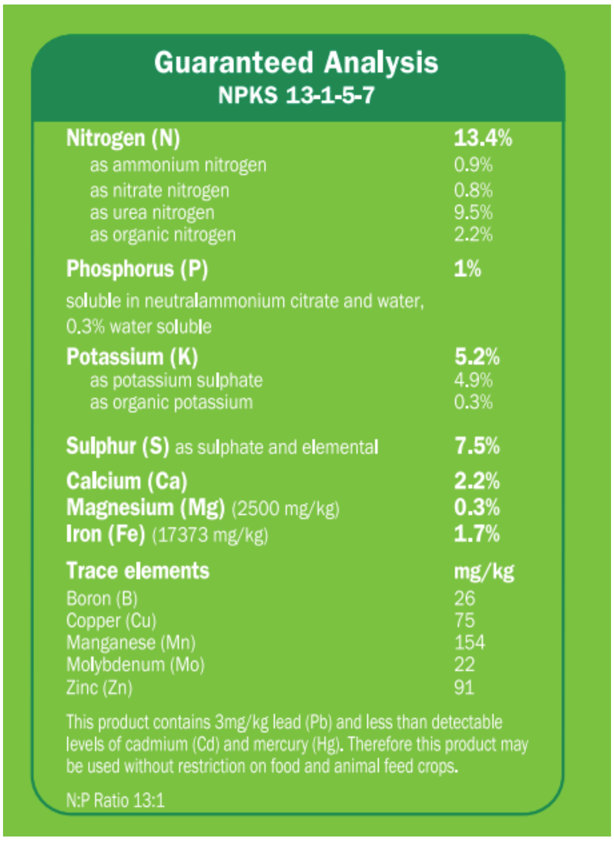


Figure 10. Richgro's organic fertiliser nutrient composition (Source: Bunnings, 2024).



Guaranteed Analysis
NPKS 13-1-5-7

Nitrogen (N)	**13.4%**
as ammonium nitrogen	0.9%
as nitrate nitrogen	0.8%
as urea nitrogen	9.5%
as organic nitrogen	2.2%
Phosphorus (P)	**1%**
soluble in neutralammonium citrate and water, 0.3% water soluble	
Potassium (K)	**5.2%**
as potassium sulphate	4.9%
as organic potassium	0.3%
Sulphur (S) as sulphate and elemental	**7.5%**
Calcium (Ca)	**2.2%**
Magnesium (Mg) (2500 mg/kg)	**0.3%**
Iron (Fe) (17373 mg/kg)	**1.7%**
Trace elements	**mg/kg**
Boron (B)	26
Copper (Cu)	75
Manganese (Mn)	154
Molybdenum (Mo)	22
Zinc (Zn)	91

This product contains 3mg/kg lead (Pb) and less than detectable levels of cadmium (Cd) and mercury (Hg). Therefore this product may be used without restriction on food and animal feed crops.

N:P Ratio 13:1

Figure 11. Osmocote's organic fertiliser nutrient composition (Source: Bunnings, 2024).

6.3 Regulations Governing the Application of Digestate-derived Fertilisers

6.3.1 Victorian Safe Production and Use of Digestate Guidelines

The Environmental Protection Act 2017 and the Environmental Protection Regulations 2021 outline how by-products, including digestate, should be managed in Victoria, Australia. These guidelines cover several aspects, including:

- Producing digestate.
- Transporting digestate.
- Applying digestate to land.
- Receiving digestate for secondary processing.
- Unpasteurised digestate.
- On-site management.
- Complying with the designation.

In Victoria, the appropriate by-products code is N205: residues from industrial by-products treatment/disposal operations, including digestate, bottom ash and char.

Complying with the Designation

EPA Victoria has released a designation to assist in the management of digestate. The designation has three main risk control measures: feedstock controls, pasteurisation requirements, and contamination thresholds.

Feedstock Controls

The designation specifies what feedstocks can be used for producing low-risk and elevated-risk digestate. Table 10 displays the risk level of typical digestate feedstocks.

Table 10. Feedstocks and associated risk classification (Revised from: Table 4, Victoria Government Gazette, 2023).

Risk	Feedstock
Low	Garden and landscaping organics
	Agricultural and horticultural crop by-products
	Untreated timber
	Natural organic fibrous by-products
	Forestry residuals
	Vegetables fruits and seeds and other food by-products
	Winery, brewery and distillery by-products
	Liquid food by-products and liquid food processing by-products (including sludges)
	Municipal food organics and garden organics
	Grease trap by-products (derived from food production only)
Elevated	Animal manure and mixtures of animal manure and animal bedding organics
	Animal mortalities, parts of carcasses, bone or fish
	Liquid animal by-products (blood) and paunch (sludge)
	Any other feedstock not specified as low-risk

Red meat processing by-products fall under the elevated-risk category due to the significant presence of animal by-products such as animal manure, parts of carcasses, blood, and paunch.

Pasteurisation Requirements

The designation outlines two options for pasteurisation, one of which must be applied to comply with the necessary pasteurisation requirements.

Process-based Pasteurisation

This option specifies time and temperature for reducing risks associated with the digestate. Low-risk feedstocks must meet one of the process-based pasteurisation requirements. Elevated-risk feedstocks must undergo both requirements. Figure 12 outlines the appropriate pasteurisation requirements for each feedstock risk level.

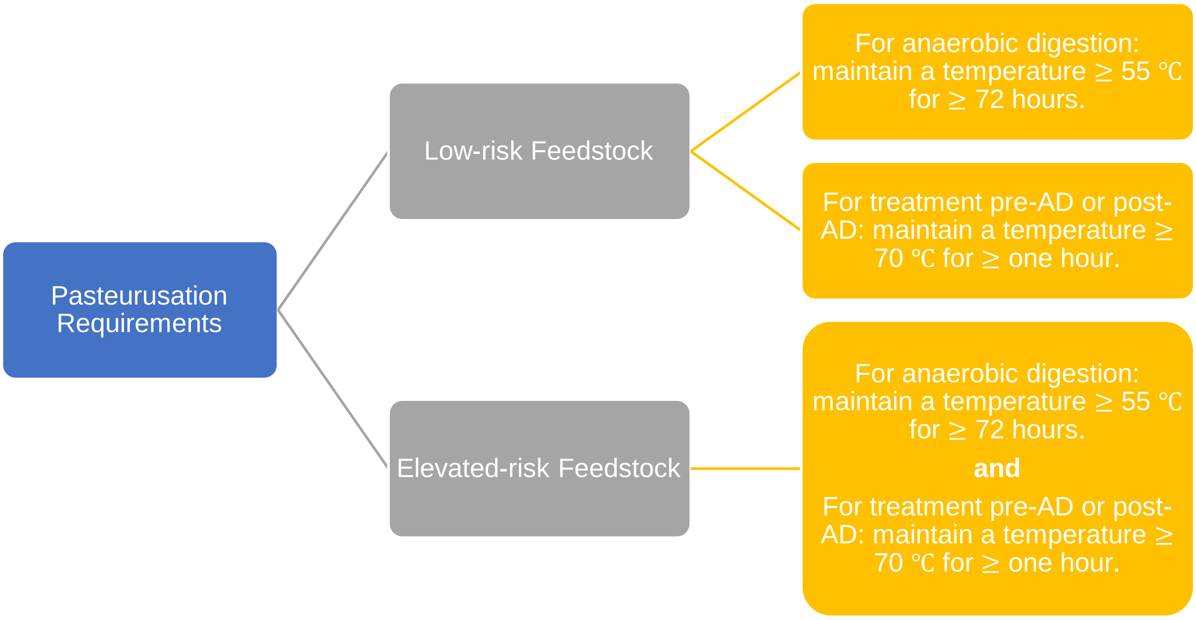


Figure 12. Process-based pasteurisation requirements for low and elevated-risk feedstocks.

Outcome-based Pasteurisation

Outcome-based pasteurisation does not depend on specific time and temperature settings. Instead, it requires controlling risks through the following:

- A risk assessment.
- Process validation.
- A monitoring program.
- Meeting microbial contaminant thresholds.

These requirements are essential for ensuring the safe production of digestate using the outcome-based pasteurisation method.

Contamination Thresholds

The designation establishes contamination limits for chemical, physical, and microbial contaminants. The digestate must not exceed the specified upper limits for any contaminants and pathogen indicators outlined in Table 11.

Table 11. Digestate contaminant limits (Revised from: Table 1, Victorian Government Gazette, 2023).

	Parameters	UOM	Upper limits (Chemical substance limits)
Chemical contaminants	Arsenic (As)	mg/kg	20
	Cadmium (Cd)	mg/kg	1
	Boron (B)	mg/kg	100
	Chromium (Cr)	mg/kg	100
	Copper (Cu)	mg/kg	150
	Lead (Pb)	mg/kg	150
	Nickel (Ni)	mg/kg	60
	Selenium (Se)	mg/kg	5
	Zinc (Zn)	mg/kg	300
	Polycyclic aromatic hydrocarbon	mg/kg	6
	Dichlorodiphenyltrichloroethane (DDT)/ Dichlorodiphenyldichloroethane (DDD)/ Dichlorodiphenyldichloroethylene (DDE)	mg/kg	0.5
	Aldrin	mg/kg	0.02
	Dieldrin	mg/kg	0.02
	Chlordane	mg/kg	0.02
	Heptachlor	mg/kg	0.02
	Hexachlorobenzene	mg/kg	0.02
	Lindane (Benzene hexachloride / BHC)	mg/kg	0.02
	Polychlorinated biphenyls	mg/kg	Not detectable (detection limit 0.2 mg/kg)
Physical contaminants	Non-organic material but excluding light and flexible or film plastic, rocks and stones	% w/w	≤0.5
	Light and flexible or film plastic including biodegradable or compostable packaging	% w/w	≤0.05
Pathogen Indicators	E.coli	/g dry weight	<100 most probable number
	Faecal coliforms	/g dry weight	<1,000 most probable number
	Salmonella spp	/50g dry weight	Absent
	Clostridium perfringens	/g dry weight	<10 organism

6.3.2 Canadian Digestate Management Guide

The Canadian Digestate Management Guide describes the characteristics of digestates derived from suitable feedstock materials produced as whole digestate and the solid and liquid digestate products resulting from the digestate mechanical liquid-solid separation. Digestate characteristics depend on the feedstock blend and the biogas plant's design and operation. Effective agricultural use of digestate requires knowledge of its specific characteristics, including organic matter, nutrient content, carbon to nitrogen (C:N) ratio, salinity, and pH, which can vary significantly.

Federal Policies

Digestate regulation in Canada is primarily managed at the provincial level. However, the Canadian Food Inspection Agency (CFIA) oversees the national Fertilisers Act and fertiliser registration program. While digestate can be managed under the Fertilisers Act, producers may opt to market it as a fertiliser, requiring adherence to both national and provincial regulations.

The Fertilisers Act mandates that fertilisers and supplements imported or sold in Canada must be safe for humans, plants, animals, and the environment, and properly labelled. Registration is granted if the product is safe when used as directed and must be renewed every 60 months.

Provincial Policies

Digestate management regulations differ across provinces and are influenced by the feedstock mix and characteristics. Below is a summary of regulations for provinces with significant biogas development.

Quebec

In Quebec, digestate is regulated under the “Guide des MRF” (Guide for Fertilising Residual Materials). This guide covers all types of anaerobic digestion with uniform regulations. To be applied to land, digestate must meet the following requirements:

- Contaminant, pathogen, and chemical standards specified in Table 12.
- Allowed for use in fertilising crops for animal use, sylviculture, and revegetation.
- Must be stored in airtight tanks for a maximum of 6 months, located at least 500 meters from any residential area.
- Maximum application limit of 13.2 tonnes per hectare every 3 years.

Table 12. Chemical contaminant limits in Quebec (Revised from: Table 8.2a, Page 86, Guide Des MRFS, 2015).

	Parameters	Contaminant limits (mg/kg dry matter)	
		Category C1	Category C2
Trace Elements	Arsenic (As)	13	41
	Cobalt (Co)	34	150
	Chromium (Cr)	210	1,000
	Copper (Cu)	400	1,000
	Molybdenum (Mo)	10	20
	Nickel (Ni)	62	180
	Selenium (Se)	2	14
	Zinc (Zn)	700	1,850

	Parameters	Contaminant limits (mg/kg dry matter)	
		Category C1	Category C2
Strict Contaminants	Cadmium (Cd)	3	10
	Mercury (Hg)	0.8	4
	Lead (Pb)	120	300
	Dioxins and Furans	17	50

For the digestate to be classified in category C1, all parameters must fall under the guidelines of the C1 limit contents. To be in category C2, all parameters must respect the C2 limit contents, and at least one parameter must exceed the C1 limit.

Ontario

In Ontario, digestate management is regulated under the Nutrient Management Act, O.Reg. 267/03. Digestate from mixed anaerobic digestion (AD) facilities treating both on-farm and off-farm feedstocks is considered agricultural source material (ASM) when at least 50% of the feedstock, by volume, is on-farm AD materials. The application of ASM must comply with the following nutrient-related conditions:

Phosphate Application:

Over any consecutive five-year period, the application rate must ensure that the total available phosphate per hectare does not exceed:

- Crop production requirements per hectare for the five years plus 85 kg of phosphate per hectare, or
- The phosphate removed from the land per hectare in the harvested portion of the crop during the five-year period plus 390 kg of phosphate per hectare.

Nitrogen Application:

During any 12-month period, the application rate must not exceed 200 kg of plant-available nitrogen per hectare.

Proximity to Water:

Nutrients must not be applied within 150 meters from the top of the bank of surface water if the maximum sustained slope of the land is 25% or greater. Setbacks from wells include no application closer than 100 meters to a municipal well and specific distances for other well types.

Application Rates Based on Runoff Potential

Maximum rates of single application to land vary depending on the runoff potential of the land, ranging from 50 cubic metres per hectare for high runoff potential to 130 cubic meters per hectare for very low runoff potential when applied to the surface. If injected or incorporated into the land, these rates are higher.

Storage and Handling

Digestate must be stored properly to prevent environmental contamination and must meet specific storage requirements

Alberta

In Alberta, biogas facilities where more than 50% of the feedstock by weight is manure are regulated under the Agricultural Operations Practices Act (AOPA), enforced by the Natural Resources Conservation Board (NRCB), which sets the standards for the storage, handling, and application of manure and digestate to ensure environmental protection and sustainable agricultural practices.

Contaminant Limits

AOPA specifies contaminant limits to protect soil and water quality, which are outlined in Table 13.

Table 13. Contaminant limits in Alberta (Source: AOPA, 2000).

Contaminant	Limit
Nitrogen (N)	Must not exceed 200 kg of plant-available nitrogen per hectare annually
Phosphate (P)	Over any five-year period, the total available phosphate must not exceed: - Crop production requirements plus 85 kg/ha, or - The phosphate removed in the harvested crop plus 390 kg/ha
Heavy Metals	- Cadmium (Cd): 3 mg/kg - Copper (Cu): 500 mg/kg - Lead (Pb): 150 mg/kg - Nickel (Ni): 62 mg/kg - Zinc: 1,850 mg/kg
Pathogens	Digestate must be treated to reduce pathogens to safe levels before land application
Salinity	Must not exceed 1 dS/m in the top 60 cm of soil
pH	Must be maintained between 6 and 8.5

Digestate Management

The storage of digestate must comply with regulations to prevent environmental contamination, including requirements for storage facility design and location. On-farm storage and land-application of digestate are subject to guidelines that ensure the material does not adversely affect soil or water resources. Digestate must be stored in facilities that prevent runoff and leaching, typically requiring impermeable liners and containment systems.

Application of Digestate

Digestate application rates are regulated to match crop nutrient needs, preventing over-application that could lead to nutrient runoff and water pollution. Specific setback distances are from water bodies and wells are mandated to protect water quality.

British Columbia

Under the Environmental Management Act, the B.C. Ministry of Environment (MoE) requires agricultural biogas plants to obtain permits for by-products releases, including emissions from upgraders and boilers, air from storage tanks, and land application of digestate. Additionally, biogas plants might need authorisation under the regional district's by-products management plan, which details the management of large by-products volumes, including by-products type, volume, and methods.

Each regional district has its requirements and processes for authorisation, which can vary significantly in terms of information needed and timeframes. For facilities processing 100% manure, the Code of Practice for Agricultural Environmental Management (AEM Code) sets guidelines for nutrient application to ensure optimal crop growth and minimise environmental risks.

6.3.3 PAS 110:2014: The British Standards Institution

The Publicly Available Specification (PAS) 110:2014 aims to promote the development of anaerobic digestion by ensuring that digestates meet consistent quality standards, thus encouraging their market use as fertilisers or soil improvers. This industry-led specification sets minimum quality requirements for digestates, supporting sustainable management of bio by-products and biodegradable materials and serving as a precursor to a future British Standard.

The PAS110 guideline, aiming to control input materials and the management systems of anaerobic digestion, provided a baseline quality specification for digestate. The guideline is used as one of the fundamental pillars of the Biofertiliser Certification Scheme in the UK, and it includes various test parameters, such as odour emission, pathogens, potentially toxic elements, stability, physical contaminants, and physicochemical characteristics. However, the regulation does not cover organic contaminants, such as PFAS and PAHs.

Contaminant and Pathogen Limits

Table 14 outlines the specific limits set by The British Standards Institution for various contaminants and pathogens present in digestate to ensure they are safe to use. The PAS sets out requirements for non-animal by product (ABP) digestate and digestate originating from ABP.

Alternative limits are presented in PAS 110 for digestate made only from manure, unprocessed and processed crops, crop residues, glycerol and/or used animal bedding that arises within the producer's/cooperative's premises or holding. These digestates shall be used entirely within the same premises or holding.

Table 14. Upper limit values for digestates (Table 1, Page 26, PAS 110:2014).

	Parameters	**Total nitrogen (N) (kg/t)**									
		<1	1-1.9	2-2.9	3-3.9	4-4.9	5-5.9	6-6.9	7-7.9	8-8.9	≥9
Potentially toxic elements	Cadmium (Cd)	0.12	0.24	0.36	0.48	0.60	0.72	0.84	0.96	1.08	1.2
	Chromium (Cr)	8	16	24	32	40	48	56	64	72	80
	Copper (Cu)	16	32	48	64	80	96	112	128	144	160
	Mercury (Hg)	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80
	Nickel (Ni)	4	8	12	16	20	24	28	32	36	40
	Lead (Pb)	16	32	48	64	80	96	112	128	144	160
	Zinc (Zn)	32	64	96	128	160	192	224	256	288	320
Physical Contaminants	Total stones	3.2	6.4	9.6	12.8	16	19.2	22.4	25.6	28.8	32
	Total physical contaminants (excluding stones)	0.04	0.07	0.11	0.14	0.18	0.22	0.25	0.29	0.32	0.36
Pathogen Limits		**Non-ABP digestate**				**ABP digestate**					
	E.coli	1,000 CFU/g fresh matter				Limits are specified by the competent authority					
	Salmonella spp	Absent in 25 g fresh matter									
Stability (l biogas / g volatile solids)	Residual biogas potential (RBP)	0.45									

Quality Assurance and Compliance for Digestate Production

To ensure compliance with quality standards, digestates must meet all specified requirements as detailed in Table 14. Regular testing for a range of parameters must be conducted at a prescribed frequencies outlined in Table 15. Producers are obligated to maintain comprehensive records of input materials, process management, additional processing steps, storage periods, and corrective actions.

Furthermore, digestate producers must validate their processes to consistently achieve the required quality. If test results exceed the specified limits, corrective actions must be implemented, followed by further testing to confirm that the digestate complies with the standards before it can be used or marketed.

Table 15. Minimum testing frequencies (revised from PAS 110:2014).

<table>
<tr><th rowspan="2">Parameter</th><th colspan="2">Minimum frequencies for testing representative samples</th></tr>
<tr><th>Non-ABP digestate</th><th>ABP digestate</th></tr>
<tr><td>Human and animal pathogen indicator species</td><td>1 per 5,000 m³ of WD/SF/SL* produced, or 1 per 3 months.</td><td>As specified by the competent authority.</td></tr>
<tr><td>Potentially toxic elements</td><td colspan="2">1 per 6,000 m³ of WD/SF/SL produced, or 1 per 3 month</td></tr>
<tr><td>Stability</td><td colspan="2">2 per 12 months and not within 3 months of each other, or sooner if and when significant chance occurs.</td></tr>
<tr><td>Physical contaminants</td><td colspan="2" rowspan="5">1 per 6,000 m³ of WD/SF/SL produced, or 1 per 3 months.</td></tr>
<tr><td>Total nitrogen (N), total phosphorous (P) and total potassium (K)</td></tr>
<tr><td>Ammoniacal nitrogen (NH_4-N)</td></tr>
<tr><td>Dry matter (total solids)</td></tr>
<tr><td>Loss on ignition (volatile solids or a measure of organic matter)</td></tr>
</table>

*WD/SF/SL = Whole Digestate / Separated Fibre / Separated Liquor.

6.4 Environmental and Agricultural Regulations

Tessele Consultants has conducted a comprehensive desktop review of the legislation and regulations governing the possible uses of by-products from red meat processing facilities in Australia. This review focused on current regulations concerning:

- Classification of by-products
- By-product disposal requirements
- By-product reuse requirements

In the USA, certain by-products can be beneficially reused, a progressive approach reflected in the policies of NSW and Queensland through the adoption of End of Waste Codes. However, in other parts of Australia, by-products and re-processing products like digestate from red meat processors are still classified as waste, necessitating disposal. Most Australian states classify ‘Animal effluent and residues, including red meat processing by-products and other by-products from animal processing’ as K100 or similar putrescible organic wastes, requiring disposal. This classification incurs costs related to transport and landfill gate fees and overlooks potential revenue from recovered resources.

Despite this, all states have by-products reduction, avoidance, and recycling strategies, driven by their respective State Governments, to move towards a circular economy. Historically, these targets have not been met, but there is now a stronger push to achieve them. States are revising their waste strategies, which aim to recover and reuse materials traditionally considered waste, like red meat processing solid by-products. Implementing these strategies will require changes in waste regulation across Australia to support greater reuse, reprocessing, and recycling, as there are currently no existing national regulations for using bio-based fertilisers in Australia. Table 16 summarises the desktop review of legislations that control the use of by-products from red meat processing facilities and waste strategies in each Australian state.

By evaluating the market value of biofertiliser derived from red meat digestate, this project will lay the groundwork for a regenerative economy within the sector. It aims to prevent the disposal of tonnes of red meat processing by-products in the country by adding value to the material and closing the loop of the circular economy.

Table 16. Desktop review of legislations that control the use of by-products from red meat processing facilities and waste strategies in each Australian state.

Jurisdiction	Current disposal of by-products*	Regulatory authorities for disposal of current by-products	By-product classifications**	Waste Strategy	Current status for similar projects
Western Australia	Landfill for class 2 or 3 for K100 (animal effluent and residues) putrescible and organic wastes, or to rendering (Government of Western Australia, 2018).	DWER, DWER meat processing facility operating licence stipulates how waste by-products from the site are to be lawfully used, disposed or processed on-site in a certain way.	Waste Product: receival facilities must be classified as 'waste receival facilities' and hold their own licences.	The Waste Strategy 2030 - 75% of waste to be re-used by 2030 (Government of Western Australia, 2020). Waste Avoidance and Resource Recovery Act 2007 (Government of Western Australia, 2021).	Applying wet digestate to land and composting in similar industries: Case by case basis, significant regulatory challenges.
South Australia	Landfill.	Not available.	K100 controlled waste (EPA South Australia, 2022).	South Australia's Waste Strategy 2020-2025 - Diverting 80% of waste from landfill by 2025 (Government of South Australia, 2020).	
Tasmania	Composting, landfill.	EPA, local Planning Authority, Department of Primary Industries, Water & Environment.	K100 controlled waste (Environment Protection Authority Tasmania, 2020).	Tasmanian Organics Strategic Framework - Diverting organic waste by 75% by 2030 (RM Consulting Group, 2022). Environment Management and Pollution Control Act (Tasmanian Government, 2022).	
Victoria	Landfill (K100: Animal effluent and residues, including red meat processing wastes and other wastes from animal processing), or to rendering. Waste duty: Reportable priority waste (EPAV, 2021).	EPA Victoria Biosolids Land Application (references biosolids derived from WWTPs containing significant quantities of red meat processing wastewater).	K100 putrescible/organic wastes (Victoria State Government, 2020).	Recycling Victoria, divert 80% of waste from landfill by 2030 (Victoria State Government, 2020).	VIC has Waste Class Exemptions on the Controlled Waste Regulations; certain types of waste can be exempt from the prescribed Controlled Waste regulations. (Government of Western Australia, 2018).

Jurisdiction	Current disposal of by-products*	Regulatory authorities for disposal of current by-products	By-product classifications**	Waste Strategy	Current status for similar projects
New South Wales	Landfill, rendering, manure for land application, dried pond sludge applied to land. Paunch can be composted (NSW EPA, 2019).	Environment Protection Authority (EPA).	General solid waste (putrescible) animal waste (NSW, 2014).	NSW Waste Avoidance and Resources Recovery Strategy 2014-21- Divert 75% of waste from landfill by 2022 (NSW EPA, 2014). NSW Waste and Sustainable Materials Strategy 2041 (NSW Government, 2021).	A Resource Recovery Order (RRO) and Resource Recovery Exemption are required via NSW EPA for waste biomass production and use of biochar. RRO for biochar application to land is considered on a case-by-case basis (ANZ Biochar Industry Group, 2021).
Queensland	QLD End of Waste (EOW) codes: Abattoir effluent pond sludge and crust Digestate Paunch Biosolids	Department of Environment and Science	Producer registers with Department of Environment as a Registered Resource Producer, then product can be sold or used. Regulated waste.	Waste Management and Resource Recovery Strategy – 80% of commercial and industrial waste diverted from landfill by 2030 (Queensland Government, 2022). Waste Reduction and Recycling Act 2011 (Queensland Government, 2022) Queensland Waste Avoidance and Resource Productivity Strategy 2014-2024 (Queensland Government, 2019).	
Northern Territory	Incineration (Northern Territory Environment Protection Authority, 2013).	NT EPA, (Northern Territory Government, 2022).	Animal effluent and residues.	Waste Management Strategy for the Northern Territory 2015- 2022 (Northern Territory Environment Protection Authority, 2015).	
Australian Capital Territory	Incinerates its biosolids.	ACT Government.		Waste Management and Resource Recovery Act 2016 (AT Government, 2022). ACT Waste Management Strategy 2011 – 2025 (ACT Government, 2011).	

*Where by-products include WWTP pond sludge, offals, fat, paunch, manure.

** Where by-products are classified as animal effluent and residues, including red meat processing wastes.

6.5 Survey Components

A survey was designed by UWA's School of Agriculture and Environment to gather insights from Australian consumers regarding their fertiliser preferences, gardening habits, and views of fertilisers made from organic waste.

6.5.1 Participant demographics and gardening habits

Survey participants were asked to provide demographic details, including age, postcode, gender, education level, and income. Only participants who were over 18 were eligible to continue with the survey. Additionally, they were asked whether they engaged in gardening activities such as maintaining lawns or gardens, which provided context for their fertiliser usage habits. The survey ensured that respondents represented a broad cross-section of Australian consumers interested in gardening and waste management. The questions asked were binary, i.e., requiring a yes/no answer. In terms of gardening habits, participants were asked if they had purchased fertiliser in the past 2 years. Those who answered “no” were disqualified from further questions about fertiliser usage.

6.5.2 Fertiliser preferences and spending

This section explored participant’s fertiliser purchasing habits, including whether they preferred solid or liquid fertilisers. Respondents were also asked about the type of fertiliser they purchased (chemical vs natural) and how much they typically spent on fertiliser per year. Data was collected on the types of plants for which fertiliser was used, such as lawns, flowers, fruits and vegetables. This provided valuable insights into the consumer fertiliser market and spending patterns. Additionally, respondents were asked about the package sizes they typically purchased, ranging from less than 1 kg to larger than 20 kg for solid fertilisers, and from 250 mL to over 10L for liquid fertilisers.

6.5.3 Organic waste, anaerobic digestion and environmental perceptions

The survey introduced the concept of anaerobic digestion, explaining how organic waste can be processed into digestate, which can be used as fertilisers. Questions were focused on their concerns regarding digestate-based fertilisers, such as potential odour or pollutants. Additionally, participants were assessed on their perceptions of greenwashing, gauging whether they believed environmental claims made by companies were exaggerated or misleading. This section aimed to gauge public awareness and acceptance of innovative waste-to-fertiliser processes.

6.5.4 Consumer choice

Participants were asked about their awareness and perceptions of using organic waste, such as food waste, manure, and biosolids, to produce fertilisers. In a choice experiment, respondents were presented with three types of fertilisers – chemical, organic-certified, and digestate-based and asked to choose which one they would purchase. Variables such as nutrient levels, and waste source were manipulated to assess how these factors influenced purchasing decisions. This section highlighted how product source and quality influence consumer behaviour.

6.5.5 Social licence and industry perceptions

This section explored participants’ views on the meat processing industry’s role in Australia, particularly its economic benefits and long-term contributions to the well-being of the population. The survey also assessed how the industry’s adoption of producing fertilisers from anaerobic digestion by-products might affect public opinion. Responses were analysed to understand whether this innovation could improve the industry’s social licence, reflecting public trust and approval of its practices. Additionally, risk tolerance concerning environmental and industrial practices was evaluated.

6.6 Survey Results

Survey responses were collected from 1,170 Australian fertiliser consumers in August and September 2024. The online survey was programmed in the Qualtrics platform. Survey participants were recruited from a panel managed by Dynata, a market research firm. A presentation of the survey's key results is shown in Appendix 3.

6.6.1 Participant demographics and gardening habits

Survey responses were collected from all states and territories, with proportions roughly representative of the Australian population (Table 17). However, Dynata was only able to collect 2 responses from consumers living in the Northern Territory, and slightly over-sampled consumers from Victoria.

Table 17. State of residence for survey respondents.

State	Sample (%)
New South Wales/Australian Capital Territory	23
Northern Territory	0
Queensland	20
South Australia	8
Tasmania	3
Victoria	36
Western Australia	9

In terms of demographics, 55% of respondents were men and 45% were women. The average age was 60, and ranged from 18 to 90 years old. Just over two-thirds (37%) of respondents had a university degree, which is roughly the same as the Australian average (38%).

Almost all respondents were personally involved in gardening activities (99%). In order of popularity, respondents' primary gardening activities were growing vegetables (26%), maintaining a lawn (25%), growing flowers (20%), growing fruit (11%), growing indoor plants (7%), growing native plants (6%), and growing trees (3%), with 2% of respondents primarily growing other plants.

6.6.2 Fertiliser preferences and spending

Most consumers believe they primarily buy natural or organic-based fertiliser (48%), while 30% of respondents said they typically buy chemical fertiliser. The remaining 21% were not sure what type of fertiliser they typically buy. Of those who buy natural fertiliser, nearly half typically buy Certified Organic (48% of natural purchasers; or 23% of the entire sample). A few respondents did not know what size of fertiliser they typically buy (3%). Nearly half of consumers usually buy bags 2.5 kg or smaller (46%), while about one-quarter buy 5 kg bags (27%), and the remaining 23% buy bags over 5 kg.

There were considerable differences in annual spending on fertiliser by household (Table 18). Notably, approximately one-quarter of respondents spend over AU$100 per year on fertiliser. When making purchases, nearly all respondents primarily go to large hardware stores (82%), followed by local garden centres (9%), and supermarkets (6%).

Table 18. Annual spending on fertiliser per household sampled.

Annual Spend	Respondents (%)
Under AU$25	17
AU$26 - AU$50	24
AU$51 - AU$75	17
AU$76 - AU$100	18
Over AU$100	24

6.6.3 Organic waste, anaerobic digestion and environmental perceptions

The survey presented information about anaerobic digestion and turning waste into fertiliser to respondents and asked whether they had heard of these concepts. Only 13% of people had heard of the term "digestate" before, and 24% said they had heard of anaerobic digestion. More respondents had heard of producing biogas from organic waste (56%) and turning organic waste into fertiliser (77%).

Respondents generally had positive sentiments about digestate-derived fertilisers and soil amendments (Figure 13). A minority believed these products may contain pollutants (37%) or could smell unpleasant (34%). Meanwhile, consumers generally understand digestate-derived garden products are good for society (70%), their soil or plant health (79%), or the environment (77%). Just over half of respondents said they would like to buy digestate-derived fertilisers or garden products (54%).

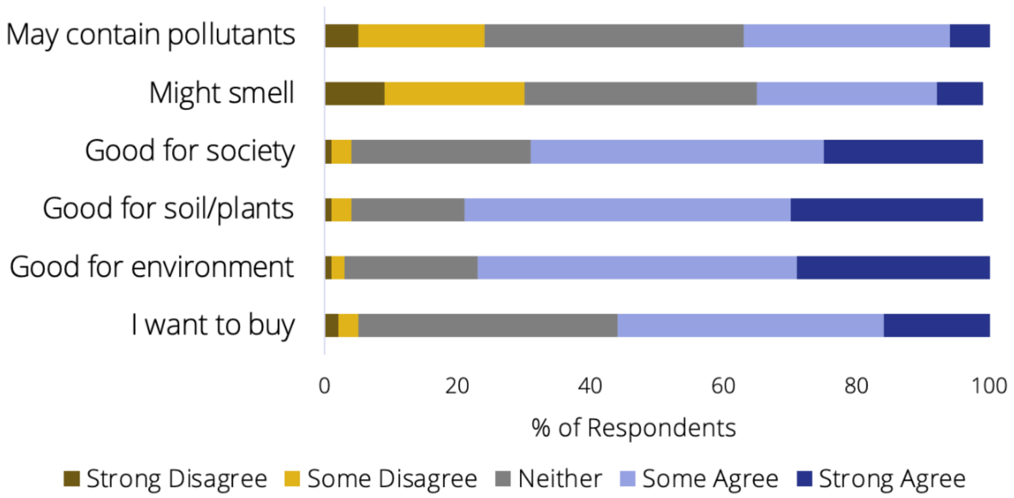


Figure 13. Fertiliser consumers' perceptions of fertilisers and gardening products derived from digestate.

Information treatments to test how different messages influenced perceptions of digestate-derived products were tested. All respondents were presented with a few sentences outlining anaerobic digestion, which described the process of breaking down organic material to produce biogas and digestate. 20% of respondents only received this base information, while 20% either saw:

- A pro-social environmental message, describing the environmental benefits of anaerobic digestion and digestate-based fertiliser (greenhouse gas emission reductions and avoiding landfills); or

- A message outlining the personal benefits of digestate-derived fertiliser, which can improve soil health and quality and ultimately improve plant growth; or
- A negative message outlining that digestate-derived products may contain some pollutants or have an unpleasant odour.

The remaining participants saw all three messages. Overall, all sources of information, including the negative message, improved perceptions of digestate-derived products. However, the message outlining personal benefits was most effective. Combined with the results in Figure 13, this finding suggests that consumers respond most strongly to messages relating to the effectiveness of products, rather than pro-social environmental benefits they provide. The positive effect of the negative information appears to have occurred by decreasing consumers' perceptions of "greenwashing". That is, by providing negative information about digestate, the survey conveyed credibility to consumers leading them to understand that pro-social benefits of digestate-derived are legitimate.

6.6.4 Consumer choice

To understand consumers' preferences for fertiliser derived from different organic waste sources, a best-worst scaling experiment was conducted. A list of different organic waste sources that can be used as a fertiliser or soil amendment was developed. In the experiment, respondents were presented with five organic waste sources at a time and asked which was the most and least acceptable. This process was repeated five times per respondent.

The odds that respondents chose a type of organic waste as the "best" or "worst" option were modelled to determine the rankings. The results are given based on the quantity of utility or satisfaction that each waste source would give a person. The measure of utility can be used to compare waste sources to one another (i.e. a waste source with a utility of 2 is twice as good as one with a utility of 1). Further, values above zero are thought to be positive or acceptable, while values below zero are viewed negatively by the public or are thought to be unacceptable.

Rankings of different types of organic waste for the entire sample are presented in Figure 14. Seaweed, food waste and manure are generally viewed positively. Animal urine is the only option that is not viewed as acceptable, while biosolids and human urine are the next least popular options. Meat processing waste is relatively low in the rankings but is still viewed as a positive or acceptable source of natural fertilisers.

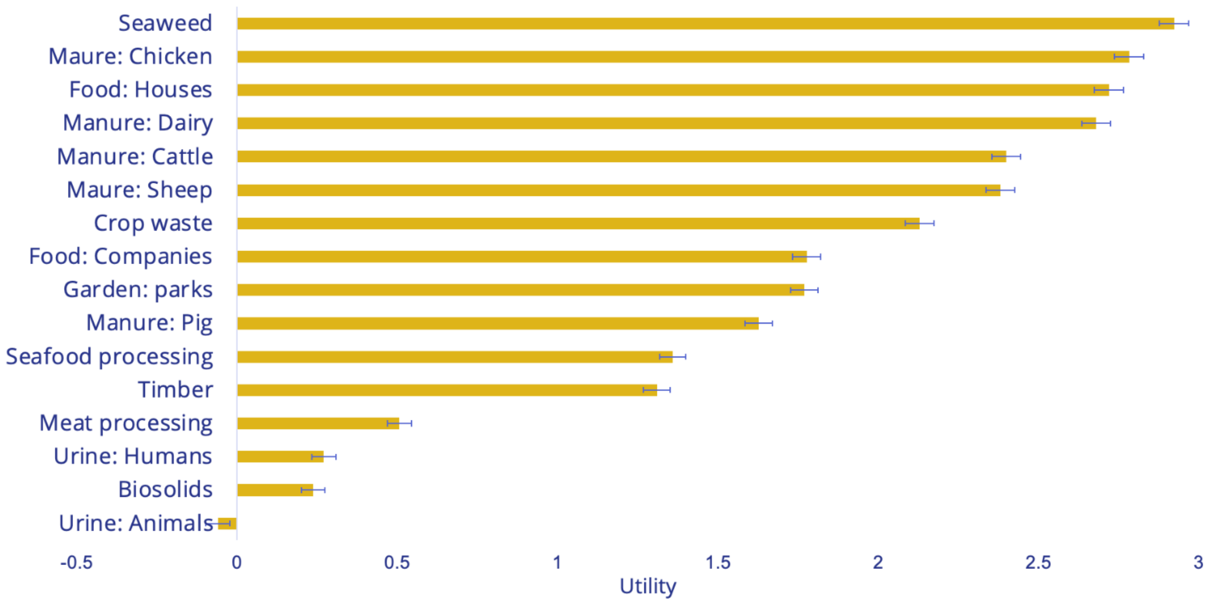


Figure 14. Consumer acceptability of different waste sources that can be used for fertilisers and gardening products.

In the choice experiment, each respondent answered five questions in which they were asked to pick one of three fertilisers that varied in price and nutrient value: a chemical fertiliser, a Certified Organic fertiliser, and a digestate-derived fertiliser. The waste source for the digestate-derived fertiliser also varied between questions and could have been food waste, biosolids, or meat processing waste.

Since the purchases in the survey are hypothetical, survey respondents often tend to overstate how much they would pay for the fertiliser products being studied. To mitigate this issue, a method to detect which respondents ignored the prices of fertiliser when making their decisions was used and excluded them from the estimation of willingness-to-pay for products. Including these respondents would lead to unrealistically high estimates.

Willingness-to-pay estimates from the choice experiment are listed in Table 19. Each additional percentage of nutrient value increases willingness-to-pay by AU$0.42 per 5 kg bag. Consumers were generally willing-to-pay higher amounts for Certified Organic fertiliser (AU$12 more per 5 kg bag) and digestate-derived fertiliser (AU$8 more per 5 kg bag) compared to chemical fertiliser, holding all else (i.e. nutrient value) constant. Within the digestate-derived fertilisers, consumers preferred those made from food waste. Products made from meat processing waste or biosolids would sell for approximately AU$1 less than products made from food waste.

Table 19. Willingness-to-pay for fertiliser attributes based on the choice experiment results (for a 5 kg bag of fertiliser).

Fertiliser attribute	Willingness-to-pay (AU$)	Std. Error
Nutrient value (1% increase)	0.42	0.03
Fertiliser type (relative to chemical)		
Organic-Certified	12.43	0.76
Digestate-derived	8.15	0.7
Digestate waste source (relative to food)		
Meat processing	-0.949	0.55
Biosolids	-1.021	0.51

6.6.5 Social license and industry perceptions

Perceptions of the meat processing industry were measured using a subset of items from a validated academic scale designed to measure social license to operate. Survey respondents had generally positive views of the meat processing sector (Table 20). Nearly all respondents believe Australia economically benefits from the meat processing industry (84%), that the meat processing industry contributes to the well-being of Australia (79%), and that the meat processing industry benefits all Australians (81%). A majority agree that the meat processing industry shares decision-making with relevant government departments (53%) and that the industry takes the public’s interest into account (58%).

Table 20. Respondents' perceptions of the meat processing sector.

	Respondents (%)		
Statement	**Agree**	**Neutral**	**Disagree**
Australia economically benefits from the meat processing industry	84	13	3
In the long term, the meat processing industry contributes to the well-being of Australia	79	15	6
The presence of the meat processing industry in Australia is a benefit to the Australian population	81	14	5
The Australian meat processing industry shares decision-making with the relevant government departments	53	38	9
The Australian meat processing industry takes into account the interests of the Australian population	58	29	13

In addition, about half of the respondents (53%) said their perceptions of the meat processing sector would improve if the practice of anaerobic digestion was widely adopted to manage organic waste (Table 21). Slightly less than half said using anaerobic digestion as a waste management strategy would not influence their perception of the industry (40%), while a small minority said the practice would worsen their perception (6%).

Table 21. Respondents' perceptions of anaerobic digestion implementation in the meat processing sector.

Industry Perception would…	Respondents (%)
Worsen a lot	1
Worsen	1
Worsen a little	4
Not change	40
Improve a little	25
Improve	20
Improve a lot	9

6.7 Economic Analysis Scenarios

The economic analysis scenarios were developed with a focus on establishing a biofertiliser production facility using combined feedstock from the digestate of the WA meat processor and the WA fertiliser company, producing a final product tailored to meet consumer preferences while also taking into account project strategies to ensure its feasibility.

Firstly, the location of the biofertiliser facility varied across the scenarios. Scenarios 1A and 1B assumed the facility would be located at the WA fertiliser company. A strategic choice given their position as a leading national manufacturer of garden products. The site already has part of the necessary infrastructure in place, such as a tailored packaging line, storage facilities, and easy access to retailers.

On the other hand, scenarios 2A and 2B assumed that the biofertiliser facility would be constructed at the WA meat processor’s site. Where, if they choose to build a bioresource recovery facility, will include wastewater treatment, biogas, and, if necessary, a biofertiliser plant.

Scenarios 3A, 3B, 4A and 4B considered the biofertiliser plant near the red meat facility, in Bunbury, since the biofertiliser plant could be part of an eco-hub in the region.

The location of the plant plays a crucial role in strategic considerations such as the ease of developing the required infrastructure on-site, securing regulatory approval for facility operation, proximity to retailers, and the cost of transporting digestate from the other facility to the biofertiliser plant for obtaining the blended feedstock.

Secondly, the nutrient content of the final product varied across the scenarios. Based on the findings from the survey accomplished by UWA, consumers are willing to pay AU$7 more for digestate-derived fertilisers made from red meat processing waste, assuming the nutrient value is equal to synthetic fertilisers (based on a 5 kg bag). Additionally, the value of the final product's nutrient content was estimated at AU$0.42 per percentage point of nutrient content, using the same baseline. Therefore, if the nutrient content of the final product falls below that of the synthetic fertiliser baseline, its market value will be lower.

The following sections of the report provide a detailed explanation of the expected nutrient composition of the blend between the WA meat processor and the WA fertiliser company digestates. It was found that the simple mix of both digestates results in lower nutrient values than standard synthetic fertiliser. Scenarios 1A, 2A, 3A and 4A considered the commercialisation of this simpler mix, with its corresponding nutrient content.

In contrast, scenarios 1B, 2B, 3B and 4B focused on achieving nutrient levels equal to synthetic fertilisers. These scenarios included the installation of a nutrient dosing system in the biofertiliser facility to enhance the final product's nutrient value.

In scenarios where no nutrient dosing system is considered, both CAPEX and OPEX for the biofertiliser facility are lower, as the dosing system and additional chemicals are not required. However, the lower shelf price of this product results in reduced revenue for the project. Conversely, scenarios that involve installing nutrient dosing systems and incorporating chemicals into operational costs would increase the biofertiliser facility's CAPEX and OPEX as well as the shelf price of the final product, resulting in higher revenue for the project. Table 22 provides a summary of the analysed scenarios.

Table 22. Summary of the analysed scenarios.

Scenario	Location of the Biofertiliser Facility	Nutrient Dosing in the Final Product
1A	WA fertiliser company	No
1B	WA fertiliser company	Yes
2A	WA meat processor site	No
2B	WA meat processor site	Yes
3A, 4A	Bunbury, WA	No

3B, 4B	Bunbury, WA	Yes

Scenarios 3A, 3B, 4A and 4B were designed to represent a situation in which the biofertiliser plant is operated by a third party. In this scenario, the WA fertiliser company, the WA meat processor, and other potential facilities would supply the feedstock (digestate), while the operation and commercialisation of the final product would be managed independently of these companies.

6.8 Project Information and Assumptions

The following sections provide a detailed analysis of operational and technical information from the WA meat processor and the WA fertiliser company, along with well-informed assumptions based on literature and previous works. They were considered for developing the project's economic assessment in the analysed scenarios.

Digestate Volume and Total Solids (%)

The digestate volume produced at the WA meat processor and the WA fertiliser company, along with their total solids' percentages, are crucial to estimate the feasibility of the project. This is attributed to the available quantity of solid digestate from each facility that will compose the biofertiliser feedstock. Impacting the amount of final product produced.

Based on the AMPC 2023-1013 project conducted by Tessele Consultants, which analysed the components of a bioresource recovery facility at the WA meat processor, if a biogas plant is implemented, the expected digestate production at their site is 36,500 tonnes per year with a total solid content of 5%.

Current digestate production at the WA fertiliser company site is approximately 21,000 tonnes per year. However, this project considered the facility's design capacity, anticipating an increase in food waste intake for their biogas plant in the coming years. Consequently, an estimated 50,000 tonnes of digestate per year was assumed, with a total solids (TS) content of 2.5%, as reported in recent lab analyses done in the WA fertiliser facility.

Digestate Dewatering – Solid Fraction (Cake)

The considered digestates would be dewatered on their respective sites, aiming to decrease transport costs from one facility to another, since the solid portion of the dewatered digestates should be mixed at the biofertiliser facility to compose the feedstock.

According to industry standards, centrifuges are liquid-solid separation equipment designed to efficiently dewater sludge materials, such as digestates. This process can be further optimised using chemical dosing agents like flocculants and coagulants.

Consequently, it was assumed that there would be one centrifuge per facility (the WA fertiliser company and the WA meat processor). In addition to their CAPEX as an expense, their OPEX was estimated at 10% of their CAPEX to account for the high energy consumption typical of centrifuges and the cost of chemicals dosed during the process. The dewatering CAPEX in the WA fertiliser company also included tanks since the liquid part leaving the centrifuges would be disposed of off-site (explained in detail in the following sections of the report). During detail design, additional equipment may be considered in this CAPEX package, such as pumps and pipes.

Table 23 shows the dewatering CAPEX and OPEX assumed in the economic assessment. The cost of the dewatering equipment was sourced from the equipment list database maintained by Tessele Consultants.

Table 23. CAPEX and OPEX of the dewatering process assumed in the economic assessment.

Dewatering Process	Value (AU$)
CAPEX	504,542
OPEX (Annual)	47,454

It's important to note that the need for two centrifuges per site, either for duty-standby or sequential operation, should be evaluated in the later stages of the project. This assessment will require a thorough characterisation and analysis of the facilities' digestates.

The dewatering process is expected to increase the digestates' solid content to 22%. Table 24 below outlines the digestate production, including total solids and the anticipated volume of cake produced post-dewatering assuming 22% TS in each facility.

Table 24. Digestate and cake production at each facility.

Parameter	WA meat processor	WA fertiliser company
Digestate Production (tonnes/year)	36,500	50,000
Digestate TS (%)	5%	2.5%
Cake Production (tonnes/year)	8,295	5,682
Cake TS (%)	22%	22%

Although the WA fertiliser company digestate production is higher than that of the WA meat processor, its low solid content results in lower cake production volumes.

Transport Costs of the Cake

Since digestate dewatering will occur separately at each facility, transport will be required to blend the combined digestates in the biofertiliser facility. The distance between the WA fertiliser company and the WA meat processor is 160 km. Assuming a truck with a capacity of 35 m³ and a transport cost of AU$55 per tonne per 100 km, Table 25 presents the total transport cost between facilities, based on the estimated cake production detailed in the previous section.

Table 25. Transport costs between facilities.

Parameter	WA meat processor	WA fertiliser company
Cake to be transported to the biofertiliser facility (tonnes/year)	8,295	5,682
Trips in a year (assuming a truck with a capacity of 35 m³)	237	162
Annual Transport Cost to the biofertiliser facility (AU$)	663,636	500,000

Transport costs were based on current trucking rates, but it is important to note that inflation adjustments in the coming years may impact this variable in the economic assessment. For scenarios 3A, 3B, 4A and 4B only the transport cost from the WA fertiliser company to the WA meat processor was considered to simplify the calculations, as the WA meat processor is located near Bunbury, where the independent biofertiliser plant would be built.

Digestate Dewatering – Liquid Fraction (Centrate)

In addition to the solid cake, the dewatering process produces a liquid fraction known as centrate. Due to the digestate's characteristics, the concerned centrate contains a high concentration of nutrients. For this project, it was assumed that the centrate produced from digestate dewatering at the WA meat processor would be directed to the wastewater treatment plant (WWTP) at their potential bioresource recovery facility. Their WWTP, equipped with biological nutrient removal technology, is capable of handling this stream, resulting in no additional costs.

Conversely, at the WA fertiliser company, the simplest solution would be to send the centrate to the local water utility for treatment, which incurs a cost (transport and treatment).

Table 26 below outlines the parameters of an anaerobically digested food waste centrate, which served as a baseline for estimating the parameters of the centrate obtained from dewatering the WA fertiliser company digestate, which is primarily derived from food waste. This estimate enabled a cost projection for disposal based on cross-referencing with Water Corporation's trade waste billing and charges (Table 27). It is important to note that Water Corporation's trade waste billing and charges are periodically updated, which may influence this variable in the economic assessment for the coming years.

Table 26. Parameters of an anaerobically digested food waste centrate (Sutherland et al., 2020).

Parameter	Value
pH	7.3
Total suspended solids (g/m3)	3,467
Volatile suspended solids / organic matter (g/m3)	3,288
Percentage volatile suspended solids / organic matter	94
Ammonium-nitrogen (g/m3)	2,140
Nitrate-nitrogen (g/m3)	10
Particulate nitrogen (g/m3)	182
Total Nitrogen (g/m3)	2,720
Dissolved reactive phosphorus (g/m3)	6.1
Particulate phosphorus (g/m3)	55
Total phosphorus (g/m3)	192
Dissolved organic carbon (g/m3)	420
Total organic carbon (g/m3)	1,940
Biological Oxygen Demand (BOD_5) (g/m3)	3,283

Table 27. Water Corporation's trade waste billing and charges.

Parameter*	Range	Charge
Volume	N/A	AU$1.65 /kL
Biochemical Oxygen Demand (BOD)	0–5,000 mg/L	AU$1.373/kg
	Above 5,000 mg/L	AU$2.802/kg
Suspended Solids	0–2,000 mg/L	AU$1.87/kg
	Above 2,000 mg/L	AU$3.766/kg
Oil & Grease	0–300 mg/L	AU$1.69/kg
	300–600 mg/L	AU$3.313/kg
	Above 600 mg/L	AU$6.682/kg
Acidity to pH 6 as CaCO3	0–100 mg/L	AU$0.465/kg
	100–300 mg/L	AU$0.98/kg
	Above 300 mg/L	AU$1.94/kg
Alkalinity to pH 10 as CaCO3	0–100 mg/L	AU$0.15/kg
	100–200 mg/L	AU$0.35/kg
	Above 200 mg/L	AU$0.70/kg
Total Kjeldahl Nitrogen	N/A	AU$1.50/kg
Total Phosphorus	N/A	AU$0.42/kg

*Salts and metals were not included since these components are not expected to be in the concerned centrate.

Transportation costs assumed the distance between the WA fertiliser company to the closest Water Corporation Wastewater Treatment Plant. Supposing truck capacities of 35 m^3 and transport cost of AU$55 per tonne per 100 km.

Further studies could explore the possibility of treating the centrate on the WA fertiliser company site to avoid disposal charges, utilising it as an upstream source for nutrient recovery—such as through struvite precipitation technologies—or repurposing it for on-site irrigation.

Currently, the WA fertiliser company uses approximately 5,000 kL of digestate per year to irrigate composting piles on-site. This volume was assumed to represent the internal use of centrate in the future, when digestate dewatering is implemented in the facility, with the remainder directed to the local water utility for treatment.

Table 28 outlines the projected annual centrate production, expected internal use at the WA fertiliser company, and the volume along with the associated disposal cost to Water Corporation, based on the production of 50,000 tonnes of digestate per year.

Table 28. Centrate quantities and disposal cost at the WA fertiliser company.

Centrate Quantities and Costs	Value
Annual Volume (kL/year)	44,318
On-site Use (kL/year)	5,000
Discharged to Water Corporation (kL/year)	39,318
Discharge Cost (Mi AU$/year)	1.4

CAPEX and OPEX for Biofertiliser Plant

Based on the dewatered digestate cake from the WA meat processor and the WA fertiliser company, a total feedstock of 13,977 tonnes of solid digestate at 22% total solids (TS) was considered for producing pelletised biofertiliser. It is known that pelletised fertilisers make handling, storage, and application easier and enhance nutrient concentration and stability. The pellet form allows for efficient transport and uniform application across fields, providing a consistent nutrient release to crops. Furthermore, pelletised fertilisers reduce odour and pathogen levels, improving their safety and suitability for agricultural use and land reclamation.

The equipment responsible for converting the digestate cake into pellets is a dryer and pelleting system. The process involves placing the mixed feedstock onto a conveyor belt directed to a dryer, where the material's solids content increases from 22% to 88% and is pelletised. Table 29 shows the total biofertiliser produced, assuming a total solids (TS) content of 88%.

Table 29. Total biofertiliser produced assuming 88% TS.

Parameter	Values
Combined Cakes (tonnes/year)	13,977
Combined Cakes TS (%)	22%
Biofertiliser Production (tonnes/year)	3,494
Biofertiliser TS (%)	88%

After being heated in a heat exchanger using hot water as the hot stream, atmospheric air flows into the dryer to enable the drying process. This is typically done with a shell-and-tube heat exchanger to prevent mixing between the heat fluid and feedstock. The final product exits the dryer at 88% TS, and hot humid air from the dryer is purified in a chemical scrubber, which receives clean water with sulfuric acid and releases clean air into the atmosphere, producing a nutrient-rich liquid waste stream.

The liquid waste stream volume for this project is estimated to be less than 1 kL/day and can be discharged along with the centrate stream for further treatment, either at an on-site WWTP or sent to the local water utility, depending on the location of the biofertiliser facility. Additional costs related to the scrubber's liquid waste stream have been excluded from the economic analysis.

In scenarios where nutrient dosing is required, a nutrient dosing system was considered between the temporary storage of the dried digestate and pelleting. This system is capable of dosing liquid or solid forms of nutrients.

Moreover, a packaging line is included in the biofertiliser system, which produces packages for 5L or 25L according to the demand.

The CAPEX for the biofertiliser system was sourced from a market supplier specialising in equipment for converting waste streams, such as digestate, into biofertiliser. The dosing system was quoted as an additional feature, included in the CAPEX only for scenarios 1B, 2B, 3B and 4B.

The annual OPEX for the biofertiliser plant is assumed to be 25% of the CAPEX across all scenarios, reflecting the high energy demand required for drying, packaging and transportation costs to retailers. For scenarios with nutrient dosing, an additional OPEX of 10% of the CAPEX was assumed annually, covering the chemical costs necessary to bring the nutrient content of the final product equal to synthetic biofertilisers. The operational cost for chemical dosing was estimated based on the approximate yearly expenses for commodity chemicals such as nitrogen, phosphorus, potassium, and sulphur, required to supplement the basic blend of the WA fertiliser company and the WA meat processor dried digestates to match the nutrient content of synthetic fertiliser in the final product.

Table 30 presents the CAPEX and OPEX of the biofertiliser plant for scenarios with and without the nutrient dosing system.

Table 30. CAPEX and OPEX of the biofertiliser plant for scenarios with and without the nutrient dosing system.

Parameter	Without Nutrient Dosing	With Nutrient Dosing
CAPEX (Mi AU$)	7.83	7.92
Annual OPEX (Mi AU$)	1.96	2.77

Digestate Characterisation and Final Product Expected Quality

The quality of the final biofertiliser product is determined by the characteristics of the digestate used as feedstock in the biofertiliser plant. Focusing on nutrient composition, average values for Total Nitrogen (TN), Total Phosphorus (TP), Total Potassium (TK), and Sulphur were analysed for the digestates of both facilities (the WA fertiliser company and the WA meat processor). For the WA meat processor, the averages were based on tests of red meat processing waste conducted by Tessele Consultants in previous works to represent their digestate profile. For the WA fertiliser company, these nutrient averages were calculated directly from recent laboratory analyses of their digestate. Table 31 presents the averaged nutrient values for the digestates of both facilities considered in this project.

Table 31. Averaged nutrient values for the digestates of both facilities (the WA fertiliser company and the WA meat processor).

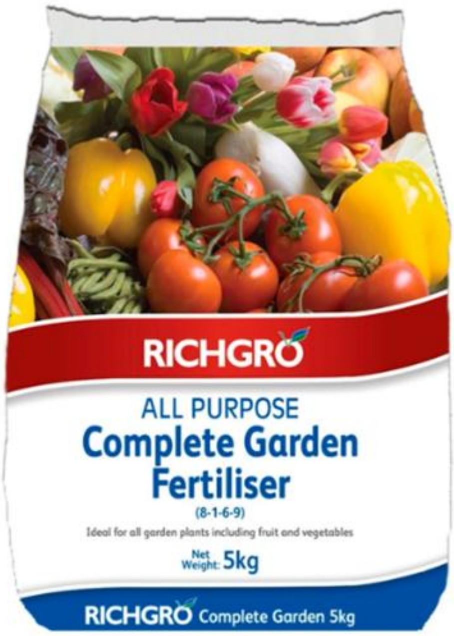
Parameter	WA meat processor	WA fertiliser company
TN (mg/L)	13,146	4,060
TP (mg/L)	13,433	253
TK (mg/L)	12,923	1,118
Sulphur (mg/L)	410	90

According to Akhiar et al. (2016) substrate including red meat processing waste processed in a screw press retains approximately 45% of TKN (Total Kjeldahl Nitrogen) in the cake. Assuming this approach for the dewatered cake from the WA meat processor and the WA fertiliser company digestates, Table 32 presents the nutrient percentages of each facility's cake, as well as the expected nutrient composition of the blended cakes, which serve as feedstock for the biofertiliser plant.

Table 32. Nutrient percentages of each facility's cake and blended cakes.

Parameter	WA meat processor	WA fertiliser company	Blended Cake
TN (mg/L)	2.6%	1.6%	2.12%
TP (mg/L)	2.7%	0.1%	1.41%
TK (mg/L)	2.6%	0.4%	1.52%
Sulphur (mg/L)	0.1%	0.04%	0.06%

For the economic assessment scenarios targeting a final product with nutrient content equal to synthetic fertilisers, the reference nutrient percentages were based on Richgro All Purpose Complete Garden Fertiliser. Its packaging and nutrient table are shown in Figure 15 below.



ANALYSIS:	%w/w
Nitrogen (N)	
N as Ammonium	6.75%
N as Organic	0.85%
Total Nitrogen (N)	**7.60%**
Phosphorus (P)	
P as Water Soluble	0.50%
P as Citrate Soluble	0.35%
P as Citrate Insoluble	0.15%
Total Phosphorus (P)	**1.00%**
Potassium (K) as Chloride	6.50%
Sulphur as Sulphate	9.40%

N:P ratio 7.6:1 *This label complies with the National Code of Practice for Fertilizer Description and Labelling.*

Figure 15. Richgro All Purpose Complete Garden and Fertiliser package and nutrient table.

Sales Revenue

Based on the survey accomplished by UWA, consumers are willing to pay AU$7 more for digestate-derived fertilisers made from red meat processing waste, assuming the nutrient value is equal to synthetic fertilisers (based on a 5 kg bag). Additionally, the value of the final product's nutrient content was estimated at AU$0.42 per percentage point of nutrient content, using the same baseline. Therefore, if the nutrient content of the final product falls below that of the synthetic fertiliser baseline, its market value will be lower. Table 33 provides a summary of this concept, including prices for both 5 kg and 1-tonne quantities to support project calculations.

Table 33. Estimated shelf price costs for the final product.

Fertiliser Type	Price per 5kg (AU$)	Price per tonne (AU$)
Synthetic Fertiliser*	15	3,000
Digestate-derived (including red meat processing waste)**	22	4,400
1% in nutrient content	0.42	84

*Assuming Richgro All Purpose Complete Garden Fertiliser as a baseline.

**Assuming the nutrient value is equal to synthetic fertilisers.

Table 34 presents the shelf prices per tonne of red meat digestate-derived fertilisers, both with and without added nutrients, along with the projected income from the biofertiliser sale. In this calculation, 50% of the listed price was allocated as income from biofertiliser commercialisation, while the remaining 50% was considered as retail margin.

Table 34. Prices per tonne of red meat digestate-derived fertilisers and projected income.

Biofertiliser	Shelf Price per tonne (AU$)	Projected Income (AU$)
Without nutrient dosing	2,770	1,405
With nutrient dosing	4,400	2,200

In the scenarios where the biofertiliser plant would be built at the WA fertiliser company or the WA meat processor site (1A, 1B, 2A and 2B), the estimated prices mentioned above were used to calculate sales revenue, assuming all fertiliser produced (3,494 tonnes/yr) would be sold through retail channels. For scenarios 3A and 3B, where the biofertiliser plant operates as part of an eco-hub, a more realistic sales revenue distribution was applied: 20% from retail, 30% from direct sales, and 50% from agriculture and horticulture. In this case, the pricing concept developed by UWA was applied only to retail and direct sales. For agriculture and horticulture, given the higher volumes and competitive market, prices of $800 and $600 per tonne were assumed for the final product with and without nutrient dosing, respectively.

For scenarios 4A and 4B, a gradual increase in retail sales was assumed, starting at 100 tonnes in the first year, 200 tonnes in the second year, and 300 tonnes in the third year, reaching a stable retail volume of 400 tonnes per year from the fourth year onward. The remaining biofertiliser produced was considered to be sold to agriculture and horticulture. As with scenarios 3A and 3B, the UWA pricing model was applied only to retail and direct sales, while agriculture and horticulture sales followed the same price assumptions of $800 and $600 per tonne for the final product with and without nutrient dosing, respectively.

Table 35 shows the expected annual sales revenue for each scenario.

Table 35. Revenue from the biofertiliser sales.

Economic Assessment Scenario	1A	1B	2A	2B	3A	3B	4A	4B
Site Location	WA fertiliser company		WA meat processor		Bunbury, WA		Bunbury, WA	
Nutrient Dosing	No	Yes	No	Yes	No	Yes	No	Yes
Sales	100% Retail		100% Retail		20% Retail, 30% Direct Sales and 50% Horticulture and Agriculture		Gradual retail sales, with the rest to Horticulture and Agriculture	
Biofertiliser Sales (Mi AU$)	4.91	7.68	4.91	7.68	3.50	5.24	2.4*	3.4*

*Maximum biofertiliser sales (assuming 400 tonnes/yr directed to retail and the remaining amount to agriculture and horticulture).

Avoided Cake and Digestate Disposal Fees

Another revenue considered for the project is the cost savings from eliminating digestate disposal fees with the implementation of the biofertiliser facility.

For the WA meat processor, where an on-site WWTP is present, it was assumed that if the digestate were disposed of according to regulations rather than sent to the biofertiliser facility, it would be dewatered on-site, requiring only the solid portion (cake) to be disposed of in regulated landfills.

For the WA fertiliser company, due to the liquid nature of its digestate and the absence of an on-site WWTP, all produced digestate would require regulated disposal. Currently, the WA fertiliser company generates revenue by selling a portion of its digestate to farmers and different markets, though these revenue and cost sources were not factored into this project. The remaining digestate is partly used on-site, with the rest disposed of off-site.

The WA fertiliser company's current disposal cost is around AU$15.71 per tonne. This rate aligns with gate fees and trucking costs for disposing of red meat processing waste, as identified in previous studies by Tessele Consultants.

Table 36 summarises the projected annual volumes of cake and digestate diverted from disposal to the biofertiliser plant, along with the associated cost savings.

Table 36. Revenue from avoided digestate disposal fees.

Parameter	WA meat processor	WA fertiliser company
Cake/ digestate volume diverted from disposal (tonnes/year)	8,295	50,000
Expected Annual Revenue (Mi AU$)	0.13	0.79

6.9 Expenses and Revenues

Table 37 provides a summarised overview of the expenses and revenues for each scenario analysed in the economic assessment, based on the project information and assumptions previously outlined.

Table 37. Summarised overview of the expenses and revenues for each scenario analysed in the economic assessment.

Economic Assessment Scenario	1A	1B	2A	2B	3A	3B	4A	4B
Site Location	**WA fertiliser company**		**WA meat processor**		**Bunbury, WA**		**Bunbury, WA**	
Nutrient Dosing	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Sales	**100% Retail**		**100% Retail**		**20% Retail, 30% Direct Sales and 50% Horticulture and Agriculture**		**Gradual retail sales, with the rest to Horticulture and Agriculture**	
Expenses* (Mi AU$)								
CAPEX Dewatering	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
OPEX Dewatering	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cake Transportation	0.73	0.73	0.50	0.50	0.50	0.50	0.50	0.50
Centrate Discharge	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
CAPEX Biofertiliser Plant	7.83	7.93	7.83	7.93	7.83	7.93	7.83	7.93
OPEX Biofertiliser Plant	2.00	2.77	2.00	2.77	2.00	2.77	2.00	2.77
Revenues* (Mi AU$)								
Biofertiliser Sales	4.91	7.68	4.91	7.68	3.50	5.24	2.42	3.36
Avoided Cake Disposal – WA meat processor	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Avoided Digestate Disposal – WA fertiliser company	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79

*Expenses (excluding CAPEX of dewatering and biofertiliser plant) and revenues are factored on a yearly basis.

6.10 Economic Analysis

Considering the different analysed scenarios and their respective expenses and revenues, an economic analysis was accomplished using an Excel spreadsheet. Which considered nominal discount and escalation rates as 5% and 6%, respectively. Moreover, the considered period for present value calculations and the effective life of the assets were assumed to be 25 years.

The capital expenditures of the project (dewatering systems and biofertiliser plant) were allocated for 2026, while the operational expenditures and yearly costs, along with projected revenues from project implementation, were accounted for starting in 2027.

Based on the expenses and revenues assumed for the proposed scenarios in the economic analysis, key metrics were calculated (Table 38).

Table 38. Key metrics for each scenario analysed in the economic assessment.

Economic Assessment Scenario	1A	1B	2A	2B	3A	3B	4A	4B
Site Location	WA fertiliser company		WA meat processor		Bunbury, WA		Bunbury, WA	
Nutrient Dosing	No	Yes	No	Yes	No	Yes	No	Yes
Sales	100% Retail		100% Retail		20% Retail, 30% Direct Sales and 50% Horticulture and Agriculture		Gradual retail sales, with the rest to Horticulture and Agriculture	
NPV (Mi AU$)	39.23	93.27	45.58	99.62	6.75	32	-23.69	-20.79
ROI (%)	561	1,185	636	1,259	179	474	-179	-142
Annualised ROI (%)	7.85	10.75	8.31	11	4.20	7.24	-199	-196
Payback Period (years)	6	4	6	4	16	7	N/A	N/A

According to the figures in the previous table, scenarios 1A and 2A have the same payback period. This is because the only difference between them is the transport cost of the digestate cake from the respective facility to the biofertiliser plant. As this cost has minimal impact on the overall economic assessment, the payback periods remain similar. The same applies to scenarios 1B and 2B.

When comparing scenarios A and B, the latter demonstrates a better return on investment. This is due to the final product's higher nutrient content—achieved through nutrient dosing—which increases revenue, despite the additional capital (CAPEX) and operational (OPEX) expenditures required to implement this system.

The location of the plant plays a crucial role in strategic considerations such as the ease of developing the required infrastructure on-site, securing regulatory approval for facility operation, proximity to retailers, and the cost of transporting digestate from the other facility to the biofertiliser plant for obtaining the blended feedstock. However, practical considerations must be taken into account: the WA meat processor specialises primarily in red meat processing, while the WA fertiliser company is a well-established Australian fertiliser producer with relevant existing infrastructure, including specialised packaging lines, storage facilities, and easy access to retail channels.

It is important to note that scenarios 1A, 1B, 2A, and 2B assume an optimistic sales model, where all 3,494 tonnes of biofertiliser produced annually are fully sold to the retail market at the estimated prices provided by UWA, starting in the first year of plant operation. To introduce a more realistic market scenario, scenarios 3A and 3B were developed. These assume a practical sales distribution (20% to retail, 30% to direct sales, and 50% to agriculture and horticulture).

Given the competitive nature of the agriculture and horticulture sectors, biofertiliser in these markets is projected to sell at approximately 40% of the retail and direct sales price. However, even at this lower price point, total sales revenue remains significant for economic feasibility.

As expected, higher nutrient content in the final product leads to greater market value. Scenario 3B, which includes nutrient dosing, results in a 7-year payback period. In contrast, scenario 3A, where the biofertiliser is sold as a simple mix of digestate cakes from the WA red meat processor and the WA fertiliser company, extends the payback period to 16 years.

Scenarios 3A and 3B assume the biofertiliser plant is located in Bunbury, allowing it to source feedstock not only from the WA red meat processor and WA fertiliser company but also from other local industries, fostering the development of an eco-hub in the region.

Scenarios 4A and 4B also assume the biofertiliser plant is located in Bunbury but adopt a gradual retail sales model, starting with 100 tonnes in year 1, increasing to 200 tonnes in year 2, and reaching 300 tonnes in year 3. From year 4 onwards, retail sales stabilise at 400 tonnes per year, with the remaining product directed to agriculture and horticulture markets.

These scenarios resulted in negative NPVs, making them financially unviable. The high project costs, combined with limited retail sales (only up to 10% of total production), do not generate sufficient revenue to offset expenses. Given the competitive pricing in the agriculture and horticulture sectors, these scenarios highlight the importance of strong market penetration and scaling up retail and direct sales to ensure profitability.

As demonstrated in scenarios 3A and 3B, even with 50% of the product sold at lower agriculture/horticulture prices, the project remains feasible—regardless of the final product's nutrient content. This underscores the need for a robust market presence and strategic sales distribution to maximise revenue and achieve a positive return on investment.

7 Discussion

Not applicable to this report.

8 Conclusion and Recommendations

The feasibility assessment confirms that a red meat digestate-derived biofertiliser is a viable and sustainable alternative to conventional fertilisers. Various technologies and processing routes were evaluated to enhance the market value of the recovered resource. The use of a centrifuge for dewatering the digestate, followed by a drying and pelleting process to produce a solid biofertiliser, emerged as the most effective approach.

A market survey conducted under Project 2022-1081 assessed demand and the potential adoption of digestate-derived biofertilisers across key sectors, including forestry, commercial off-takers, landcare, natural resource management, mining, and municipal applications. The findings highlighted that product quality, pricing, and regulatory compliance are critical factors for successful commercialisation in Australia.

A detailed review of red meat by-products, such as anaerobic pond sludge and pasteurised digestate, demonstrated that these materials have a nutrient-rich composition with lower contaminant levels than traditional biosolids, aligning well with regulatory benchmarks for safe land application. Additionally, integrating food waste digestate with red meat digestate was found to enhance its overall nutrient content.

Given that Australia lacks specific national regulations for digestate-derived biofertilisers, The national biosolids regulations were used as a benchmark for quality standards. International guidelines from Canada and the UK were reviewed for comparison, with Canada regulating digestate under the National Fertilizers Act and the UK setting limits on key quality parameters, excluding organic contaminants like PFAS and PAHs. Victoria has introduced state-level guidelines for digestate management. Ensuring regulatory compliance will help repurpose red meat processing by-products, adding value to the recovered resource and promoting circular economy principles.

The consumer purchasing behaviour survey conducted by UWA provided key insights into economic feasibility. The results indicated that consumers are willing to pay AU$12 more for Certified Organic fertilisers and AU$8 more for digestate-derived fertilisers, assuming nutrient value remains unchanged. Among digestate-derived products, those sourced from food waste were preferred, while fertilisers made from meat processing waste or biosolids were expected to sell for approximately AU$1 less than food waste-derived alternatives.

Economic scenario analyses were performed to evaluate different biofertiliser plant locations, including the WA red meat processor site, the WA fertiliser company location, and an independent biofertiliser plant in Bunbury, Western Australia. Variations in nutrient levels in the final product were also considered. A detailed assessment of feedstock from the WA red meat processor and the WA fertiliser company production to the biofertiliser plant was undertaken. The most well-presented and realistic economic scenario simulated a product sales distribution of 20% in retail, 30% in direct sales, and 50% in horticulture and agriculture—along with enhanced nutrient levels, resulting in a projected payback period of 7 years, confirming the financial viability of the project. However, refining assumptions and conducting internal discussions with stakeholders to review feedstock characteristics and product specifications, as well as assess operational approval in the selected location, is recommended.

The involvement of key stakeholders, including the WA red meat processor, the WA fertiliser company, UWA and Tessele Consultants underscores the collaborative effort required to validate market potential and regulatory compliance for this innovative biofertiliser. The recommendations from this project are focused on refining assumptions, conducting further tests on the biofertiliser plant feedstocks (digestates), finalising product specifications, and securing operational approvals. These efforts will ensure the successful production and commercialisation of the red meat digestate-derived biofertiliser while promoting circular economy principles and sustainable agricultural practices in Australia.

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10 Appendices

6.3 Appendix 1: Dewatering Technologies

Table 39 below shows the available dewatering technologies in the market, with their benefits, disadvantages and technology readiness levels.

Table 39. Dewatering Technologies.

Technologies	Benefits	Disadvantages	TRL
Decanter Centrifuge	- High dewatering level (up to 30% TS). - Handles different sludge types. - Depending on the scenario, can dewater small volumes without chemicals. - Large processing range.	- High CAPEX and OPEX. - High power consumption.	9
Lime-amended centrifuge	- Similar to decanter centrifuges. - Reduces odour and sanitises final product.	-Similar to decanter centrifuges plus the additional cost of lime. - Lime needed.	9
Screw Press	- High dewatering level (up to 70% of total solids). - Suitable for high-fibre content. - Reduced CAPEX and OPEX.	- Flocculant usage is recommended. - Can't handle small particles. - Process water required.	9
Squeez-R	- High dewatering level (15-70%TS). - Low energy consumption. - Suitable for a wide range of sludge. - Large capacity, 1kg to 1326kg DS/h.	- Flocculant usage is recommended. - Process water required.	9
Geobags	- Can be removed after dewatering. -Low CAPEX and OPEX.	-Totally time and weather-dependent (Usually from 6 to 24 months; dry weather). - Large areas needed.	9
Belt Filter Press	- Applicable to all sludge types. - Compact. - Quick start-up and shutdown times.	- Doesn't contain odour. - Requires screening and a well-mixed feed. - Process water required.	9
Vacuum filter	- Automatic and continuous operation. - Cake thickness can be controlled.	- Cake tends to crack due to negative pressure. - Suitable for only low flowrates. - High energy consumption.	8
KDS Multidisc Roller System	-Typical dryness of waste activated sludge of 15-18% and 25-35% for cattle manure. - Low noise and vibration levels. - No wash water is required. - Self-cleaning; handles oily and fibrous material. - High solids capture in solids stream. - Very low power requirements. - Low operator and maintenance attention required. - Small footprint required. - Can be fixed plant or mobile.	- Designed for smaller to medium-sized applications, throughput of 1kL-15.5kL/hour at 2%TS.	8
Shale Shakers	- Can handle a high flow rate of feed (up to 200m3/h).	- Less proven for this application.	6

Technologies	Benefits	Disadvantages	TRL
Solar Drying Systems	- Low power consumption. - Capable of providing up to 85% of total solids.	- Needs a large area to install. - High CAPEX and OPEX. - Can be weather and time-dependent.	7
Lamella Clarifier	- Ideal when solids load and sizing are variable. - Compact system. - Absence of moving parts.	- Needs pre-treatment depending on the feed (fine screening and grease removal). - Used as pre-dewatering technology/thickening only – treats to a lower %TS product. - Can cause some resuspension of solids during the process. - Regular maintenance and cleaning. - Although well-proven in the municipal wastewater and water industry, it isn't well-tested for abattoir wastes.	7
Electroosmosis (ELODE)	- Removes free and absorbed water from sludge cake. - Can produce high solids content (90%). - Improve dryness by 20% solids in three minutes. - Non-thermal dewatering system.	- Recommended as a second-stage dewatering. - Highly complex, with specialist maintenance required. - Intended for secondary dewatering only, after a pre-dewatering step with other technology.	6
Trident Wave Separator & Thickener	- Low OPEX, maintenance requirements and power consumption. - Fully automated or in batch. - Self-cleaning mechanism doesn't require wash water.	- Low product dryness, typically 2 to 10% TS. - Low operational speed.	6
Rotary Press	- Low maintenance. - Low OPEX, power and process water requirements. - Low odour. - Simple operation and low labour. - High product %TS. - Large processing volume range (order of 1-60kL/hr).	- Polymer required.	8
Dryers (non-solar)	- Final product up to 80% TS. - Final product ready for sale.	- Recommended as a second-stage dewatering. - High power consumption (requires heat source).	8
Continuous Pressure Filter	- Handles samples with 100% of biological content. - Modular design for varying conditions. - High %TS product. - Low power consumption. - High volume throughput. - Excellent filtrate quality and solids capture.	- High CAPEX and OPEX. - Requires chemical. - Relatively large area required for small treatment plants (OK for large plants).	8
Hydraulic Piston Press – Dehydris Twist	- Higher %TS product than traditional dewatering (up to 42%). - Automatic, unmanned operation. - Automatic washing cycle.	- Batch process. - Smaller capacity (up to 800kg DS/h). - Not proven for this application. - Flocculant use advised. - Process water for cleaning required.	6
Gravity Table	- High thickening capacity. - Low power consumption. - Minimal flocculent required. - Low wear and maintenance. - Good filtrate quality.	- Intended for pre-dewatering only. - Lower solids content product than other options (up to 22%TS).	8
Mobile dewatering units	- Small area requirement. - Can be moved around easily. - Can be leased when not in use.	- Limited capacity range. - Output varies depending on the supplier.	Ranges from 5 to 9

6.4 Appendix 2: Processing Technologies

Table 40 below shows alternative technologies for digestate processing with their benefits, disadvantages and technology readiness levels.

Table 40. Alternative technologies for digestate processing.

Technologies	Benefits	Disadvantages	TRL
Digestate Concentration System (DCS)	- Low-temperature demand (60 – 90ºC). - Fully automated system. - Closed loop process (heat and water reused).	- Requires technical support.	8
Torrefaction	- Pyrolysis under mild temperatures (200 – 320 ºC). - Volatiles can be used as heating fuel for the process. - More homogeneous properties from a variety of raw biomass.	- No significant volume reduction.	7
Unity Process	- Homogeneous output. - Usage of bio-based solids as cooling fluid in the reactors. - Use of existing fertiliser processing equipment.	- Requires concentrated chemicals. - Complex process.	6
Struvite Precipitation	- Slow-release fertiliser product. - Final product with enhanced dewaterability.	- High concentrations of Mg required. - High level of control required on variables. - Side-stream process only – solid organic carbon content still requires processing.	6
Nitrogen Recovery	- N/A.	-Low economic viability. - Side-stream process only on a liquid fraction – solid organic carbon content still requires processing.	6
Phosphorous Recovery (RAVITA™)	- High P recovery. - Marketable final product (phosphoric acid).	- Side-stream process only – solid organic carbon content still requires processing.	6
Phosphorous Recovery (ViviMag)	- High P recovery as a mineral. - Removes iron in digestate.	- Demands specialised support (use of magnetic separation). -Side-stream process only – solid organic carbon content still requires processing.	5

6.5 Appendix 3: Presentation of the Survey's Key Results

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Consumer perceptions of digestate-derived fertilisers and soil amendments

Dr. Curtis Rollins

19 September 2024

Methodology

- Responses from 1170 fertilizer consumers
  - Bought fertiliser/soil amendment within last 2 years

State	% of sample
NSW/ACT	23
Queensland	20
South Australia	8
Tasmania	3
Victoria	36
Western Australia	9

Primary Objectives

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- Compare public preferences: different organic wastes for fertiliser/soil amendments
  - Best-worst scaling
- Perceptions of products derived from meat processing digestate
  - Choice experiment

Preferences for Different Organic Wastes

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- Best-worst scaling
- Presented 5 wastes at a time
  - As which was most and least acceptable
  - Repeated 5 times per person
- Also asked whether each waste was acceptable
- Gives us a ranking, plus a cut-off of acceptability

Organic Wastes: Overall Ranking

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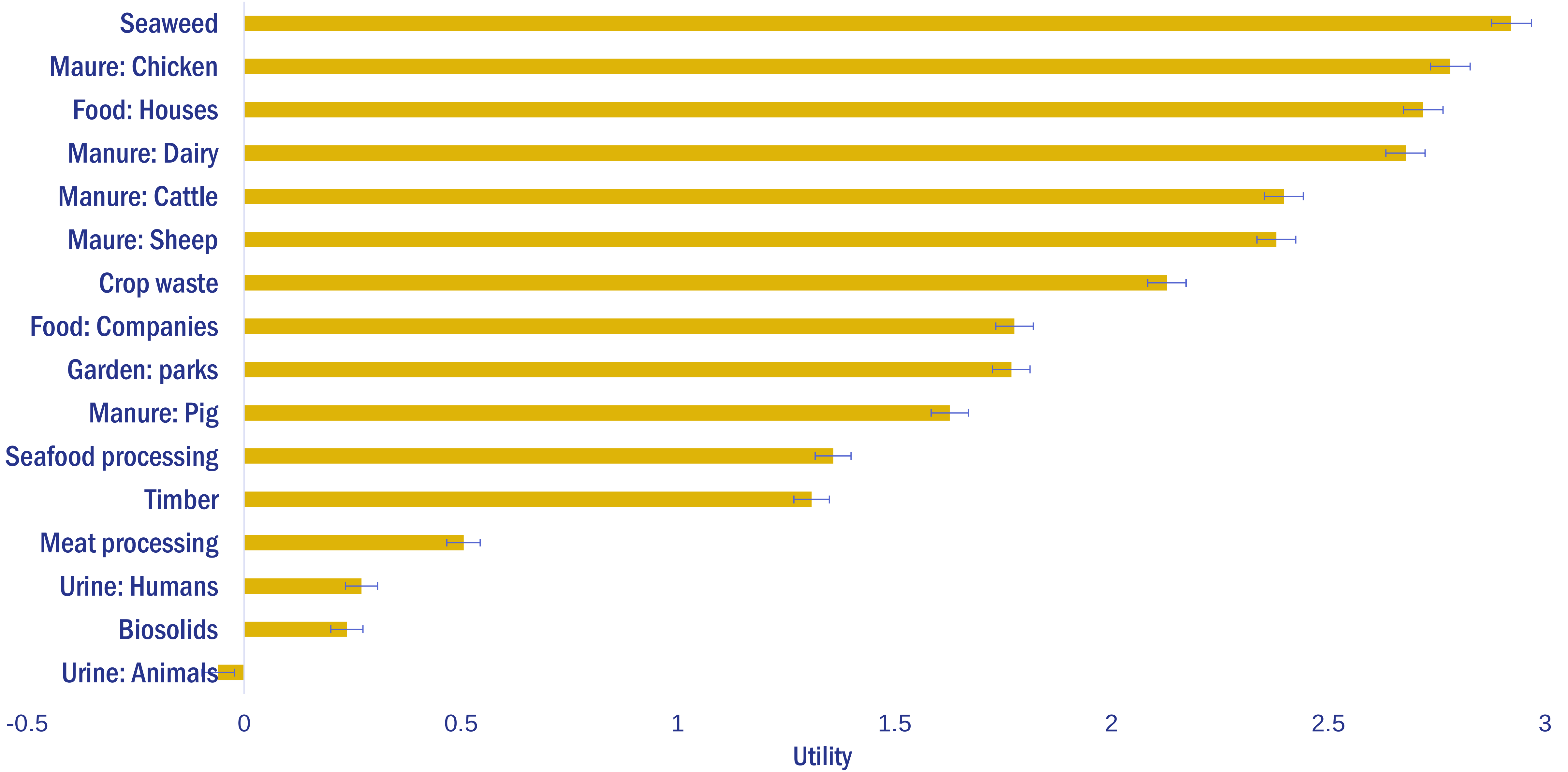

Differences in Preferences

- Overall rankings often mask differences of opinion across people
- Latent class model: allow different groups of people to emerge from the data based on their rankings
- Four groups of consumers emerged

Ranking: Group 1

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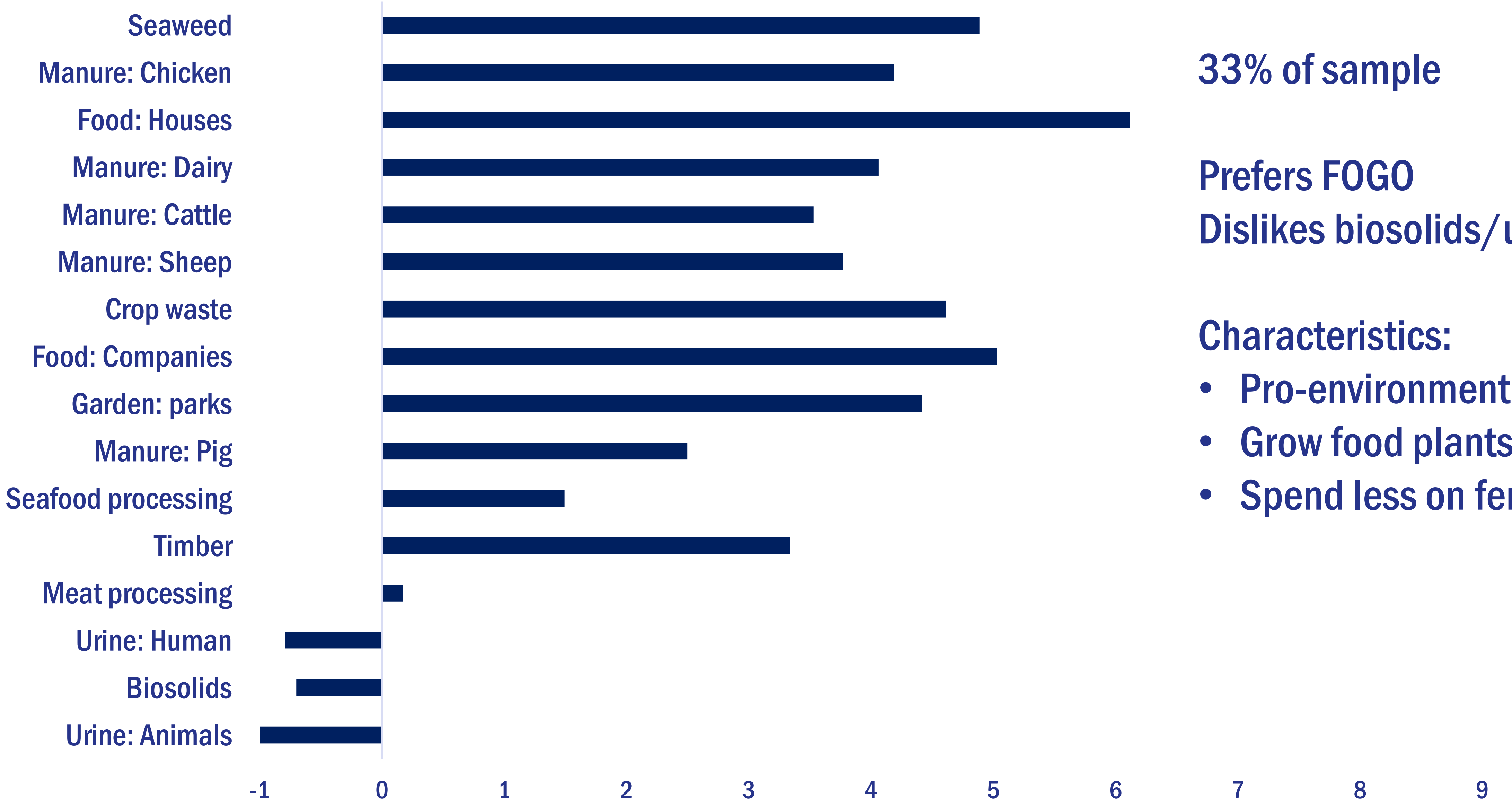

33% of sample

Prefers FOGO
Dislikes biosolids/urine

Characteristics:
- Pro-environment
- Grow food plants
- Spend less on fertiliser

Ranking: Group 2

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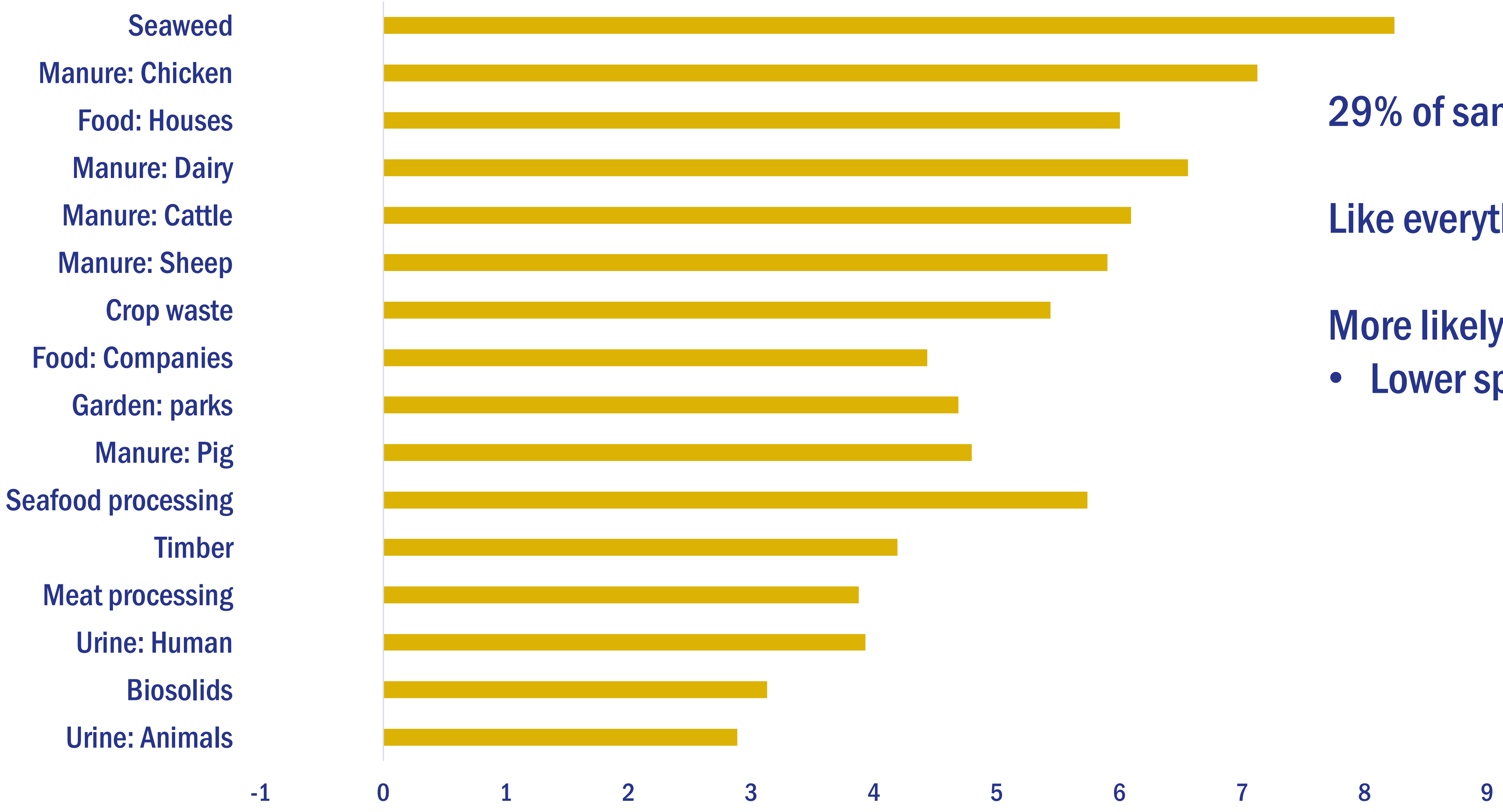

29% of sample

Like everything

More likely to be:

- Lower spenders

Ranking: Group 3

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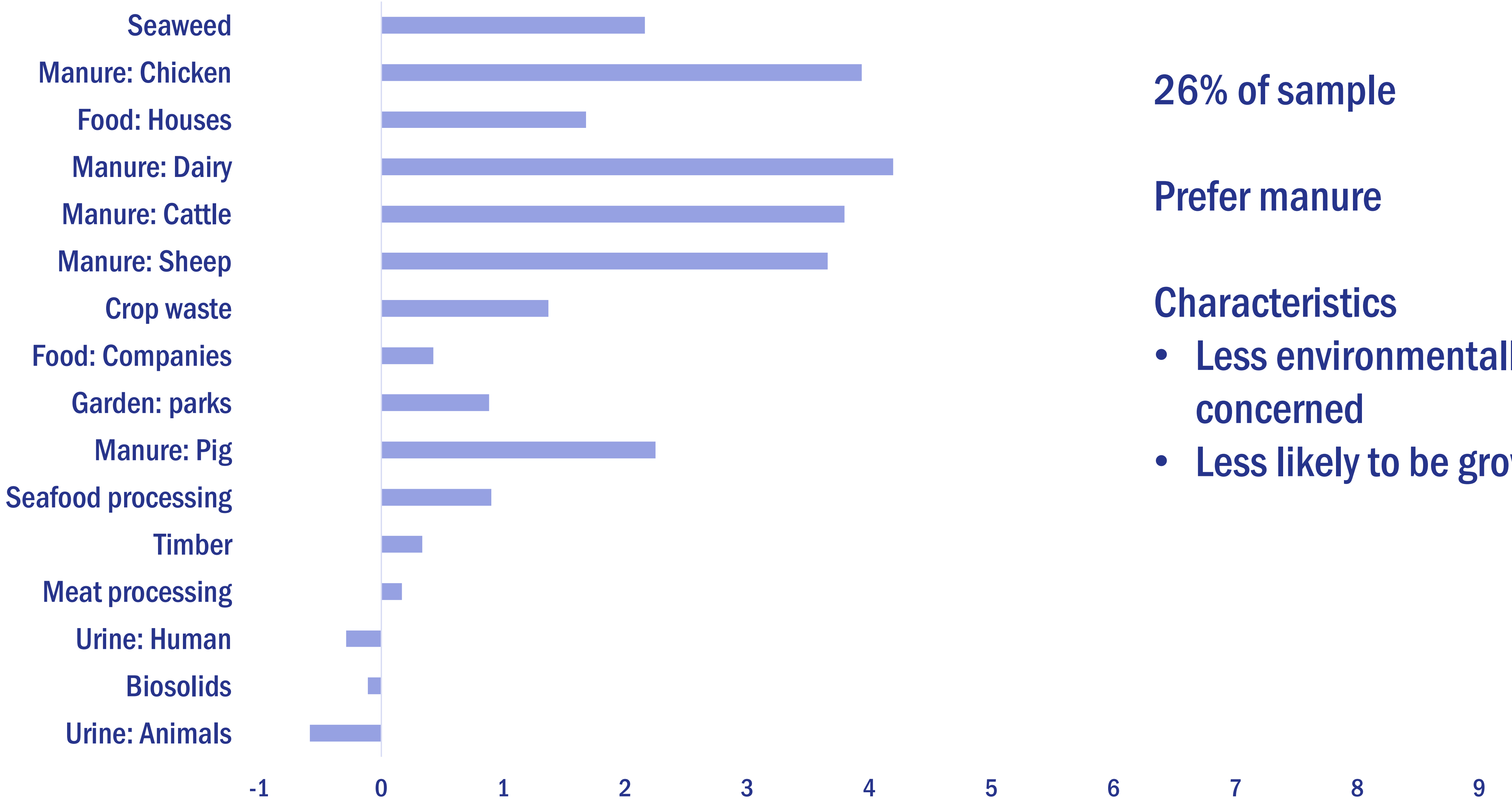


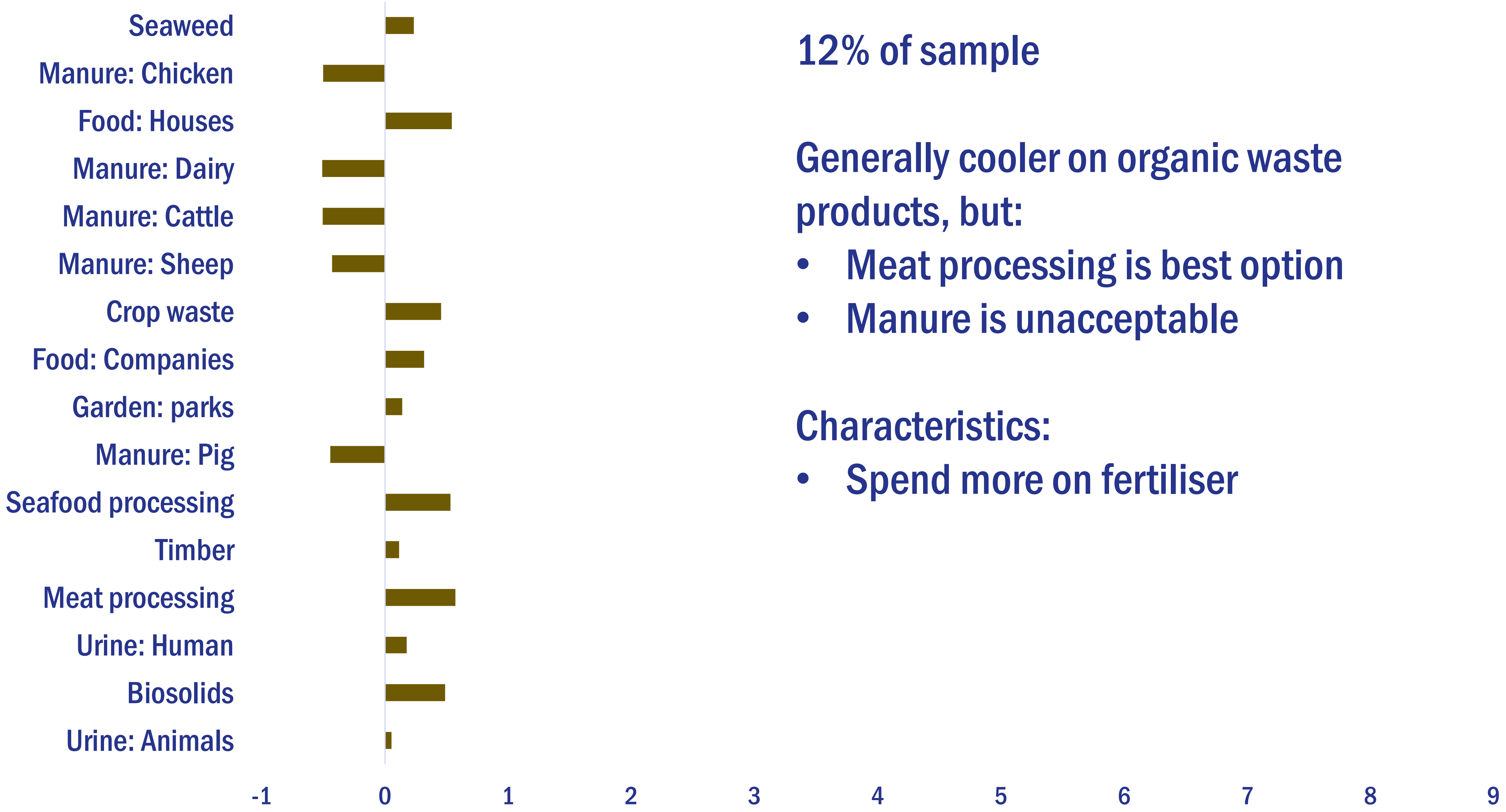
26% of sample

Prefer manure

Characteristics

- Less environmentally concerned
- Less likely to be growing food

Ranking: Group 4



12% of sample

Generally cooler on organic waste products, but:

- Meat processing is best option
- Manure is unacceptable

Characteristics:

- Spend more on fertiliser

All Groups: Diversity of Preferences

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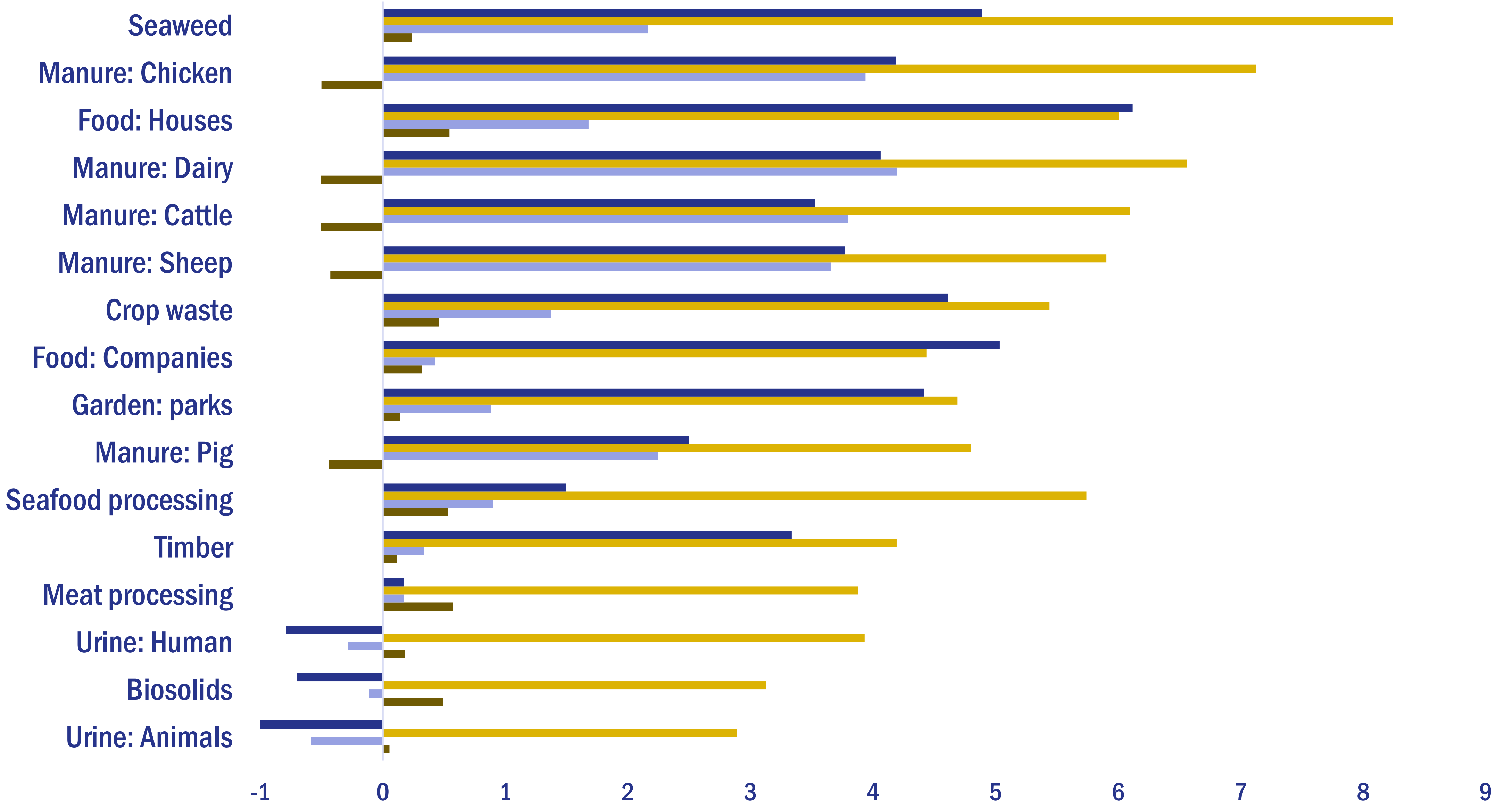

Preferences for Sources: Overview

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- Other organics preferred over meat processing waste
  - However, all groups view it positively
- Highest spenders view meat as the best organic source
  - However, they are least interested in waste to fertiliser/soil amendment

Choice Experiment: Methods

- 5 questions per person
- Presented 3 fertilisers at a time (5kg bag):
  - Chemical
  - Organic-Certified
  - Digestate-derived
    - 3 waste sources: FOGO, meat processing, and biosolids
- Different nutrient levels, prices for each fertiliser in each question

Example Choices

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	Chemical	Organic-Certified	Digestate-based
Nutrient Level (% N + P + K)	Medium-High 20%	Medium-Low 10%	Medium 15%
Waste source	N/A	N/A	Food waste
Price	$25	$30	$20

	Chemical	Organic-Certified	Digestate-based
Nutrient Level (% N + P + K)	High 30%	Medium-Low 10%	Medium-Low 10%
Waste source	N/A	N/A	Biosolids
Price	$20	$30	$15

But First: Perceptions of Digestate

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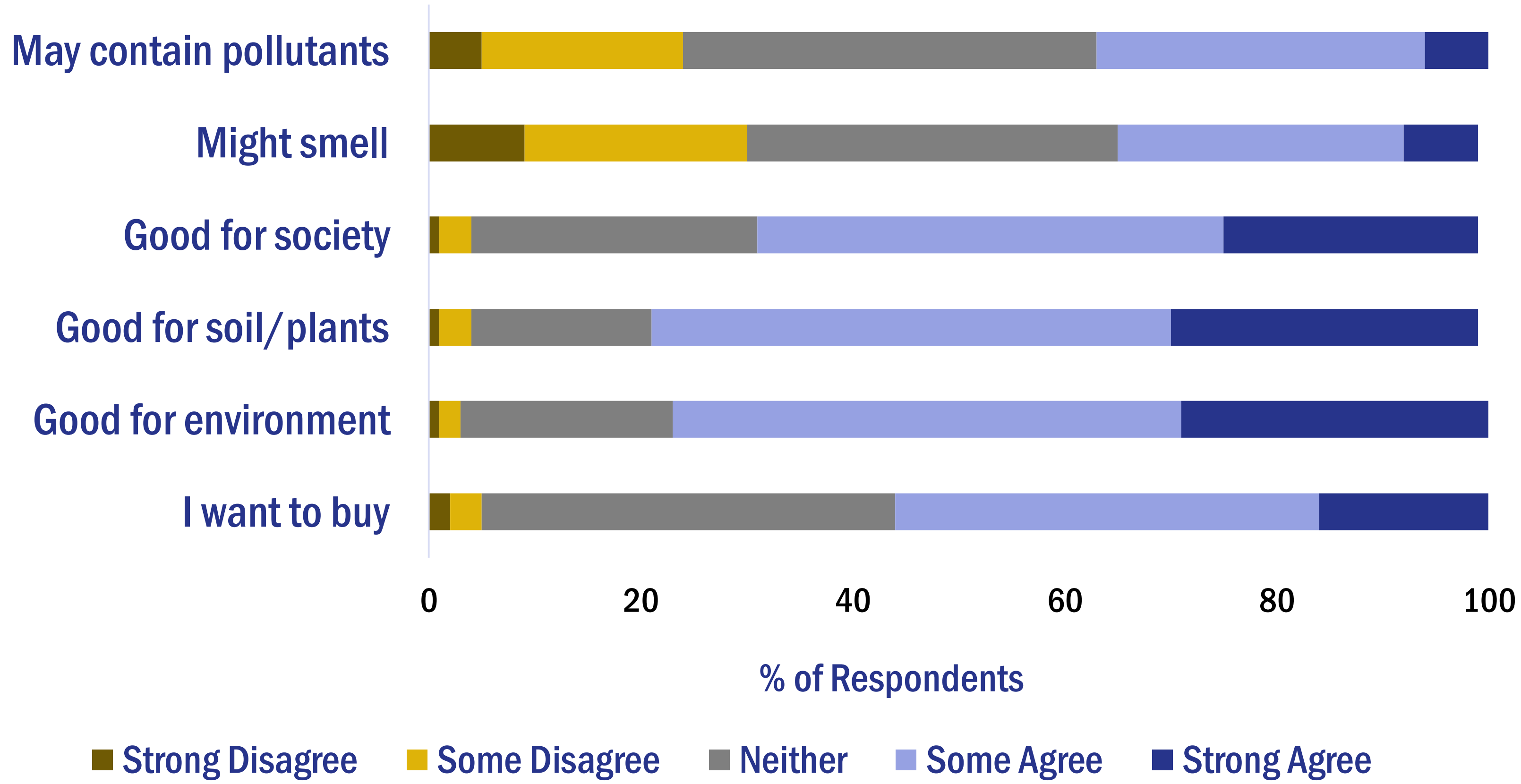
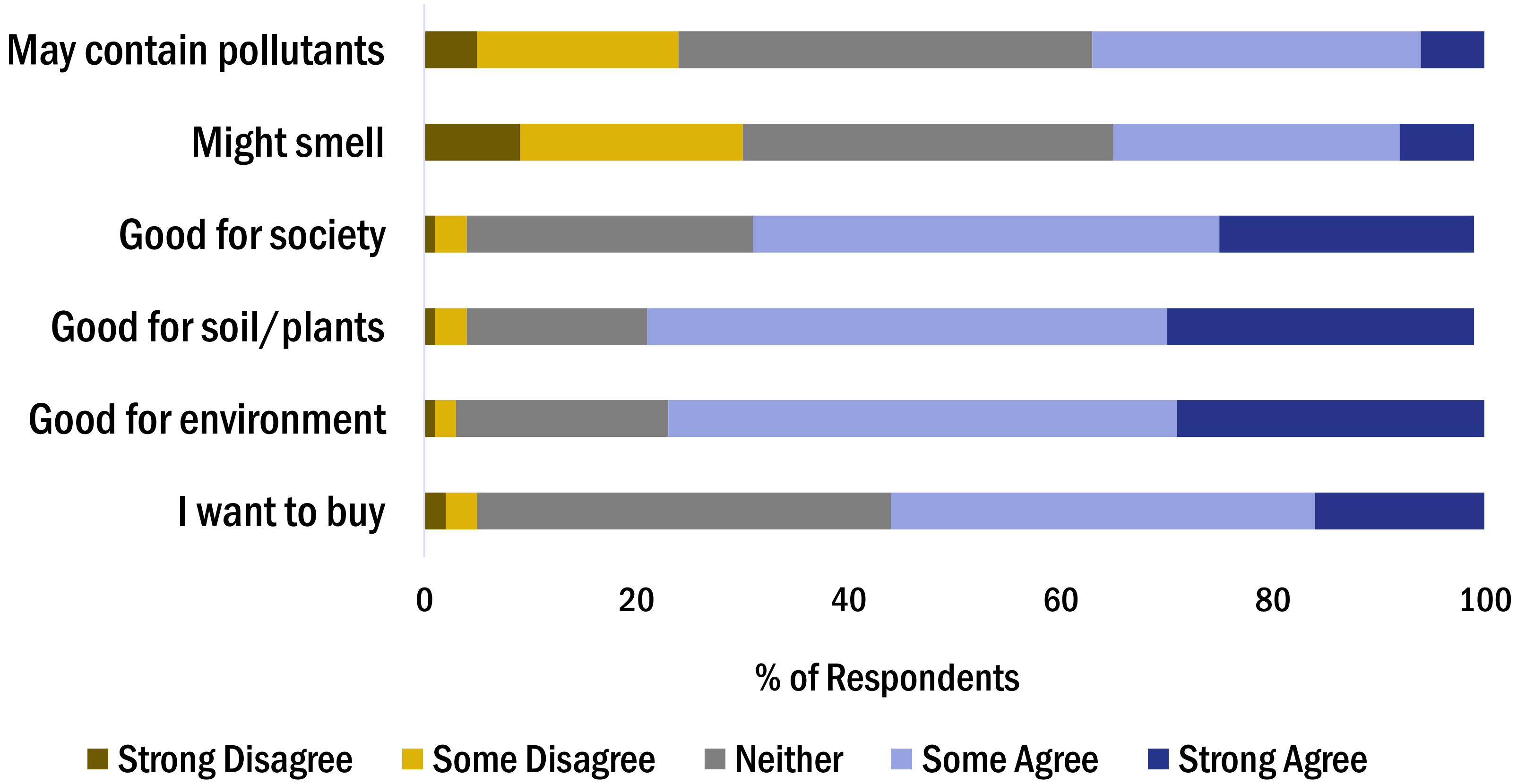


- Generally positive
- All information improved perceptions
  - Personal benefits most effective


May contain pollutants
Might smell
Good for society
Good for soil/plants
Good for environment
I want to buy
0
20
40
60
80
100
% of Respondents
Strong Disagree
Some Disagree
Neither
Some Agree
Strong Agree

Choice Experiment: Model

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- Understand why people pick a fertiliser based on price, nutrient value, type
- Control for people who ignored the price
  - Hypothetical purchases, so many will overstate willingness to pay
- Look at trade-offs between price increases and other fertiliser attributes:
  - Value of each attribute in $

Choice Experiment: Results

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- Price premiums for organic-based alternatives over chemical fertiliser:
  - $12 for Organic-Certified, $8 for digestate-derived

- But, 1% of nutrients worth 42 cents

- For digestate: prefer FOGO
  - $1 less per bag for biosolids, meat processing

Big Picture: Summary

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- People generally support digestate-derived products & waste-to-fertiliser
  - Prefer FOGO, seaweed
- Higher spenders more supportive of meat-based products
  - May indicate experience/familiarity
- Some opportunity for meat processing products
  - Risks: other waste streams preferred
  - Likely depends on effectiveness/nutrients