Closing the Loop on Waste
Roadmap for the Australian Pork Industry

APL R&D Report

Final Report
APL Project 2020/0087

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1. Introduction

This report has been prepared as a complementary document for the Closing the Loop Roadmap for the Australian Pork Industry (APL Project 2020/0087). The objective of this report is to provide industry recommendations that will :

- Provide guidance for the next steps in Closing the Loop across the Australian pork industry.
- Outline the research gaps that may improve the knowledge base on waste reduction strategies relevant to the Australian pig industry.
- Identify opportunities/limitations associated with the target of zero waste status.
- Identify opportunities for extension.

Future research in this waste minimisation sector has potential to provide a valuable basis for the Australian pig industry to continue consumer and government communications, both as a means of conveying the achievements made by industry, and also as a way of developing support for further advancements.

2. Baselining, Benchmarking and Setting Targets

2.1 Baselining and Benchmarking

To our knowledge, no baseline data exists for waste generation within the Australian Pork industry. To measure progress towards a goal requires measuring waste generation rates over time. Table 1 provides a range of waste indicators for different production systems, allowing an operation to benchmark their current position regarding waste generation and monitor progress towards reducing their waste footprint.

Table 1. Waste indicators for the Australian pork industry

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

Recommendation

We recommend selecting a set of preferred indicators from Table 1.

Collection of periodic data (i.e. every 2 years) across the national herd is recommended to assess waste generation at industry scale. This could be co-ordinated alongside other industry initiatives (benchmarking and APL surveys).

2.2 Target Setting

Progress rarely happens without measuring and setting a target to reduce impacts. Whilst the general "closing the loop" target set by Australian Pork will provide guidance across the industry, a quantifiable target would allow progress to be tracked over time and provide an increase in

promotional opportunities resulting from progress made. Industry goals could be aligned with the state and/or national targets.

Recommendation

For the industry to make serious progress in waste reduction, we recommend the following process.

1. Formalise the structure of an industry target.
2. Establish a series of options to deliver against waste reduction targets at 2025, 2030 and out to 2050. This should also investigate economic costs and policy settings required to achieve these ambitions.
3. Engage with industry stakeholders to establish an industry position.
4. Put the plan into action, with industry research and extension to support the program.

3. Production and Feed

Feed is the largest input for a piggery operation. Because of this, there are opportunities for closing the loop through minimising the requirements of traditional inputs and by utilising waste from other industries such as by-products, co-products and wastes from the pre-consumer human food chain. This section outlines research development and extension options which would help to minimise the knowledge gaps and improve uptake of waste products as feed, with the aim of reducing the waste footprint.

3.1 Reducing waste feed/Improving FCR

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

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

Research and Development

Waste feed is very hard to measure at piggeries. Tools that would allow a rapid modelling or measurement to quantify feed wastage to enable improvement in waste feed to be reported could be beneficial. This could be done using marker technology.

If these new approaches could be established, a range of research questions could be investigated around feeder type, feeder maintenance, diet formulation and presentation etc. Further insight from this could be gained from management and nutrition experts.

Extension and Adoption

Insights have been gained previously by using AusPig to compare actual performance with expected performance, then providing an estimate of feed wastage. This has provided specific estimates, highlighting losses. Benchmarking waste feed either via this modelling approach or using measurement techniques would deliver new targets for industry to work towards. Extension of this information could be provided to industry.

Benchmarking HFC and FC (wean to finish) more broadly across the industry via data collected in surveys. Extend this to industry to enable producers to benchmark their performance against industry best practice.

Provide "real life" case studies of producers who have adopted strategies that have improved their HFC and FC.

3.2 Unlocking zero input feed sources

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

A number of barriers to adoption exist, including information on what products are available, what requirements exist for using these, availability of suitable feeding systems and how to develop diets that suit waste products. Further to this, barriers may exist around handling large and mixed food waste sources, particularly if the supplier is unable or unwilling to disaggregate the waste source.

Where mixed sources include food offered to people or meat, this material is regulated and can't be used for pigs at present. Developing systems to overcome these barriers would be beneficial.

Research and Development
A full survey of potential feed sources suitable for piggeries, including their location, feed value, current use/disposal, cost (if any), availability and any constraints to their availability or usability is recommended.

Research may be needed to identify better ration formulation in diets with high levels of by-products, particularly if new sources are discovered.

Extension and Adoption
Following the survey of potential feed sources, APL could able to assist by:

1. Co-ordinating offtake agreements with large companies such as Coles and Woolworths
2. Exploring the realistic potential of post-processing of waste sources that are currently illegal under swill feeding laws. This could involve:
    a. examining the regulatory framework and proposing options for treatment and regulation of these sources in such a way that they are suitable for feeding. For example, would heat treating or rendering these sources overcome current barriers?
    b. If step a) holds promise, examine potential volumes of these sources from the fast-food sector (such as McDonalds) and engage to examine the possibility of developing partnerships to establish waste supply chains.
3. Engage with metropolitan councils to examine options to separate suitable material from the waste stream that could be used for pigs and gauge support for large scale off-take agreements for these waste streams with the pig industry.

Showcasing the benefits of using by-products via case studies would be beneficial, to raise the profile of this as a viable option for piggeries.

3.2.1 Alternative Feed Sources

The use of alternative feed sources in pig diets can utilise waste from one system and reduce the use of grains/protein sources and associated waste along the supply chain. Insect meal has been recognised as a cost-effective and sustainable alternative to reducing protein meals in pig diets, with black soldier fly larvae (BSFL) the most promising candidate in place of high-protein feeds.

Alternative waste utilisation includes duckweed and algae. For the adoption of alternative waste utilisation, extensive foundational research and development of guidelines and legal frameworks is required.

Research and Development

There is a large amount of research underway across the world investigating insect protein meal. One challenge is that any system that involves feeding material to another organism rather than feeding the pig directly has the biological disadvantage of a direct efficiency loss equivalent to the FCR of the organism being fed. For BSFL systems this often runs at 2.5 to 6 depending on the feed source. If it is not already being done, a literature review covering insect options and environmental benefits would be beneficial. Analysing the 'whole of system' benefits in an LCA is recommended, alongside a BCA.

It is quite possible that insect based systems could form part of an integrated waste management system at a piggery, utillising sources of waste material that can't be directly fed but are more valuable as insect feed than as biomass feedstock for digestion. This potential feed source fits with a holistic approach and we have outlined this in section 8 below.

Extension and Adoption

Pending research findings, extension to industry nutritionists and companies may be warranted, to increase awareness and consideration of environmental performance in diet formulation.

APL could investigate the partnering with companies willing to invest in technology to generate alternative feed sources.

4. Energy

4.1 Methane capture

Residual energy potential in manure is a combination of excreted faeces (50-60%) and waste feed (40-50%). Closing the loop on energy loss begins with reducing waste feed and improving HFC and FC, then for the remaining energy, this can be biologically converted to methane and utilised in a range of ways.

Methane capture from anaerobic ponds and digesters is well recognised by industry as a proven method for utilising the piggery effluent waste for the generation of energy. The implementation of covered aerobic ponds or anaerobic digestors is a key aspect of closing the loop on waste across the industry.

We have identified a number of research opportunities below. However, the single largest barrier in this space is the cost-effectiveness of covered ponds and the willingness of businesses to sign off on the investment. We have provided options in the low emissions RDE report on methane capture and this should be referred to. We have not repeated this content here.

It is noted that biomethane utilisation (noted in the GHG guide) is energetically more efficient than electricity generation and from a zero waste perspective this is the most-preferred approach.

4.2 Co-digestion

The capital investment associated with the construction of a methane capture and reuse system is significant for a piggery operation, and one method which assists in maximising the return on investment as well as assisting in closing the loop on waste for the pig industry and other organic waste producing industries is co-digestion. A comprehensive review of the opportunities associated with co-digestion in the pig industry was undertaken by in CRC 4C-109 *Enhanced methane production from pig manure in covered lagoons and digesters* (Tait et al., 2017).

Research and Development
Research that could benefit the industry may include:

- Identification of most suitable material for co-digestion with pig manure for both a covered pond with the production of guidelines with preferred VS.
- Assistance for producers within the industry that already have anaerobic digestion to determine the capacity of their systems and identify opportunities for increasing energy production through co-digestion.

Extension and Adoption
Develop guidelines for operators considering the construction of anaerobic digestion systems outlining the opportunities for co-digestion and factors to include into designs to allow maximum energy recovery.

5. Nutrients

Piggery by-products contain significant quantities of nitrogen, phosphorus, potassium, trace elements and carbon which are valuable commodities in agricultural production. Closed loop technologies to recover nutrients from manure are available but are generally not cost effective at the present time. However, noting that fertiliser prices have once again risen to historic highs, the economics could change if these high prices are sustained. Development of demonstration sites and markets for fertilisers (particularly for emerging organic markets) would be beneficial, particularly where this can utilise excess and low cost heat and power from CHP units. Market analysis may be warranted to help establish the business case for investment. This would reduce GHG emissions via production of new outputs from the piggery, and via reduction of emissions from current manure management systems by reducing ammonia losses and field application losses.

Research and Development

Research that could benefit the industry may include:

- In 2015 a 'closing the loop' analysis was done for APL. Now 6 years later, it would be beneficial to update this project, particularly to examine cost-effectiveness of nutrient recovery and to explore any new technologies that have come to market in this time. This could be expanded to include a market study of the quality and expected wholesale price that could be expected from re-selling bulk nutrients extracted from sludge. With the growth of niche sectors such as organics, it would be worthwhile investigating whether these products could be certified as organic, and the size of this premium market.
- Pending updating of the analysis, the real need in this space is to establish a minimum viable scale project to demonstrate and refine the technology for nutrient recovery in Australia. We have proposed this in section 7.1.
- Alternatively, a lower cost option could be to develop a pilot, modular plant that could be deployed at piggeries to de-sludge ponds, delivering fertiliser grade products based on established technology such as ammonia stripping and struvite.
- To upscale and distribute the knowledge generated from the above, it would be beneficial to develop the business case of these technologies at scale.

Extension and Adoption

For the technical solutions, research is required prior to extension and adoption.

However, traditional nutrient utilisation has focused on crop production for manure and effluent utilisation. This is an area that always needs to be promoted, to encourage the industry to use best-practices for nutrient utilisation. It would be beneficial to survey the industry (as part of APL's general survey efforts) to find what proportion utilise nutrients for crop production currently, at agronomic application rates. Improving current effluent and manure application rates (matching nutrient application to plant requirements) is recommended as an ongoing extension and adoption activity.

6. Water

Water is both the most important nutrient for pigs and the most valuable natural resource (after land) in Australia. Advanced water treatment plants (AWTPs) are becoming more common in Australian meat supply chains. However, there is low uptake at a farm-scale compared with processing plants.

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

Within the piggery, work has been done to quantify water use, recycling and reduction potential. This work should be periodically updated and expanded to cover more regions in Australia.

Research and Development

Almost all waste generated from a piggery site can be reused or recycled if the correct method of disposal is followed Research that could benefit the industry may include:

- Investigate AWTP technologies and treatment trains for piggeries as they become available.
- Investigate the embedded water usage in feed for production regions in northern and southern Australia, and identify suitable nutritional and cost effective alternatives from non-irrigated production areas.
- Determine the maximum recycling rates through conventional piggery systems, including guideline parameters (ie. ammonia, salts, volatile fatty acids) to monitor to ensure conditions within the ponds remain compatible with anerobic digestion.

Extension and Adoption

Promote to industry the benefits of reusing and recycling water, along with methods to reduce fresh water usage.

7. Solid Waste

Almost all waste generated from a piggery site can be avoided or recycled if the correct method of disposal is followed. As the proportion of agricultural waste recycled is generally low, extension and adoption could be used to improve the awareness of recycling across the industry.

Research and Development

Research that could benefit the industry may include:

- Collection of data across the industry to identify the quantity and diversity of solid waste produced onsite, and identify which waste streams present the greatest challenge for recycling or repurposing.

Extension and Adoption

Assist with identification of recycling service providers that can meet the needs of the pig industry.

- Production of clear simple factsheets to show how some common waste streams need to be packaged (ie bundling of AI straws, bailing twine) to allow them to be included in the recycled product stream.

8. Closed Loop Farm

Current technology exists that would allow the development of a wholistic and large scale demonstration of a closed loop farm. This was proposed as part of the low carbon emissions RDE report but is repeated and expanded here as it is highly relevant to the zero waste program. This farm would demonstrate how the ambitious goal of closing the loop on waste with the aim of achieving net zero waste could be achieved. Research on integrated, farm scale initiatives must occur in the near term if such options are going to be available in 2030 and beyond.

A closed loop farm would show how food waste, pig systems and energy can be worked in tandem. This site could be established with the ambition of demonstrating positive energy production (export of energy), low-cost pork production and zero non-by-product feed requirements.

The full cascading system of food waste recovery could be demonstrated, as per the hierarchy shown in **Error! Reference source not found.**.

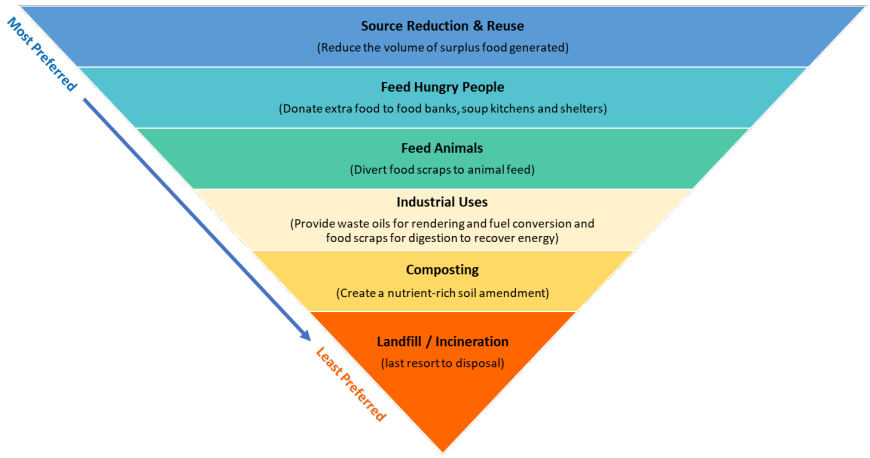

Figure 1. Food recovery hierarchy triangle (U.S. EPA 2021e)

This site would:

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

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

3. Demonstrate energy recovery technology.
    a. Optimizing biogas yield and quality
    b. Value recovery from CO_2
    c. Biomethane generation

    d. Energy recovery from manure and mixed biomass (i.e. energy generation with all biomass not suitable for feeding to pigs)
    e. Heat recovery and utilisation (for example, rendering)

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

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

9. Summary

A large number of recommendations have been provided in this short report. These have been prioritised in Table 2 and Table 3.

Table 2. Research Priorities for Closing the Loop on Waste

No	Target Area	Waste Mitigation opportunity	Waste Reduction Potential	Proportion of the industry where this is relevant	Waste reduction potential (in pigs, or broader economy)	Technical - Readiness	Ease of Adoption	Other benefits/ disbenefits	R&D cost*	Cost to implement	Horizon#	Chance of Success	Possible co-funding partners	Priority
1.1	**Diet - By-product Usage**	A full survey of potential recovered waste feed sources suitable for piggeries, including their location, feed value, current use/disposal, cost (if any), availability and any constraints to their availability or usability is recommended.	High	100%	10%	H	M	aligns with low carbon	L	L	H1	H	poultry, Fed Govt, CRC	1
1.2		Research to identify better ration formulation in diets with high levels of by-products, particularly if new sources are discovered.	High	100%	10%	H	M	aligns with low carbon	M	L	H1	H	poultry	1
1.3		Industry co-ordination of waste feed collections with major companies and municipalities	High	60%	6%	L-M	M	aligns with low carbon	H	M	H2	M	municipalities, retailers, ARENA	2
1.4		Develop systems to allow safe utilisation of currently restricted products (swill)	High	74%	7%	M	M	aligns with low carbon	H	M	H2 - H3	L	0	1
1.5	**Diet - Alternative Feeds**	Undertake a literature review covering insect options and environmental benefits would be beneficial. Analysing the 'whole of system' benefits in an LCA is recommended, alongside a BCA.	Medium	74%	7%	L-M	M	aligns with low carbon	L	H	H2	L-M	poultry	1
1.6	**Diet - Feed Wastage**	Establish methods either by modelling or measurement to quantify feed wastage to enable improvements to be reported.	High	74%	10%	M	H	aligns with low carbon	L-M	L	H1	M		
2.1	**Manure - Co-digestion**	Identification of most suitable material for co-digestion with pig manure for both a covered pond with the production of guidelines with preferred VS.	High	74%	5%	H	H		L	M	H2	M	Fed.Govt, ARENA, CRC	2
2.2		Assistance for producers within the industry that already have anaerobic digestion to determine the capacity of their systems and identify opportunities for increases energy production through co-digestion.	High	16%	5%	H	M	offsets more energy, reducing GHG	M	L	H2	H	Meat processing	2
3.1	**Nutirents**	Undertake update of 2015 'closing the loop' analysis was done for APL, particularly to examine cost-effectiveness of nutrient recovery and to explore any new technologies that have come to market in this time, including a market study of the quality and expected wholesale price that could be expected from re-selling bulk nutrients extracted from sludge.	Medium	74%	5%	M	L	better on-site nutrient management, new fertiliser sources for grain	L	H	H1	M	grains	1
3.2		Establish a minimum viable scale project to demonstrate and refine the technology for nutrient recovery in Australia.	Medium	74%	5%	M	L	new revenue stream and less on-site water quality impacts	H	H	H2	M	meat processing, ARENA	2
3.3		Develop a pilot, modular plant that could be deployed at piggeries to de-sludge ponds, delivering fertiliser grade products based on established technology such as ammonia stripping and struvite.	Medium	74%	5%	L	M-H	could solve desludging problems	H	L - generates revenue	H2-3	M	meat processing	2
3.4		Develop the business case for nutrient recovering technologies at scale.	Medium	74%	5%	L	M-H		L	L	H1	M	meat processing	1

No	Target Area	Waste Mitigation opportunity	Waste Reduction Potential	Proportion of the industry where this is relevant	Waste reduction potential (in pigs, or broader economy)	Technical - Readiness	Ease of Adoption	Other benefits/ disbenefits	R&D cost*	Cost to implement	Horizon#	Chance of Success	Possible co-funding partners	Priority
4.1	**Water**	Provide up-to-date information to industry on AWTP technologies and treatment trains for piggeries as they become available.	Medium	74%	3%	M	M	reduce water stress	L	M-H	H2	M	meat processing	2
4.2		Investigate the embedded water usage in feed for production regions in northern and southern Australia, and identify suitable nutritional and cost effective alternatives from non-irrigated production areas.	Medium	100%	10%	H	M		M	L	H2	H	poultry, feedlot (feed grains)	3
4.3		Determine the maximum recycling rates through conventional piggery systems, including guideline parameters (ie. ammonia, salts, volatile fatty acids) to monitor to ensure conditions within the ponds remain compatible with anerobic digestion.	Medium	74%	3%	H	H		L	L	H2	H		3
5.1	**Solid Waste**	Collection of data across the industry to identify the quantity and diversity of solid waste produced onsite, and identify which waste streams present the greatest challenge for recycling or repurposing.	High	100%	5%	H	H	cost reduction	L-M	L	H1	H		1
6.1	**Closed Loop Farm**	Full scale closed loop demonstration farm with biomass processing, feed generation, nutrient, energy and water recovery	Towards 100%	100%	50%	L	L	aligns with low carbon	V.H	V. H	H3	M	ARENA, Municipalities, State Govt, Universities, Retailers, large pork producers	1

* Cost brackets are for general guidance. L <$50,000. M = $50,000-$250,000. H $250,000-$1M. VH = >$1M.

#Horizon (H1 = 2022-24, H2 = 2025-29, H3 = 2030+)

Table 3. Extension, Adoption and Policy Priorities for Closing the Loop on Waste

No	Target Area	Extension, Adoption and Policy Priorities for Closing the Loop on Waste	Implementation Cost	Chance of Success	Waste Priority
1.1	**Diet - By-product Usage**	Co-ordinating offtake agreements with large companies such as Woolworths and Coles.	M	H	2
1.2		Engage with metropolitan councils to examine options to separate suitable material from the waste stream that could be used for pigs and gauge support for large scale off-take agreements for these waste streams with the pig industry.	M	H	2
1.3		Showcasing the benefits of using by-products via case studies would be beneficial, to raise the profile of this as a viable option for piggeries.	M	H	1
1.4	**Diet - Swill Feeding**	Exploring the realistic potential of post-processing of waste sources that are currently illegal under swill feeding laws. This could involve: (a.) examining the regulatory framework and proposing options for treatment and regulation of these sources in such a way that they are suitable for feeding. For example, would heat treating or rendering these sources overcome current barriers? (b). If step a) holds promise, examine potential volumes of these sources from the fast-food sector (such as McDonalds) and engage to examine the possibility of developing partnerships to establish waste supply chains.	H	L	2
1.5	**Diet - Alternative Feed S**	Pending research findings, extension to industry nutritionists and companies may be warranted, to increase awareness of alternative feed sources including insects including consideration of environmental performance in diet formulation.	H	M	2
1.6		APL could investigate the partnering with companies willing to invest in technology to generate alternative feed sources.	H	M	2
2.1	**Manure - Co-digestion**	Develop guidelines for operators considering the construction of anaerobic digestion systems outlining the opportunities for co-digestion and factors to include into designs to allow maximum energy recovery.	M	H	1
3.1	**Nutirents**	Survey the industry (as part of APL's general survey efforts) to find what proportion utilise nutrients for crop production currently, at agronomic application rates. Improving current effluent and manure application rates (matching nutrient application to plant requirements) is recommended	M	M	2
4.1	**Water**	Promote to industry the benefits of reusing and recycling water, along with methods to reduce fresh water usage.	M	M	2
5.1	**Solid Waste**	Production of clear simple factsheets to show how some common waste streams need to be packaged (ie bundling of AI straws, bailing twine) to allow them to be included in the recycled product stream.	M	H	1

* Cost brackets are for general guidance. L <$50,000. M = $50,000-$250,000. H $250,000-$1M. VH = >$1M.