

GUIDANCE MANUAL

OPTIMISING WASTE AND BY-PRODUCT UTILISATION AND CONVERSION TO VALUE STREAMS



A report for Australian Eggs Limited

By Mary-Frances Copley, Eugene McGahan, and
Stephen Wiedemann

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Foreword

This project was conducted to quantify, by housing system, the volume of waste and by-products produced by the industry. A secondary objective was to identify strategies to utilise by-products within the industry and/or to convert these into revenue streams, packaging these findings in a manual designed to further promote closed-loop production within the egg industry.

This project was funded from industry revenue, which is matched by funds provided by the Australian Government.

This report is an addition to Australian Eggs Limited's range of peer-reviewed research publications and an output of our R&D program, which aims to support improved efficiency, sustainability, product quality, education and technology transfer in the Australian egg industry.

Most of our publications are available for viewing or downloading through our website:

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Printed copies of this report are available for a nominal postage and handling fee and can be requested by phoning (02) 9409 6999 or emailing **research@australianeggs.org.au**.



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Egg producers and facility managers

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Project steering committee and peer reviewers

We thank the members of the project steering committee for their support and insights, and for reviewing the draft manual. We also thank the peer reviewers for their feedback on the draft manual.

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Glossary

By-products	Organic matter produced by the industry. By-products include manure/ spent litter, spent hens, mortalities, shells, and wastewater.
Composting	A controlled, aerobic, and heat generating process that degrades organic material and turns it into a relatively stable organic material similar to soil (Hussain et al. 2022).
Discount rate	The rate of return that the investor expects on an investment. It is the rate of interest that is used to determine the present (today's) value of future cash flows associated with an investment. In this document, a discount rate of 4% is used.
Internal Rate of Return (IRR)	Estimates the profitability of potential investments. If the IRR is greater than the cost of capital or required rate of return (e.g. the discount rate), the investment is estimated to be profitable. In this document, a profitable IRR appears in black text, e.g. as 8%. When the IRR is lower than the cost of capital, the investment is not estimated to be financially viable. In this document, an IRR that indicates a not financially viable investment appears in red text, e.g. as '-5%' or '3%'.
Net Present Value (NPV)	Used to analyse the profitability of a potential investment or project. It represents the difference between the expected cash inflows and outflows (in today's dollars) over the life of the project/investment. In simple terms, an NPV less than zero dollars indicates that the project will cause the investor a financial loss whilst a positive NPV indicates that it will turn a profit.
Spent hens	Flock hens at point of depopulation, i.e. live birds at end of lay.
Wastewater	Water used on-site in cleaning (e.g. to wash downs sheds, or clean eggs at grading) that contains contaminants (e.g. chemicals, organic matter, nutrients).



1. Disclaimer

1.1. Scope of the document

1.1.1. Facilities to which this manual applies

The manual details relevant strategies and technologies, their methods, and any key considerations (scale, labour, capital investment) to assist producers and facility managers with identifying, implementing, or further improving by-product management and utilisation.

While the document focuses on layer farms, the principles outlined may equally apply to breeder farms and standalone rearing farms. The manual is designed for the Australian egg industry only, i.e. may not be applicable to meat chicken farms (breeder or grower), or other species such as ducks, quails, or ratites (flightless birds).

The principles outlined in this document are applicable to both small and large enterprises. Where feasibility or ease of practical implementation may vary between facilities based on scale, efforts have been made to flag this. The strategies and technologies described in this document are not exhaustive and do not preclude producers using alternative means to manage or utilise by-products.

1.1.2. Content is not legal advice

While this document was developed with reference to State (all references to 'State Government' contained in this manual include 'Territory Government') regulatory frameworks, it is not a guide to regulatory compliance. This manual does not claim that its recommendations meet regulatory requirements, it only advises on important issues to address when processing and using industry by-products. It is recommended that producers and end-users review their State or Territory's requirements for by-product regulations.

1.1.3. Guidance does not preclude alternative practices

The information in this manual is based on current information, knowledge and practices that can be used as a reference standard. Future research and innovation may identify new strategies and best practice methods for waste and by-product utilisation and conversion to value-add these materials.

The manual aims to provide industry with the necessary information to take a risk-based approach to utilisation. Where potential solutions and strategies have been identified, there may be alternatives (and alternative methods) not covered here that also achieve the desired outcome.

1.1.4. Guidance is subject to other requirements

Egg industry facilities are subject to other requirements including biosecurity, animal welfare, food safety, and labelling standards. Any changes to these standards can have flow-on effects with respect to waste and by-product generation, management and utilisation and must be considered.

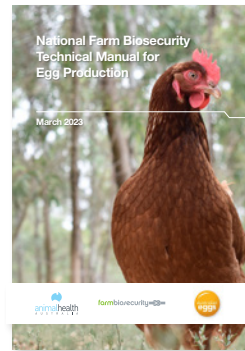
The economic analysis in this document reflects the current pricing of inputs, technology, and selling prices for products at the time of writing. Users of this document should exercise their due diligence when evaluating the economics of a technology, as there may have been a significant change in potential costs or revenues since writing this manual. Site specific considerations must be accounted for when determining the on-farm viability and feasibility of the strategies outlined in this document.

The benefit-cost analysis is done at a high level only, and includes capital (including infrastructure, equipment) and operating (labour, fuel, energy) costs, and benefits (e.g. revenue from product sales, avoided energy costs).



1.2. Biosecurity considerations for by-product management and utilisation

It is important to consider all factors that may affect the biosecurity of the production area, including by-product management, handling, and use. The following objectives and requirements are quoted directly from the National **Farm Biosecurity Technical Manual for Egg Production** (Animal Health Australia et al. 2023). They should be considered in any by-product management and utilisation strategy:



Objective: *“To limit and control access to poultry production areas by vehicles, equipment and people, and prevent access by livestock, wild birds and other animals (including rodents and insects) as much as possible.”*

Requirements of the objective include:

“Dead bird storage and disposal methods must conform to applicable hygienic containment and environmental compliance requirements.”



Objective: *“To minimise the risk of introduction of disease or contaminants by specified movements.”*

Requirements of the objective include:

“... after depopulating spent layer hens, pick-up crews should not handle pullets for transfer on the same day ... Pick-up vehicles, modules and crates must be thoroughly cleaned, detergent washed and disinfected between farms. A thorough inspection of the vehicle and trailer should be undertaken prior to entry on the farm and the movements of the driver and crew validated. Boots and clothing of the pick-up crews should also be clean. Prior communications should ensure that there is a clear understanding by the contractor of their biosecurity responsibilities and policies of the poultry farm operator.”

“Fresh litter delivery and collection of manure and used litter should be dedicated to those tasks only - trucks carrying new litter should be from reputable companies and not used for carting used litter and manure. Trucks carrying manure and used litter should not be used for back loading grain without a prior thorough cleaning program and the knowledge of all parties involved.”



Objective: *“To ensure that water used in poultry sheds for drinking, cooling and cleaning, is of a standard suitable for livestock.”*

Requirements of the objective:

“... The effectiveness of water treatment systems, including alternative systems (e.g. ultraviolet), must be validated before use and treatment systems require a programme of maintenance and monitoring to ensure effectiveness. Production area records able to demonstrate the effectiveness of water treatment must be kept. Microbiological validation of the efficacy of the treatment system must be carried out at least once a year. Producers are advised to see the National Water Biosecurity Manual - Poultry Production for more detail on water biosecurity.”



Objective: *“To reduce the likelihood of the introduction of disease agents and contaminants into poultry sheds and enclosures and reduce the attraction of rodents and wild birds to production areas.”*

Requirements of the objective:

“The use of untreated manure or litter on adjoining land to the free-range areas from other parts of the poultry operation or from other poultry farms should take into account the spread of potential endemic disease agents e.g., Salmonella, infectious laryngotracheitis virus, Marek’s disease virus and the introduction of litter beetles. The use of windrow composting or off-site disposal is preferable, to remove these risks. Alternatively, manure or litter should be deposited at least 1 kilometre away from the production area.”

“If the farm does not have the capability to treat the manure and used litter on the farm, the company which collects/purchases the manure and used litter should have measures in place to treat the manure and used litter before they can on-sell products as fertiliser for crop production and horticultural use.”

The objectives and requirements described here are not exhaustive and producers/facility managers should consult the relevant biosecurity requirements and guidelines directly and in full.





2. Introduction

This manual is designed to assist egg producers and facility managers to identify, assess and implement strategies to beneficially use or convert by-products into alternative revenue streams.

Industry can use this manual to understand the opportunities and factors that determine the viability of managing, utilising, or converting by-products, contributing to closed-loop production and/or circular economy principles. The manual also provides information on how to implement/conduct the strategies and outlines potential barriers to adoption (e.g. capital requirements, scale) to ensure that industry has access to precompetitive information to prioritise targeted investment.

The manual is primarily aimed at small-medium farms, outlining the strategies and technologies broadly feasible for farms of this size. High-cost engineered solutions found (in this study) not to be cost-effective for small-medium farms (i.e. only relevant for the largest farms) are outlined in the Appendices.

The strategies and technologies are outlined in order of preference against the waste hierarchy. This follows an avoid, reduce, reuse, recycle approach. Producers should consider this idealised hierarchy in light of their own farm, including their own waste and by-product volumes and other factors (e.g. labour availability, proximity to neighbours), to identify their best options for waste and by-product utilisation. Fundamentally, the most preferred option to manage a given by-product may differ from farm to farm.

State and Territory regulations may also be a barrier to by-product use, and requirements can vary significantly between jurisdictions. Regulations should be reviewed before implementing by-product management or utilisation strategies.



3. Developing a waste and by-product management strategy

Developing an effective waste and by-product management plan for a farm requires undertaking the following steps, the first of which is to audit the types and volumes/weights produced on your farm.



Step 1:

Populate egg farm waste and by-product audit template for your farm for a given period (e.g. one year). Note that not every waste and by-product listed below may be generated on your farm. Equally, you may generate other waste and by-products on your farm that are not listed below. You should add these under the 'other' categories.

A hard copy version of the template is available in **Appendix 1 – Farm waste and by-product audit.**

Guidance on how to estimate some volumes/weights are provided in the notes sections of the farm waste audit template.

Step 2:

Understand the total quantities of waste and by-products produced on your farm. This involves quantifying the amount of each type of waste and by-product produced. This will identify the amount of each waste or by-product stream. This will allow you to focus on the most important (i.e. largest) residue streams. You may choose to focus on developing strategies to reduce or better manage your largest sources of waste and by-products.



Step 3:

Compare the waste and by-product volumes produced on your farm with the industry averages reported in **Appendix 2 – Industry baseline** per one thousand birds housed and eggs graded. This will demonstrate how your farm differs from average industry values, i.e. it will show if/where you produce less or more waste and by-products than what the industry does on average. You may choose to focus on developing strategies to reduce or better manage the waste and by-products that you produce more of on average than does the rest of the industry.

Note that not all waste types were disaggregated or trackable at the industry level in the baseline assessment (**Appendix 2 – Industry baseline**). In future, as more farms begin auditing and tracking waste and by-products, it may be possible to update/expand on the industry baseline.

Step 4:

Familiarise yourself with the **Principles of waste and by-product management** (Section 4). This is an important step in identifying the ‘best’ strategies and technologies for each waste and by-product stream. As you are doing this, identify any waste or by-product management practices that currently fall into the ‘least preferred’ category, e.g. anything that goes to landfill or even burial. You may choose to focus on developing strategies to avoid this altogether or to at least reduce the volumes going to landfill or burial as a first step.

Step 5:

For your priority waste and by-product streams, review current practices and the options available (strategies and technologies) to manage these. A list of available options is outlined in **Management and processing options** (Section 5), with hyperlinks to the relevant section in this manual where the strategy, process management, and any pros and cons are outlined. For each section (i.e. each major by-product or waste stream), the options are presented from the theoretically most preferred to the least preferred, based on the **Principles of waste and by-product management** (Section 4). The best options for your farm, however, will depend on the scale of your farm, the capital available for investment, the amount of labour and land available, proximity to sensitive receptors, intended use, etc.

Step 6:

Implement selected strategies and technologies on your farm/continue to assess whether there is scope to improve your existing implementation of selected strategies and technologies. This process may include periodic re-evaluation as to whether variations or upgrades could (financially) or should (reduction in environmental risks) be made to your existing operations/facilities, e.g. if managing mortalities in mostly static piles with temporary walls, is there sufficient capital to justify upgrading to a permanent (e.g. timber walled, roofed) facility, reducing the risk of runoff, etc.

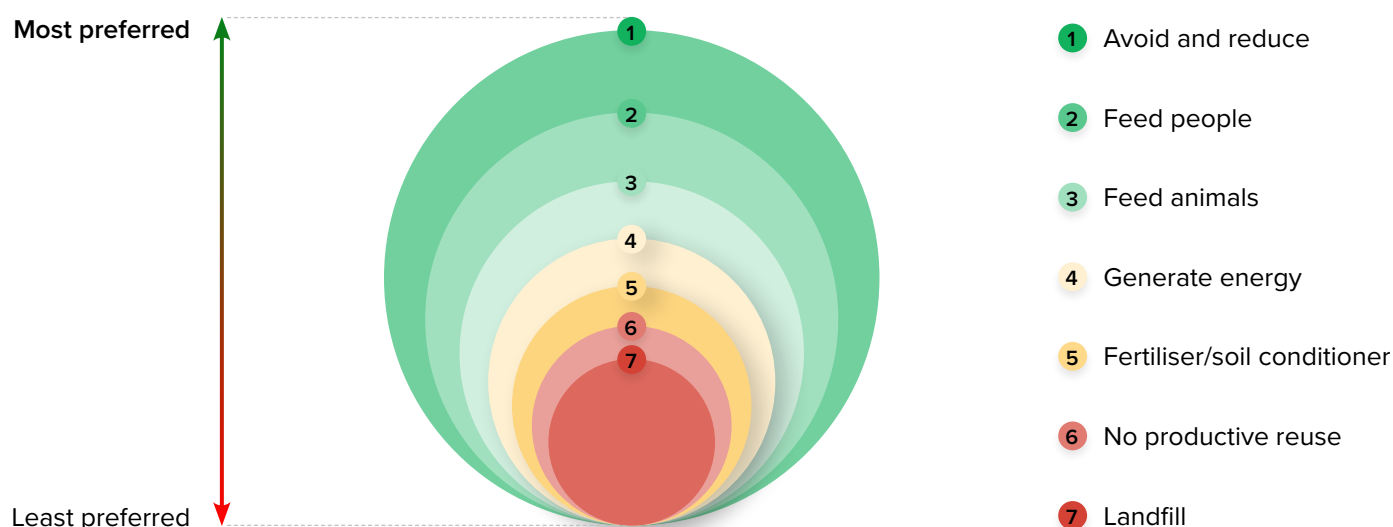
Step 7:

Repeat the audit in future (e.g. in another year) to track how waste and by-product volumes have changed since your baseline/previous audit. This will demonstrate whether new priority streams have emerged (e.g. an increase in volume since the baseline/previous year) and whether a change in management practices is needed or is now feasible for particular streams.



4. Principles of waste and by-product management

Figure 1: Waste and by-product management hierarchy for egg production
Source: Adapted from US EPA (2023)



After conducting a waste and by-product audit for your farm, the next stage in developing your management plan is to understand the general principles of waste management so that you can identify preferred technologies and strategies.

A hierarchy of the most preferred to least preferred waste and by-product management options for the egg industry is provided in **Figure 1**. If you keep in mind the general principles of waste and by-product management (avoid, reduce, reuse, recycle), it should be relatively straightforward to identify appropriate strategies and technologies, resulting in improved (more preferred) waste and by-product management outcomes.

Not every option in **Figure 1** will be available or practically applicable to every waste or by-product produced on your farm, e.g. spent hens cannot be 'avoided' and plastic wrap cannot 'feed people or animals'.

Improvements in production efficiency (e.g. reduced mortality, increased eggs per hen per year, improved FCR) will generally reduce most waste and by-product volumes on-farm. Conducting regular audits will allow you to track this change over time on both a whole of farm (total) and intensity basis (per 1,000 birds housed, etc.).



5. Management and processing options

A list of management and processing technologies for each category of by-product or waste is shown in **Table 1**. More detailed descriptions and assessments are set out for each of these categories in Sections 6 to 13 of this manual.

Suitability for small-medium and large farms are colour-coded: green means the option is available and generally suited to a given farm size, orange means it may be feasible, red means it is not feasible, and blue means it is a 'blue-sky' option, i.e. could potentially become available in the future.

Table 1: Options available (or potentially available) to manage egg farm by-products and waste

Options (Click on links for more information on each)	Suitable for small-medium farms	Suitable for large farms	Capital and operating cost	Labour requirement	Used/treated productively on-farm?
Manure and spent litter					
<u>On-site land application</u>	●	●	Low	Moderate	✓ Yes
<u>Stockpiling (covered)</u>	●	●	Low, Scalable	Low	✓ Yes
<u>Stockpiling (uncovered)</u>	●	●	Low	Low	✓ Yes
<u>Windrow composting</u>	●	●	Low, Scalable	Scalable	✓ Yes
<u>Passive aeration</u>	●	●	Low, Scalable	Scalable	✓ Yes
<u>Forced aeration</u>	●	●	High	Scalable	✓ Yes
<u>Value adding to compost</u>	●	●	Moderate	Scalable	✓ Yes
Advanced options – <u>Anaerobic digestion</u>	●	●	Very high	Variable	✓ Yes
Advanced options – <u>Pelletisation</u>	●	●	Moderate–High	Moderate–High	✓ Yes
Advanced options – <u>Combustion</u>	●	●	Very high	Moderate	✓ Yes

● available ● may be feasible ● not feasible ● available in the future



Options (Click on links for more information on each)	Suitable for small-medium farms	Suitable for large farms	Capital and operating cost	Labour requirement	Used/treated productively on-farm?
<u>Selling off-farm direct from sheds*</u> - dependant on state requirements	●	●	Low	Low	⊗ No
<u>Centralised organic fertiliser production</u>	●	●	Low	Low	⊗ No
<u>Feedstock for insects</u>	●	●	Moderate–High	Moderate	○ Maybe
Spent hens and off-sex chicks					
<u>Meat processing</u>	●	●	Low	Low	⊗ No
<u>Rendering</u>	●	●	Low	Low	⊗ No
<u>Windrow composting</u>	●	●	Low, Scalable	Scalable	✓ Yes
<u>Bays and piles</u>	●	●	Scalable	Scalable	✓ Yes
Advanced options <u>Anaerobic digestion, drying</u>	●	●	Very high	Variable	✓ Yes
<u>Selling off-farm to local markets*</u>	●	●	Low	Low	⊗ No
<u>In-ovo technology</u>	Hatcheries only		High	Unknown	● N/A
<u>Dedicated spent hen processors</u>	●	●	Low	Low	⊗ No
<u>Maceration/grinding</u>	●	●	Unknown	Moderate	✓ Yes (could be composted)
<u>Burial</u>	●	●	Low	Low	⊗ No
<u>Landfill</u>	●	●	Low	Low	⊗ No

* Not suitable due to biosecurity and bird health risks.

● available ● may be feasible ● not feasible ● available in the future



Options (Click on links for more information on each)	Suitable for small-medium farms	Suitable for large farms	Capital and operating cost	Labour requirement	Used/treated productively on-farm?
Day-to-day mortalities					
<u>Windrow composting</u>	●	●	Low	Low	✓ Yes
<u>Small bin composting</u>	●	●	Low	Low	✓ Yes
<u>Bay and pile composting</u>	●	●	Scalable	Scalable	✓ Yes
<u>Rotary drum processing</u>	●	●	Moderate	Scalable/ variable depending on design	✓ Yes
<u>Commercial providers</u>	●	●	Moderate	Low	✗ No
<u>On-farm incineration**</u>	●	●	Moderate–High	Moderate	✗ No
<u>Burial</u>	●	●	Low	Low	✗ No
<u>Landfill</u>	●	●	Low	Low	✗ No
Wastewater					
<u>Hot water heaters</u>	●	●	Moderate–High	Low	✓ Yes
<u>Reverse osmosis</u>	●	●	Moderate–High	Low	✓ Yes
<u>Filtration</u>	●	●	Moderate–High	Low	✓ Yes
<u>Evaporation</u>	●	●	Low	Low	✗ No
<u>Composting</u>	●	●	Scalable	Scalable	✓ Yes
<u>Irrigation</u>	●	●	Low	Low	✓ Yes
<u>Release to sewer</u>	●	●	Low	Low	✗ No

** Depending on jurisdiction, it may be possible to land apply ash, but most beneficial nutrients will have been destroyed.

● available ● may be feasible ● not feasible ● available in the future



Options (Click on links for more information on each)	Suitable for small-medium farms	Suitable for large farms	Capital and operating cost	Labour requirement	Used/treated productively on-farm?
Shells and broken eggs					
<u>Animal feed</u>	●	●	Low	Low	✓ Yes
<u>Separation</u>	●	●	Moderate	Moderate	○ Maybe
<u>Co-composting</u>	●	●	Scalable	Scalable	✓ Yes
<u>Other uses</u>	●	●	Variable	Variable	! Variable
<u>Burial</u>	●	●	Low	Low	✗ No
<u>Landfill</u>	●	●	Low	Low	✗ No
Waste (plastic, cardboard, other solid waste)					
Avoid/reduce	●	●	Variable	Variable	● N/A
Reuse/recycle	●	●	Variable	Variable	✓ Yes
Digestion	●	●	Very high	Moderate	✓ Yes
Composting	●	●	Scalable	Scalable	✓ Yes
Burning	●	●	Low	Low	✗ No
Landfill	●	●	Low	Low	✗ No

● available ● may be feasible ● not feasible ● available in the future



6

Manure and spent litter

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6. Manure and spent litter

To develop a management plan for manure and spent litter, you should work through the following steps to identify which options are feasible for your farm.

Step 1:

Audit manure/spent litter volumes and predict likely volumes for a set (e.g. 12-month) period. Consider whether there is likely to be an increase or decrease in volume in the short- to medium-term (e.g. new sheds, change in housing system). Indicative manure volumes for litter-free (cage) and litter-based systems are provided in **Table 2**.

Table 2: Indicative volumes of manure produced in litter-free and litter-based layer systems

	Litter-free layer systems	Litter-based layer systems*
Fresh manure production per 1,000 birds per year (m ³)	65	45*
Average moisture content	55%	40%
Density (kg/m ³)	450	400

*Value is lower than in litter-free (e.g. cage) systems due to decomposition in the shed.

Step 2:

Review your local and State regulations around manure/spent litter management and reuse. Identify what is permitted and what is not permitted in your area, and whether there are limitations around the use (on and off-site) of end-products.

Step 3:

Research and review the options available for manure/spent litter management and identify those feasible on your farm. Consider, for example, what level of investment is available, whether it is possible to source additional labour, what land area is available to dedicate to manure/spent litter treatment, where that land sits in relation to sensitive receptors, etc.

Step 4:

Prioritise feasible options for your farm based on the Steps 1–3.

From a waste hierarchy perspective, in order of most to least preferable, the options are:

1. Land application (on-farm). The material is used productively on-farm.
2. Covered stockpiling. The end-product can generally be used productively on-farm or sold off-farm.
3. Uncovered stockpiling. The end-product can be used generally productively on-farm or sold off-farm.
4. On-farm composting (windrows, bays and piles or small bins, depending on the scale of production). The end-product can (generally) either be used productively on-farm or sold for productive use elsewhere in the economy.
5. Passive aeration. A variation on stockpiling which may be of benefit in limited circumstances. The end-product can generally be used productively on-farm or sold off-farm.
6. Forced aeration. An engineered variation on stockpiling, which may be of benefit in limited circumstances but is a high-cost technology. The end-product can generally be used productively on-farm or sold off-farm.
7. Value adding to compost. When conducted in conjunction with other stockpiling or composting techniques, the end-product may be higher value. It can generally be used productively on-farm or sold off-farm.
8. Selling off-farm direct from sheds. The material is not used productively on-farm but will generally be used productively elsewhere in the economy.



It can be challenging to reduce manure and spent litter volumes as manure is directly tied to feed consumption (though any improvement in the latter should reduce excretion) and litter/bedding is often tied to third party accreditations, e.g. RSPCA. In addition, it may be counter-productive to other business goals to reduce manure/spent litter volumes given the potential benefits from using the material on-farm or processing/managing it to generate a revenue stream.



The list of options in this section is not exhaustive. Depending on scale of production, it may be possible to use manure/spent litter to generate energy (see **Appendix 4 – Anaerobic digestion, Combustion**), in processes to capitalise on the nutrient value of the material (see **Appendix 4 – Pelletisation; Appendix 6 – Centralised organic fertiliser production, Rapid composting**), or potentially as a feedstock for insects (see **Appendix 6 – Feedstock for insects**).

Regardless of the strategy chosen, producers should also adhere to the following principles to ensure that they operate a well-managed manure removal and shed clean out program.

- Clean out sheds during daylight hours to minimise noise impacts.
 - This may also reduce dust and odour impacts due to the increased dispersion potential of atmospheric conditions during daylight hours.
- Clean up any manure or spent litter spilt outside the shed.
- Open the side shutters/curtains of sheds during manure or spent litter removal to prevent the build-up of gases in the shed that may threaten the health and safety of workers. Do so gradually to avoid a large release of odour/dust that may cause off-site impacts.
- Consider wind direction and strength during shed clean out. If possible, clean out should occur when the wind is blowing away from sensitive receptors.
- Consider contacting neighbours if the clean out may affect them so that they are aware that odour impacts may occur over a short period of time before returning to normal operating conditions.
- Consider neighbour movements when cleaning out manure and spent litter. Try to avoid clean out at times that have the greatest impact on neighbour amenity (weekends, holiday periods).
- Ensure that staff are wearing the correct personal protective equipment (PPE), are trained for all machinery use, and do not compromise hen welfare (e.g. stop hens from getting onto manure belts).





6.1. Land application

Land application to crops and pasture is the most widely adopted and cost-effective way of utilising the nutrients in manure and spent litter from egg production. If performed correctly, it reduces the need for synthetic fertilisers, potentially lowering the cost of crop production. Another advantage of applying these by-products is that some nutrients are contained in a slow-release form, ensuring nutrient supply over a longer timeframe. Application of organic matter contained in manure/spent litter also improves soil structure, reduces soil erosion, and aids the infiltration and retention of water and nutrients.

Key considerations when developing a manure management strategy that involves land application include climate, topography, groundcover, and ensuring that application rates are sustainable. Information on methods for calculating sustainable application can be found in [Appendix 3 – Nutrient budgeting](#).

To safely land apply manure or spent litter, follow these steps:

1. **Identify an appropriate site for land application outside the egg production zone.**
 - a. It should not be near to watercourses or drainage lines, or have a steep slope (> 10%) where erosion losses may occur.
 - b. The planting of appropriate buffer strips (grass and trees) can be useful in intercepting nutrients, dust, and other particles.
 - c. Riparian zones around watercourses should be protected with appropriate buffer zones and vegetative filter strips (refer to Appendix 1 of the Egg Industry Environmental Guidelines (McGahan et al. 2018)).
 - d. The land should not be rocky or highly erodible.
 - e. The soil should not be highly impermeable.
 - f. The area should not be prone to waterlogging, flooding, or have a high groundwater table.
2. **Ensure that an appropriate crop is being grown or preferably that the land is in a fallow period.**
 - a. Horticultural crops require specific controls regarding the application of organic soil amendments that can be found in the Freshcare standards (Freshcare 2020).
 - b. Manure and spent litter should not be applied to the foliage of crops that are to be consumed by humans.
 - c. Maximise the time between application and crop harvest.
3. **Determine suitable application rates.**
 - a. Refer to [Appendix 3 – Nutrient budgeting](#) (general information) for how to match application rates to crop uptake.
4. **Identify a suitable time to land apply.**
 - a. Consider the wind speed and direction (to minimise dust and odour nuisance with nearby receptors).
 - b. Only apply manure and spent litter when the soil is not saturated, and when heavy rain is not expected.
 - c. Avoid spreading material that is too dry (< 15% moisture wet basis) to avoid dust problems (i.e. wet down the material if required). Generally, manure with a moisture content of 25–30% will spread best.
 - d. Consult with neighbours about the best time to apply, which may reduce nuisance and help avoid complaints.
 - e. Consider the timing of other management events (e.g. cultivation and sowing).
 - f. Application 2–6 weeks before sowing (or peak pasture demand) is recommended to allow time for nutrients to mineralise – if the material has been composted first, timing is less critical.
5. **Cover manure and spent litter during transport to the application site to minimise spillage and odour emissions.**
6. **Apply the manure/spent litter using the previously determined suitable application rate.**
 - a. Calibrate the spreader to ensure application at the correct rate evenly across the paddock.
 - b. Check that the spreader is running efficiently, i.e. that the application rate and spreading pattern is acceptable:
 - i. Lay a strip of builder's plastic or tarpaulin (ideally 10 m x 10 m) in the path of the spreader.
 - ii. Run the spreader over the centre of the sheet at the correct operating speed.
 - iii. Collect and weigh manure from 1 x 1 m squares at several points across the sheet.
 - iv. Multiply the mass of manure weighed (kg/m²) by 10,000 to convert to kg/ha. Then divide this figure by 1,000 to get tonnes per hectare.
 - c. Set up the spreader to run on controlled traffic lines (to reduce soil compaction) as much as the machine allows this.
 - d. Depending on groundcover, proximity to waterways, and slope, leave a 10–30 m buffer at the edge of paddocks free of manure or spent litter. See Best practice guidelines for using poultry litter on pastures (Griffiths 2011) for further detail.



- e. Spreading manure on a three- to five-year rotation, and supplementing with inorganic fertiliser as required, also reduces compaction risk and saves money by reducing the application frequency.
 - f. Applying gypsum alongside manure/spent litter may inhibit some ammonia volatilisation (resulting in more nitrogen being retained).
7. **Incorporate manure and spent litter as soon as possible.**
- a. This will minimise the chance of contamination from wind drift or rainfall runoff, will also maximise the value of the material by reducing potential losses, and will reduce odour releases.
 - b. In minimum till operations, stubble should be retained and manure or spent litter should be applied to recently harvested cropland.
 - c. For application to pasture, manure or spent litter should be applied to recently harvested or grazed areas (once livestock have been moved) with 5–10 cm of stubble remaining.
8. **Allow at least three weeks between application and the introduction of grazing animals to the area.**
- a. Relevant State biosecurity guidance may specify longer times, including for the introduction of poultry (e.g. for systems with mobile sheds).
9. **Maintain a record of where and when manure and spent litter were land applied on-farm and the quantities involved.**

Specific regulatory requirements for land application of manure and spent litter may vary. Ensure that you comply with any approval or licensing conditions.

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

6.2. Covered and uncovered stockpiling

Stockpiling involves storing manure and by-products in static piles for later use on-farm or sale off-farm. These piles can be covered or uncovered.

Creating a storage area for manure/spent litter improves management flexibility and allows supply to be matched to demand. Shed cleaning operations are generally timed to fit in around other farm operations. This can lead to large volumes of manure/spent litter on hand when demand for on-farm reuse is low. Having a properly designed, constructed, and operated storage area/facility improves handling as material can be safely stored for an extended period and removed in an orderly fashion.



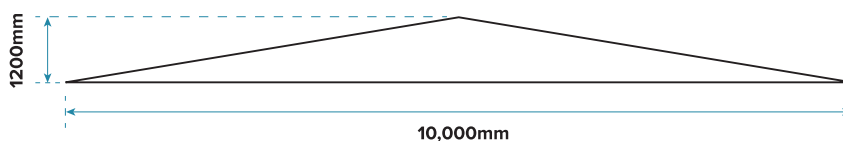
Different types of storage areas suit different production systems and locations. If the facility is in a rural area, uncovered stockpiling may be an option. However, if the farm is in a more densely populated area, a covered stockpile is likely to be more appropriate, to reduce potential odour impacts and retain more nitrogen.

If you are planning on stockpiling spent litter or manure, the following steps provide a general guide on how this might be done.

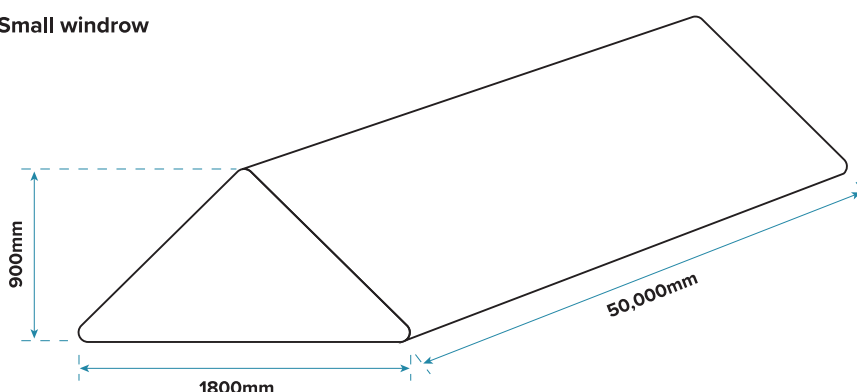
1. **Identify an appropriate site.**
 - a. Based on the audit of waste and by-products produced on your farm, determine the size of the area required. This is a major determinant of construction costs.
 - i. This will also help inform the type of machinery that will be used to construct the pile (loader size) and truck sizes needed for delivering and removing the product.
 - ii. You will need to consider how long you will need to store manure before it can be removed (the storage period). For example, if it needs to be stored for six months to align with cropping cycles, the storage area must be large enough to hold six months' worth of manure/spent litter.
 - iii. As a rough guide, a small windrow with a 45° side slope, 1.8 m wide, 0.9 m in height, and 50 m long would contain approximately 40 m³ of manure. An equivalent volume pyramid-shaped stockpile would be about 10 m wide at the base and 1.2 m high (see **Figure 2**). This is about two-thirds of that produced by 1,000 layers in a cage system over a 12-month period (see **Table 2**).
 - b. Choose a site which will also minimise dust, noise, and off-site impacts (odour), e.g. one with appropriate separation distances and (or potential for) vegetative buffers.
 - c. Locate the site at a sufficient distance from production facilities to minimise the risk of pathogen spread.
 - d. If your sheds are in different locations, try to minimise transport distances, or consider establishing more than one storage location.

Figure 2: Example stockpile construction

Pyramid



Small windrow



2. **Build the facility.** A general list of requirements/ specifications include:
 - a. An impermeable surface (e.g. concrete, cement stabilised earth, or compacted clay pad). This will ensure that the pad is trafficable in all weather conditions and prevent leaching to groundwater.
 - i. The base should be designed to achieve a design permeability of 1×10^{-9} m/s over a depth of 300 mm.
 - ii. A sealed concrete base is most preferred to minimise leaching.
 - iii. Depending on available equipment and expertise, producers may be able to do this themselves, or a contractor could be engaged (e.g. particularly for lime or cement stabilisation).
 - b. Where there is only a small amount of runoff from the storage area, a vegetative filter strip may be adequate.
 - c. Where there is potential for a large amount of runoff from the storage area (i.e. high rainfall areas), consider a roof structure to eliminate runoff. If water needs to be captured, use a detention basin and vegetative filter area to avoid stagnant water being stored hence reduce biosecurity risks.
 - d. At locations where surface water risks are present (see Section 2.6.3 and Appendix B of the *Egg Industry Environmental Guidelines* (McGahan & Wiedemann 2018)), use bunding (i.e. earthen banks and/or hay swales) to divert overland flows, and prevent entry and contamination from stormwater.
 - e. A heavy storm may carry sediment from the stockpile and/or pad to the holding pond/dam. A simple sediment trap can collect the solids before they enter any detention dam, reducing the solids and nutrient loading.
3. **Form stockpiles.**
 - a. Put down a 300 mm layer of bulking dry, carbonaceous material (dry, carbonaceous material such as sawdust, straw, or other carbon source) as the base of the pile.
 - b. Piles should be peaked (triangle-shaped) so they can shed rainwater and should be no higher than 3 m.
 - c. For uncovered stockpiling, ensure that there is 300 mm of bulking material over the top of the manure/spent litter once it has been set up.
 - d. For covered stockpiling, cover the stockpiles with an impermeable material (e.g. tarpaulin, silage cover) once it has been set up.
 - e. Note that ventilation may be required to manage odour production. If odour is identified as a problem, check that the pile is covered properly and, if the issue is not resolved, land apply as soon as possible. Subsequent stockpiles may require bulking material (e.g. 300 mm) to cover the stockpile before covering with an impermeable material.



4. **Actively manage any risks** (e.g. water pooling) arising at the storage facility until it is time for the material to be used.
 - a. The composition of the material will depend on how long it has been stockpiled. Generally, the amount of carbon and nitrogen will decline the longer it is stored, while other nutrients (such as phosphorous) are concentrated in relative terms due to the loss of carbon and nitrogen. Seepage and leachate contain high nutrient concentrations, dissolved organic carbon and pathogen concentrations, which are an environmental hazard, particularly for surface and ground water bodies.
 - b. Stored heaps may need to be sprayed to control fly breeding. Local regulations need to be checked regarding storage, land application, and transport of poultry manure and spent litter.
5. **Sanitise/quarantine equipment** used in moving manure/spent litter prior to use in production areas or use separate machinery.

Specific requirements for stockpiling may vary between jurisdictions. Local and State regulators should be contacted in advance to ensure that all requirements are met.

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

An example of nitrogen budgets with covered and uncovered stockpiling is provided in **Table 3** for spent litter generated in a 100,000 bird cage-free farm. The partial cost-benefit analysis is for covered stockpiles versus the business-as-usual approach of uncovered stockpiles (**Table 4**). In this scenario, the end-product is land applied on-farm, and the 'revenues' are the avoided costs from reduced synthetic fertiliser use.





Table 3: Nitrogen budget and expenditure in covered and uncovered stockpiles for a 100,000 bird farm

	A – Covered stockpiling	B – Uncovered stockpiling	Notes
Costs			
Capital*	\$15,130	\$0	Covers for stockpiles.
Production			
Total spent litter harvested at clean out (kg/yr)	1,622,900	1,622,900	At 20.8% moisture, from <u>Composition and Value of Layer Manure.</u>
Nitrogen in spent litter (kg DM/yr) at clean out	34,704	34,704	Based on 2.7% nitrogen (per kg DM) from <u>Composition and Value of Layer Manure.</u>
Nitrogen lost during stockpiling as ammonia (kg)	1,041	6,941	A: Based on 3% loss rate reported by Naylor et al. (2016). B: Based on 20% loss rate from the National Inventory Report (Commonwealth of Australia 2023).
Nitrogen lost during stockpiling as nitrous oxide (kg/yr)	0	1,735	A: Based on negligible loss rate by Naylor et al. (2016). B: Based on 5% loss rate from the National Inventory Report (Commonwealth of Australia, 2023).
Nitrogen remaining in final product (kg/yr)	33,663	26,028	
Benefits			
Annual theoretical maximum value of remaining nitrogen	\$43,908	\$33,950	Based on value of nitrogen of \$1.30/kg, derived from assumed selling price of urea (\$600/t) at 46% nitrogen.

*Site construction costs not included.

Table 4: Partial benefit cost analysis for covered stockpiles (relative to uncovered stockpiles), based on the value of retained nitrogen for a 10-year project life and a discount rate of 4%

	Total benefits (present value)	Total costs (present value)	Net present value of investment	Internal rate of return
100,000 bird farm	\$80,772.89	\$75,285.81	\$5,487.08	14%



6.3. Composting manure and spent litter (general information)

Definition and process

Composting is generally considered a controlled, aerobic, and heat generating process that degrades organic material and turns it into a relatively stable organic material similar to soil (Hussain et al. 2022). The final material does not look or feel like the raw ingredients and will have an earthy smell if fully mature and stable.

Although it is relatively straightforward to perform when some key parameters are followed and monitored, composting is a complex biochemical process that involves many different microorganisms, fungi, bacteria, and a range of chemical reactions. The composting process can be broken down into four basic phases:

1. Initial phase – once organic material is mixed and piled up under the right conditions (carbon content, nitrogen content, moisture, oxygen levels) it will begin to heat up naturally due to the activity of microorganisms (mesophilic) that decompose organic compounds and rapidly reproduce between about 20 and 45°C. This phase generally takes a day or two, depending on conditions.
2. Sanitation and main composting phase – once the material reaches about 45°C, the mesophilic microorganisms die off and are replaced by thermophilic microorganisms that are most active and effective between 45 and 70°C. It is in this phase that potentially harmful microorganisms (e.g. *Salmonella*) and seeds are destroyed by the high temperatures.
These first two phases can be described as the active stage and can generally take between one to three months.
3. Curing phase – at this stage the temperature of the composted material slowly declines, allowing mesophilic microorganisms to return to the composting material as temperatures decline to 40–45°C. **This curing stage can take one or more month, depending on material characteristics (moisture, residual N and labile C) and the composting conditions (size of pile).**
4. Maturation phase – at this stage the temperature of the composted material will stabilise at roughly ambient. During this stage oxygen requirements decline, and the material continues to decompose slowly, resulting in a stable and mature or finished compost. **This maturing stage generally takes one to three months; however, it can take much longer if the entire process occurs under conditions that are not optimum.**



The *Australian Standard – Composts, soil conditioners and mulches* (AS4454-2012) (Standards Australia, 2012) provides chemical, physical and biological product quality requirements for various types of organic soil amendment products. For a product

to be sold as “AS4454 compliant compost/ compost manufactured to AS4454 standards” the requirements of the Australian Standard must be met, although compliance and use of the Standard is voluntary. There is no legal requirement for compost to comply with AS4454 requirements, or any other standard or quality specification, however, compost products, as any other organic soil amendment, need to be fit for purpose and meet the requirements of end-users who may specify certain requirements to be met (e.g. that the material is pasteurised). In addition, the AS4454 document provides guidance on managing and monitoring the composting process to help meet AS4454 requirements.

When selling a material as compost, it should be subject to the phases described above. This does not preclude selling materials that have only partially been through the process (e.g. selling the material as a pasteurised and partially stabilised material).

Each farm and each combination of raw material for composting will likely be different and each situation, and will need to be designed and managed to meet a range of requirements, including, but not limited to the needs of the farm, and end-user specifications if sold off-farm. Key material and process characteristics for composting are moisture, temperature, oxygen, and the carbon to nitrogen ratio. Some general information on how to manage for these factors is outlined in the following subsections.

**C:N ratio**

Poultry manure will compost under a wide range of C:N ratios from 10:1 up to 60:1 or more.

However, when feedstock with low C:N ratios (< 20:1) is composted, or if the carbon is not easily available for microbial degradation, there is surplus nitrogen (not enough carbon) for building microbial biomass, which can result in nitrogen losses via ammonia volatilisation. Composting feedstock with low C:N ratio, such as raw layer manure, results in marked nitrogen losses, reduced nutrient value of the final product, and higher odour and greenhouse gas emissions. Conversely if the C:N ratio is too high (> 40:1), the composting process will take longer, because microbial activity will be limited by the lack of nitrogen. C:N ratios of between 20:1 and 40:1 are best for composting feedstock at the beginning of the process, with 25:1 being considered ideal.

Layer manure, egg waste, and carcasses usually have a very low C:N ratio (< 10:1) and high moisture content. The addition of a dry carbon source (e.g. sawdust, straw, or cardboard) at a ratio of about 1 part manure/by-product to 2–3 parts carbonaceous material (by volume) will increase the C:N ratio to more desirable levels and dry the composting mix.

It is important to consider the form of carbon added with the bulking material, as some are more readily degraded than others. Carbon in straw, made up mainly of cellulose and hemi-cellulose, will degrade relatively quickly during composting, while lignin fibres found in wood (sawdust) will take considerably longer to compost. If co-composting cardboard, shred it before adding to the pile so that it has a greater surface area and will break down faster. Particle size distribution and structural stability could also be important characteristics when selecting bulking materials, particularly if the bulk density of egg production residues is high.

**Oxygen supply**

The composting process occurs primarily due to the activity of living aerobic microorganisms that require oxygen to facilitate the breakdown

of organic matter and transformation into humus-like substances, without producing much odour. If this process occurs without adequate oxygen supply, i.e. in anaerobic conditions, significant odour emissions are likely. Oxygen supply in a windrow or pile is influenced by its size and shape, the frequency of turning, the pore space in the material (porosity), and the moisture content.

Windrows and static piles are passively aerated as convection forces, driven by temperature differentials, expel hot air at the top of the row or pile, and draw cool ambient air in at the base, provided there is adequate pore space to allow for air movement within the composted material. Turning results in only a temporary (15–30 minutes) increase of oxygen levels inside compost windrows or piles. The main advantage is in the increased porosity, which aids the passive aeration process.

**Moisture level**

Water is key to the composting process. If the moisture level drops too low (30–35% on a dry basis), the microbial activity that drives the composting process will slow or stop altogether. But if moisture levels are too high and the material is too dense (low porosity), there may not be enough oxygen for the aerobic microorganisms to survive. Anaerobic microorganisms proliferate in these conditions, resulting in methane and odour generation.

Generally, the preferred moisture content for a compost mix is 50–60%, although composting will still occur between 40 and 65% moisture. The preferred moisture content of the material to be composted will largely depend on its porosity. It should be moist to touch but not drip when gently squeezed. Depending on the materials used initially, water may need to be added when establishing the feedstock mix. If spent hens or mortalities are being composted, only a small amount of water may be required to wet down the feathers as carcasses generally have enough moisture. If windrows are too wet, they may cool down (slowing the rate of composting) and produce odour. Turning or adding more dry bulking material can help alleviate the problem.

Moisture content in composted material will decline relatively quickly, which is why moisture levels need to be monitored and maintained within the preferred range. Maintaining adequate moisture levels in composted material is one of the major challenges in hot and dry environments. The ideal time to add additional water is when the material is being turned.

**Temperature**

Energy is released as microorganisms breakdown the organic matter. The insulating effect of large windrows or piles (> 1 m³) results in heat energy being trapped inside the composted material. Temperatures inside composted material are indicators for progression of the composting process, and possible problems.

After initial mixing, the temperature in the centre of the windrow will start to rise within a few hours. Provided the windrows are large enough to maintain the heat, temperatures of 55–65°C will be reached within a few days. Ideally, these temperatures should be maintained for a prolonged period (generally several weeks) before they gradually decline to ambient temperature, at which point the active phase of the composting process is complete.

Provided there is enough nitrogen, carbon, moisture and oxygen in the composting material, temperature should be largely self-regulating. The microbial activity will be fastest when the temperature is maintained between 45 and 55°C. If the temperature does not increase to above 55 or 60°C during the initial phase, the feedstock might contain excessive or insufficient water, oxygen or nitrogen, or the windrow/pile might be too small. The composting



process will be complete when temperatures within the pile do not rise after being watered and turned. Temperatures above 55°C are necessary to inactivate pathogens and weed seeds. Windrows must be turned to ensure that all material is exposed to the high temperatures above 55°C at the centre of the pile. Temperature monitoring is most accurately undertaken with a temperature probe that is able to reach the centre of the windrow/pile (at least 1 m long).

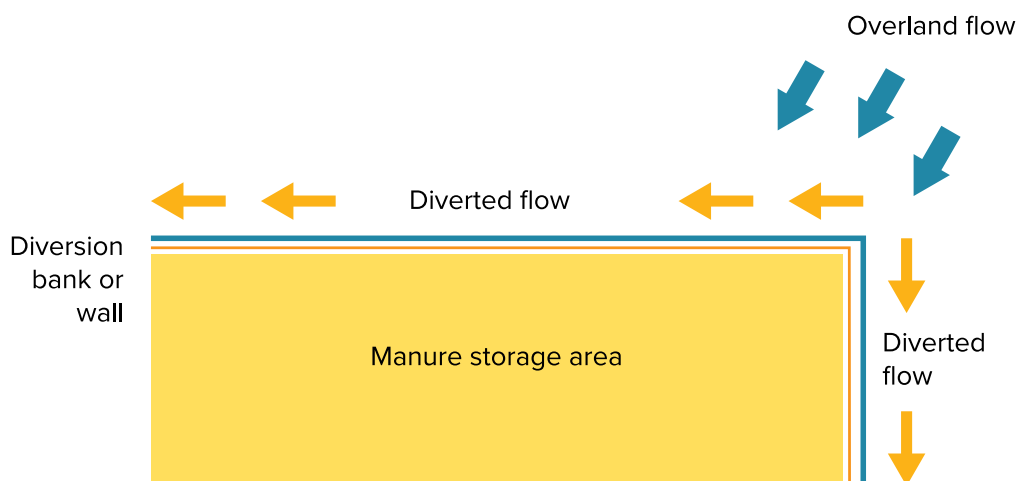
6.4. Conventional (windrow) composting

Composting is a process whereby organic matter (such as manure or spent litter) is microbiologically transformed and pasteurised in a controlled aerobic environment (see **Definition and process** in Section 6.3). It is important to familiarise yourself with **Section 6.3 – Composting manure and spent litter (general information)** to understand the various processes that occur during composting before embarking on windrow composting of organic by-products produced from layers.

To establish a composting facility and start composting manure or spent litter in windrows, an example of the process that could be followed is to:

1. Identify an appropriate site and plan the site layout.
 - a. Based on the audit of waste and by-product volumes produced on your farm, determine the size of the area required to process the predicted volume of manure/spent litter, and other materials (e.g. daily mortalities) that you wish to co-compost.
 - i. *To calculate an area, you will need to determine the volume of manure/spent litter and bulking material, and the height, width, and number of windrows.*
 - ii. *As a rough guide, a small windrow with a 45° side slope, 1.8 m wide, 0.9 m in height, and 50 m long would contain approximately 40 m³ of manure. An equivalent volume pyramid shaped stockpile would be about 10 m wide at the base and 1.2 m high. This is about two-thirds of that produced by 1,000 layers in a cage system over a 12-month period (see **Table 2**).*
 - iii. *Allow additional area for machinery to pass between windrows. Note that front-end loaders require more space to operate than straddle turners.*
 - b. It will need to minimise dust, noise, and off-site impacts (odour), e.g. choose a site with appropriate separation distances and (or potential for) vegetative buffers.
 - c. It must be located at a sufficient distance from production facilities to minimise the risk of pathogen spread.
 - d. Check if you need a permit to build and operate a composting facility at your preferred location. This might depend on whether or not you are planning to use bulking material from external sources.
2. Build the facility and obtain required equipment. A general list of requirements/specifications include:
 - a. An impermeable surface or compacted clay pad. This will ensure that the pad is trafficable in all weather conditions and prevents leaching to groundwater.
 - i. *The base should be designed to achieve a design permeability of 1x10⁻⁹ m/s over a depth of 300 mm.*
 - ii. *A sealed concrete base is most preferred to minimise leaching.*
 - iii. *Depending on available equipment and expertise, producers may be able to do this themselves, or a contractor could be engaged (e.g. particularly for lime or cement stabilisation).*
 - b. The site needs to be well drained to avoid excessive moisture and muddy conditions.
 - c. Where there is potential for a large amount of runoff from the composting pad area (i.e. high rainfall), consider a roof structure to eliminate rain falling on compost. If contaminated water needs to be captured, use a detention basin and vegetative filter area to avoid stagnant water being stored hence reduce biosecurity risks.
 - d. Where surface water risks are present (see Section 2.6.3 and Appendix B of the Egg Industry Environmental Guidelines (McGahan et al. 2018)), water should be excluded from the area through bunding or diversion banks/swales (see **Figure 3**).
 - e. Obtain quotes for appropriately sized new/used composting equipment, and purchase/hire preferred machine.
 - i. *Front-end loaders are often the first choice for windrow or pile turning in smaller composting operations, as they may already be available on-farm and can be used for other purposes (ensure Step 6 below is followed). They are, however, slow to operate and care should be taken to ensure that the compost is adequately mixed.*
 - ii. *A variety of windrow compost turners are available, including three-point linkage units, PTO driven trail behind units, self-powered units (driven off a separate engine but attached to a tractor), and self-propelled units.*
 1. The scale of the composting operation is usually the best determiner of the required size of the compost turner. For example, three-point linkage units are available for small- to medium-scale composting, while trailing or self-propelled units are more suited to large-scale operations.
 2. Tractor-drawn models can generally turn a windrow less than 3 m high, whilst some self-propelled models can turn windrows up to 4 m high by 4 m wide.

Figure 3: Diversion banks



3. Turning rates will vary with the size and type of turner. Three-point linkage turners are limited to a turning rate of 200–400 m³/hr, tractor drawn turners may have a rate of 400–800 m³/hr, and self-propelled turners can turn at rates of 1,200–6,500 m³/hr.
- f. Devise a system of adding water to windrows, and establish required infrastructure/ obtain required equipment.
 - i. *Some turners can apply water to windrows using a trailing hose system. Alternatively, some windrow turners can tow a tanker that will supply water during turning, or the tanker could be used independently to apply water immediately prior to turning. The latter option may be more appropriate for small- to medium-operations without water infrastructure.*
- g. Check if you own a tractor with creeper gears (to travel at low speed). If not, you need to obtain an appropriately sized tractor with creeper gears. Alternatively, hydraulic assist features are available for turners to negate the need for a creeper gear.
- h. Check if you have adequate material handling equipment (e.g. loader), and if not, you need to obtain the appropriate equipment.
- i. Obtain suitable bulking material.
- j. If you are aiming to sell compost, you might require a screen.
3. Begin the composting process.
 - a. Put down a 300 mm layer of bulking material (sawdust, straw, or other carbon source) as the base of the windrow.
 - b. Place the manure/spent litter on top of the base layer. This can be done by tipping the manure directly from trucks, or by placing it with a loader after transfer from a storage area.
- c. If additional bulking material is required, place it evenly on top of the windrow prior to the first turn.
- d. The appropriate size of windrows depends on the equipment that is used for turning. Windrows managed with a tractor-driven turner are generally 1.0–1.5 m high and 3–4 m wide at the base. Windrows that are turned with self-propelled turners or a loader are usually considerably larger.
- e. Windrows should be peaked (triangle-shaped) so they shed rainwater (to a certain extent).
 - i. *Any runoff from the composting pad must be captured in a detention pond. The collected water can be reused in the composting operation or applied to land.*
- f. Add water to the composted material as needed (see **Moisture level** in Section 6.3).
- g. Add additional bulking material as needed (see **Moisture level** in Section 6.3). However, it is preferable to get the feedstock mixing ratios right when setting up the windrow.
4. It is important to manage the physical and chemical characteristics of the composted material to maintain temperature, moisture, pH, and nutrient ratios within the appropriate ranges, and ensure that the generated product is pasteurised, and its characteristics are within a range of expected values.
5. The composting process needs to be managed and monitored in order to generate products that meet certain product characteristics for both on-farm and off-farm use:
 - a. Monitor the temperature and moisture level and turn regularly from about Week 2 to Week 10. Add water as required.
 - b. After about 10 weeks into the process, record the temperature before and after turning (next day). If turning does not result in increased temperatures, provided the moisture content is adequate, the

material is approaching maturation stage. Allow to mature for around 4 weeks, i.e. the process will be complete after about 14 weeks – see **Figure 4**.

- i. *If it does heat, test again, 1–2 weeks later, then allow 4 weeks to cure, i.e. the process will be complete in about 16 weeks – see **Figure 4**.*
- ii. *Repeat this process until the windrow no longer heats above 30–35°C.*
- c. Ensure that material does not dry out and is adequately dampened during the turning process to reduce risk of aerosolised pathogens. As dry organic materials are hydrophobic, it is difficult to re-wet composted material that has dried out. Exercise caution as excessive application of water can cause nutrient runoff or anaerobic conditions, increasing odour potential.
- d. Time turning to avoid strong winds blowing toward the production area or sensitive receptors.
- e. The end-product should no longer resemble the original materials, i.e. it should be a brown/black, earthy material, and any leftover coarse woody material should be easily broken down if rubbed between your fingers. The material should not smell like vinegar or rotting matter but should smell like soil, although composted layer manure tends to retain the smell of ammonia for a long time. If the material smells bad, it should be turned and left to cure further before being tested again.
- f. Move the finished compost from the composting pad to the storage area, or load onto trucks for immediate land application.
- g. If the compost is used off-farm, particularly in horticultural production systems, it might be necessary to screen the compost to allow delivery of product with defined particle size (e.g. < 10 mm) and to ensure that the compost does not contain undesirable impurities (e.g. rocks, plastic).
6. Sanitise/quarantine equipment used in moving manure/spent litter or managing compost prior to use in production areas.

Examples of the inputs, outputs, costs, and revenues associated with windrow composting are provided in **Table 5**. Example A is for a 1,000,000 bird cage farm, and Example B is for a 100,000 bird cage farm. For both scales of production, windrow composting should be a viable and profitable operation (see **Table 6**).

Figure 4: Indicative composting time scale

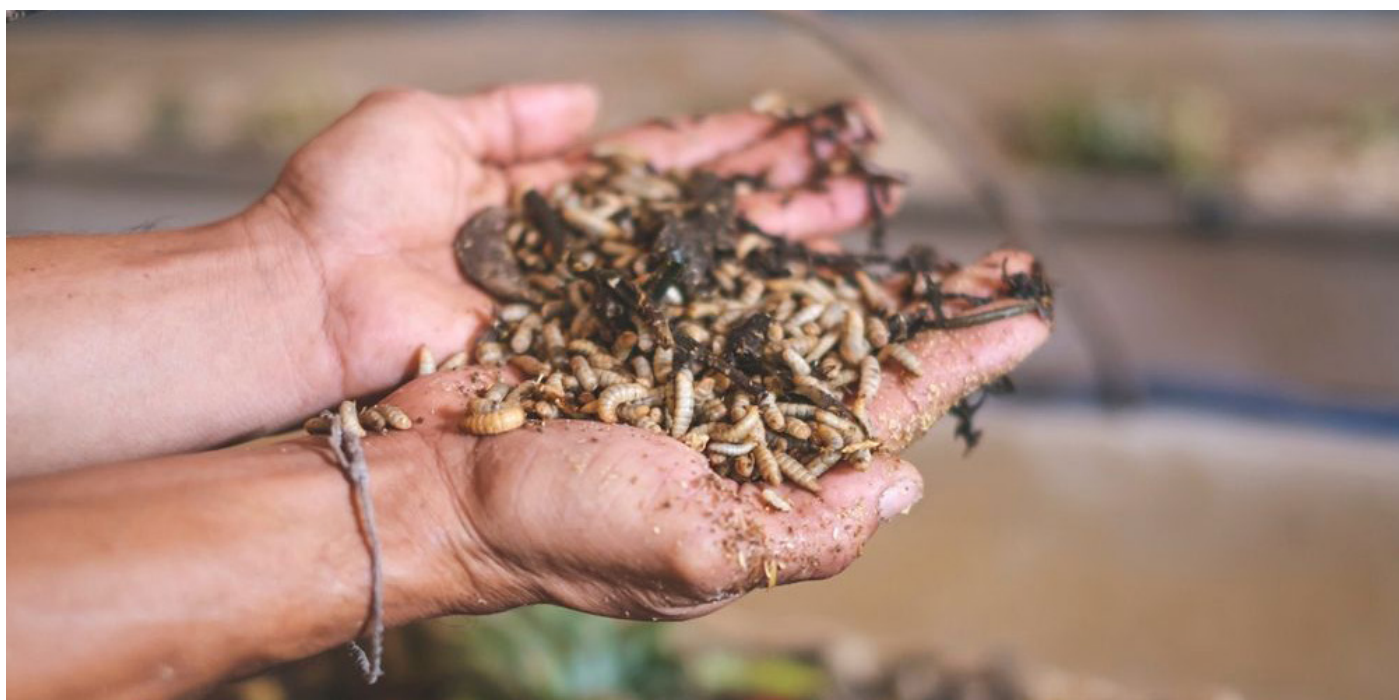
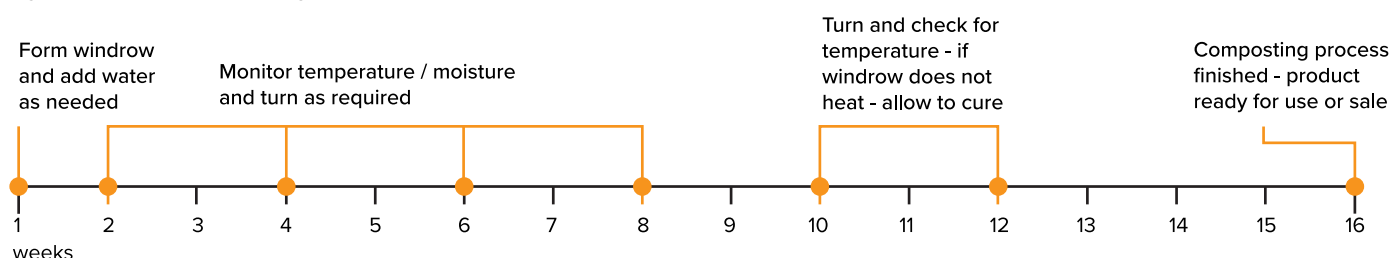




Table 5: Example of windrow composting requirements, annual costs, and benefits for 1,000,000 and 100,000 bird farms

	A – 1,000,000 bird farm	B – 100,000 bird farm	Notes
Costs			
Capital*			
Straddle turner	\$120,000	-	Assume that B uses loader to turn compost.
Hose and reel for watering	\$25,200	\$25,200	
Water wagon and tank	\$44,00	\$44,000	
Front-end loader	\$75,000	\$75,000	
Operating			
Labour (per year)	\$80,000	\$20,000	Assume 1 FTE for 1 million bird farm, 0.25 FTE for 100,000.
Fuel (per year)	\$77,313	\$7,731	
Bulking material (per year)	\$316,667	\$31,667	Where wheat straw is bulking agent.
Production			
Total manure available for composting (t/yr)	12,190	1,219	
Total compost produced (t/yr)	13,981	1,398	Incl. added mass from bulking material. Based on 40% reduction in feedstock weight as a result of composting process.
Benefits			
Revenue from compost sales (per year)	\$1,013,598	\$101,360	Based on selling price of \$72.50/t. Note that, in some cases, compost may need to be screened prior to sale. This analysis does not include the associated costs.

*Note that facility costs (e.g. impermeable base) are not included here.

Table 6: Partial benefit cost analysis for windrow composting, based on a 10-year project life and a discount rate of 4%

	Total benefits (present value)	Total costs (pres- ent value)	Net present value of investment	Internal rate of return
1,000,000 bird farm (A)	\$8,221,190	\$4,097,582	\$4,123,608	213%
100,000 bird farm (B)	\$822,119	\$625,971	\$196,148	26%

6.5. Passive aeration

Passive aeration is a variation on the traditional method of stockpiling, intended to increase oxygen supply to the base and centre of the pile without turning. This is typically achieved by laying perforated plastic pipes at the base of the pile at regular intervals prior to stacking manure on top of the pipes (to a height of 1.5 m to 2.5 m). Beyond this, the **Covered and uncovered stockpiling** method (Section 6.2) should be followed.

Note that passively aerated static piles do not have significant advantages over stockpiling without aeration or conventional windrow composting. In fact, due to high

moisture content, high bulk density, and low porosity of most layer manure/litter, this technology is unlikely to be suitable for these materials unless large quantities of coarse bulking material are blended with it prior to setting up the pile. The only benefit is that in some cases odour may be reduced, however, properly covered stockpiles should not generate significant odour.

6.6. Forced aeration

Forced aeration systems have a similar objective to passive aeration but achieve aeration of the static pile through an engineered system, which forces air through aeration pipes (see **Figure 5**).

Figure 5: Forced aeration of a static pile

Source: Washington State University via AgriFutures Chicken Meat Program (2023)



Forced aeration systems typically require moderate–high capital investment and maintenance, meaning the technology may only be suited to very large operations. The market offers cheaper systems with smaller blowers, which may be more suited to smaller farms, or it might be possible that farmers build their own forced aeration composting system. There are, however, only a handful of static pile forced aeration systems operating in Australia, none of which processes animal manures. The technology does not achieve a better product than other systems. The advantage of the system is that it may accelerate the composting process (although curing will still be required).

Egg producers interested in installing a forced aeration system should engage with equipment suppliers and a consultant to conduct a prefeasibility analysis as to whether this technology is suitable for processing organic farm residues from a technological, biosecurity, and financial point of view, i.e. whether there is sufficient benefit to justify the investment. Additional consideration should also be given to the potential challenges associated with operating these systems (e.g. the material drying out and how to add water, non-pasteurisation of the outer layer, removal of pipes prior to removal of material) against any potential benefits over windrow composting (e.g. faster process).

6.7. Value adding to compost

Adding minerals and other nutrient dense materials to compost may improve the nutrient content and balance of the end-product, and hence its value. Amongst the most well-known value-added poultry compost products is Dynamic Lifter, which combines composted poultry manure with blood and bone meal (containing slow-release N and P), fishmeal (high in N), and seaweed (high in potassium and containing trace elements). Another potential additive is gypsum. Adding gypsum during composting or mixing it into a stockpile has been found to reduce ammonia volatilisation, reducing the amount of nitrogen lost.

Producers interested in value adding their compost should evaluate the costs and benefits of doing so. If compost is sold off-farm, compost producers should engage with major customers to understand the primary expected benefits from using the product (e.g. nutrient requirements of the crop) to determine whether value adding is possible and worth undertaking. Key questions, for example would be as to (i) whether an additive is available that can increase the nutrient value (or other characteristic) of the product to the point the customer requires, and (ii) whether the customer is willing to pay the incurred additional costs for the value-added compost. If the compost is used on-farm, producers should conduct a nutrient budget (see **Appendix 3 – Nutrient budgeting (general information)**) to identify where nutrient supply deficiencies exist and whether it is worth including additives, or other substances such as microbial stimulants.

For further information on advanced composting technologies, please see **Appendix 4**.

6.8. Selling off-farm

A large proportion of manure and spent litter is sold off-farm by producers to third parties, with sellers generally having limited insight into its specific final handling/ use, however, direct land application and processing (composting) are most common.

Selling spent litter or manure off-farm direct from sheds (e.g. at cleanout) reduces not only some risks and liabilities for the egg producer but also the labour and handling costs associated with managing/processing the manure on-farm. However, this is a 'less preferred' scenario when assessing against closed-loop principles, as there is no direct benefit to the producer/farm. It does, however, contribute to a circular economy as it will presumably be used productively off-farm (i.e. produce crops and/or food). Additional benefits associated with selling manure and spent litter off-farm direct from sheds include that the egg producer avoids greenhouse gas emissions associated with handling/treatment being generated on-farm, and reduced land area requirements for stockpiling or composting.





There is no set process or method to go about selling manure and spent litter off-farm, however, producers should:

- Implement a well-managed manure removal and shed clean-out program.
- Cover vehicles (or require vehicles to be covered) that transport manure and spent litter.
- off-farm to minimise potential dust and odour impacts.
- Retain a record of who took/bought manure and spent litter, and the quantities involved.
- Provide the buyer with a recent analysis of the supplied manure.
- Understand that industry and regulators encourage manure suppliers to exercise their duty of care and general environmental duty to ensure that their by-products sold or taken off-site are used sustainably. Although egg producers may not control the management of manure or spent litter after sale, their environmental responsibility for the sustainable utilisation of the by-products still exists.
 - A contract between producers of manure and end-users can define the quantity of by-product involved and the application method. It is helpful for producers to inform the purchasers of their environmental responsibilities, and give the purchasers some idea of the composition of the material (nutrient analysis).
- Inform the end-user about the characteristics of the material to ensure that the material is fit for its end use and used appropriately.
- Consult and follow all relevant biosecurity requirements and guidance.

Given that the principal value of poultry manure/litter is its nutrient content and organic matter, producers should implement low-cost management strategies to retain as much of the valuable nutrients as possible (e.g. covered stockpiling if manure or spent litter must be stored for a time before collection). Organic N is slow releasing and, particularly where N is lost during storage, processing or land application, there is a greater risk of oversupplying P and doing harm to the crop/environment.

Producers should work to identify potential customers and engage with them to clarify the final use of the manure/spent litter, and what are desirable characteristics and the most valuable attributes. For example, in mushroom production, straw-based spent litter may be preferable to spent litter with shavings or sawdust (Noble et al. 2024). Spent litter from meat chicken farms has historically been preferred to layer manure for mushrooms in Australia, but the decline of domestic rice production (and reduction in availability and replacement of degradable rice husks with shavings as a litter material for broilers) has seen an increase in the number of composting yards that generate mushroom production substrate using manure from the layer industry. In some countries, the manure may be turned into a slurry and used in that form as the fertiliser (Noble et al. 2024).

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.



7

Day-to-day mortalities

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7. Day-to-day mortalities

To develop a waste management plan for daily mortalities, you should work through the following steps to identify which options are feasible and best suited for your farm.

Step 1:

Audit mortality volumes and predict likely volumes for a set (e.g. 12-month) period. Consider whether there is likely to be an increase or decrease in mortality numbers in the short- to medium-term (e.g. new sheds, change in housing system). A known imminent increase in production may justify investing in a permanent system now. This may be preferable to just managing current mortality numbers in several home-made systems. When conducting the initial audit, producers should consider whether the results are outside normal operating conditions (e.g. high mortality in a flock due to disease, weather) and if so, exercise caution before making a significant investment decision or if sizing a facility.

Step 2:

Review your local and State regulations around mortality management and disposal. Identify what is permitted and what is not permitted in your area, and whether there are limitations around the use (on- and off-site) of end-products made from material containing daily mortalities. Your farm consultants may be able to assist in identifying relevant legislation and site selection.

Step 3:

Research and review the options available for mortality management and identify those feasible and well-suited to your farm. Consider, for example, what level of investment is available to manage mortalities, whether it is possible to source additional labour, what land area is available to dedicate to mortality management, where that land sits in relation to sensitive receptors, etc.

Step 4:

Prioritise feasible options for your farm based on Steps 1–3.

From a waste hierarchy perspective, in order of most to least preferable the options are:

1. On-farm **Windrow composting** (regularly turned) or semi-static systems (**Bays and piles**). The end-product can (generally) either be used productively on-farm or sold for productive use elsewhere in the economy.
2. **Rotary drum processing**. The end-product can be used productively on-farm.
3. **Commercial composting systems**. These avoid landfill and the end-product (following further treatment off-site) can be used productively elsewhere in the economy. These systems usually involve the egg producer paying for equipment hire and material handling, including transportation.
4. **On-farm incineration**. This avoids landfill but may be a high-cost disposal method as incinerators need to be purpose built for animal streams. Mortality incinerators do not produce an end-product that has a beneficial use.
5. **Burial**. This avoids landfill but does not make any beneficial use of the by-product and can have negative environmental and biosecurity risks if not managed correctly.
6. **Off-site disposal in landfill**. This is the last-resort scenario as it makes no beneficial use of the by-product. Producers will have to pay to dispose of the by-products, which will be treated as (hazardous) waste.

The biosecurity risk of the options must also be assessed and evaluated. For example, composting on-farm may represent a higher risk for some free range operations than off-farm disposal methods.

The list of options in this section is not exhaustive. Depending on the scale of production, it may be possible to use mortalities (in conjunction with other materials) to generate energy (see **Appendix 4 – Anaerobic digestion, Combustion**).



7.1. Composting carcasses (general information)

Carcass composting follows similar general principles as were outlined for other composting processes in this manual. However, there can be slight variations in the process, depending on farm circumstances and processing/end-use objectives. Carcass composting can be used to manage daily mortalities as well as spent hens, although these processes operate at very different scales and time intervals.

The process can be undertaken with either mostly static piles or windrows, or regularly turned piles or windrows, if established and managed correctly. However, mostly static piles will take longer to breakdown the carcasses, while windrow composting may pose a higher biosecurity (risk of carcass exposure) and odour risk.

Carcass composting requires different practices compared with composting of manure because characteristics of the feedstock material are different, and so is the heating profile. Composting of carcasses can be odorous, may pose a biosecurity and pathogen risk, and may also attract vermin if not properly managed. To manage these concerns, the mortality composting process needs to abide by the following key principles:

- Birds must be composted fresh (daily) or stored in a fridge/freezer prior to composting, to avoid a build-up of pathogens and odour generation. It is imperative that birds are not heaped and left to begin decomposing anaerobically prior to composting, as this will increase the risk of *Clostridium botulinum*.
- Compost piles must maintain complete coverage of the birds with a significant buffer between the carcasses and the surrounding environment (minimum of 300 mm of bulking material). Operators must check after every turning event that no carcasses are exposed.
- The composted material must have adequate moisture, oxygen, carbon, and nitrogen to compost effectively, which is indicated by high temperatures within the compost pile (greater than 55°C).
- Whatever the type of composting process used, it needs to remain aerobic.

These conditions must be met to safely compost carcasses and avoid the risk of botulism. However, meeting these conditions alone may not be sufficient to ensure that the generated compost (see **Section 6.3 – Definition and process**) is fully pasteurised or mature.

The following sections outline the general requirements for the composting of carcasses.



Carbon:nitrogen ratio for carcass composting

Poultry carcasses have a high level of nitrogen and require a carbonaceous bulking material to effectively utilise the high nitrogen content from the decaying bird as part of the composting process. This is best done by using sawdust, chopped straw, finely mulched green waste, barn litter or material that is already actively composting. Straight layer manure is not a good co-composting material for carcasses as it also contains high moisture and nitrogen levels, and too little carbon for effective composting of dead birds. However, a mix of different bulking materials used for mortality composting can contain up to 25% (v/v) layer manure.

By mass, carcasses will require about twice as much carbon bulking material. By bulk (volume), this equals about 3 parts bulking material to 1 part carcasses. These amounts of bulking material used and the number of carcasses in each layer provide guidance only, and may need to be adjusted depending on the process used to ensure complete pasteurisation and safeguard biosecurity.

In addition to establishing an effective C:N ratio to facilitate the composting process, additional bulking material is also needed to surround/cover the carcasses to reduce scavenging and to absorb excess moisture from the decaying carcasses. This improves on-farm biosecurity and creates a product that is a lower risk for land application. Dead birds should be kept at least 300 mm from the edge of the pile.



Oxygen for carcass composting

Carcass composting requires careful management to ensure that all dead birds are covered continuously and are not exposed to the surrounding environment. This can make oxygen supply challenging, as the material is turned only infrequently. Generally, compost windrows and piles containing dead birds are established and left for 1–2 months after the last carcass is added to allow the carcasses to mostly decompose before turning for the first time.

For effective composting to occur during this time, the composted material needs to have adequate porosity to maintain sufficient oxygen supply. In a mostly static pile, oxygen is primarily supplied by convection, where warm air rises through the pile drawing in fresh air from the base of the pile. This process can be aided by having porous and structurally stable material such as straw, wood chips or coarse green waste in the bottom layer of the pile. This coarse material should not be added at more than about 25% (v/v), as the base of the pile needs to be able to absorb moisture generated by the decaying birds. These piles may require turning and watering if the microbial breakdown process stops before the organic material has decomposed.

**Turning for carcass composting**

After an initial phase of composting, piles can be turned to improve porosity, mixing and speeding up the process. After piles are turned, coverage of any exposed carcasses is essential to ensure biosecurity. Any exposed carcasses, or parts thereof, must be covered immediately after turning, using additional bulking material or finished compost to prevent scavenging and odour production.

As a general rule, hen carcasses are likely to be decomposed within 2–3 months with regular turning (e.g. fortnightly) after the initial static phase. The time period for decomposition can increase to 6–9 months if composted in static piles with minimal turning. Avoid turning for the first time until the carcasses have mostly decomposed, which is about 1–2 months after the last carcass has been added.

Because turning speeds up the composting process significantly, the decision on how often to turn is driven by the number of carcasses that need to be processed, the amount of space available, and when in the year the generated compost is mostly required for utilisation (either on-farm or off-site).

**Moisture for carcass composting**

Chicken carcasses have a high amount of liquid, which is released during decomposition.

Therefore, it may not be necessary to add water when establishing the composting pile, except to wet the feathers. Additional moisture may be provided by rainfall if composting without a roof, but timing and quantities are unpredictable. If the composting area has a roof, water can be added with a hose or sprinkler if necessary. Water may also be added at the point of turning.

If a mortality compost site has insufficient drainage, moisture can pool around and in the composting area. This can lead to unfavourable conditions for composting (anaerobic), generation of unpleasant odours, and the formation of *Clostridium botulinum* toxins. For this reason, it is important to establish composting sites with adequate water diversion and drainage to avoid water ingress and moisture being drawn into the compost pile from below. In high rainfall areas, consider composting mortalities undercover, since heavy or prolonged rainfall can saturate compost piles (particularly smaller ones), and generate large quantities of leachate and runoff.

Runoff from the site also needs to be managed to minimise contamination of surface and ground waters with nutrients, organic matter, and pathogens. Some materials, such as sawdust, are very effective at shedding rainfall, provided the piles or windrows are sufficiently peaked. Rain tends to seal the pile surface and reduce the aeration rate, and piles may require turning after rain to improve aeration, provided it is safe to do so.

If runoff is likely to occur, detention basins and vegetative filter areas should be used to avoid the prolonged retention of water that is a biosecurity risk. In high rainfall areas, composting carcasses is best done under a roofed structure to manage moisture and runoff.

**Temperature for carcass composting**

As with other forms of composting, carcass composting will develop high temperatures.

Ensuring each layer of carcasses is separated by 100–150 mm of bulking material and maintaining 300 mm around the carcasses on the sides of a pile, helps ensure that all carcasses are exposed to high temperatures (> 55°C). After turning and mixing, recovering with 300 mm bulking material will also assist in ensuring the carcasses are exposed to high temperatures and the generated compost is pasteurised.

Measuring and recording temperatures inside a compost pile is a useful means for monitoring the composting process. Turning and possibly watering is required when temperatures begin to fall below about 45°C, to ensure effective pasteurisation.

**Bulking material requirements for carcass composting**

Poultry carcasses are high in moisture and nitrogen compared to many other organic materials. To successfully compost carcasses, it is necessary to add a dry carbon source (such as sawdust or chopped straw) to soak up moisture and feed the composting process.

To calculate the quantity of bulking material required, it is necessary to know the estimated number (mass) of dead birds per day or week, or per shed cleanout. The average number of daily mortalities equals the total number of birds on the farm multiplied by the mortality rate and divided by the days of occupancy, e.g.:

$$\begin{aligned} &10,000 \text{ birds} \times 3\% \text{ mortality} \\ &= 300 \text{ birds} \\ &300 \text{ birds} / 365 \text{ days} \\ &= 0.8 \text{ birds per day, or 6 birds per week.} \end{aligned}$$

At an average weight of 2 kg per bird, an average total mass of about 12 kg of carcass per week is generated, which will require about 25 kg of bulking material (i.e. 0.1 m³ of sawdust). Annually, this amounts to about 5 m³ of sawdust to compost the 300 dead birds. All or some of the generated compost can be reused as bulking material for composting a further batch of carcasses to reduce cost.

If there is a mass mortality event, the above processes can be used, but more area will be required. Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.



7.2. Windrow composting

To compost mortalities in windrows with manure and spent litter, producers should familiarise themselves with the general principles outlined in **Section 7.1 – Composting carcasses (general information)**.

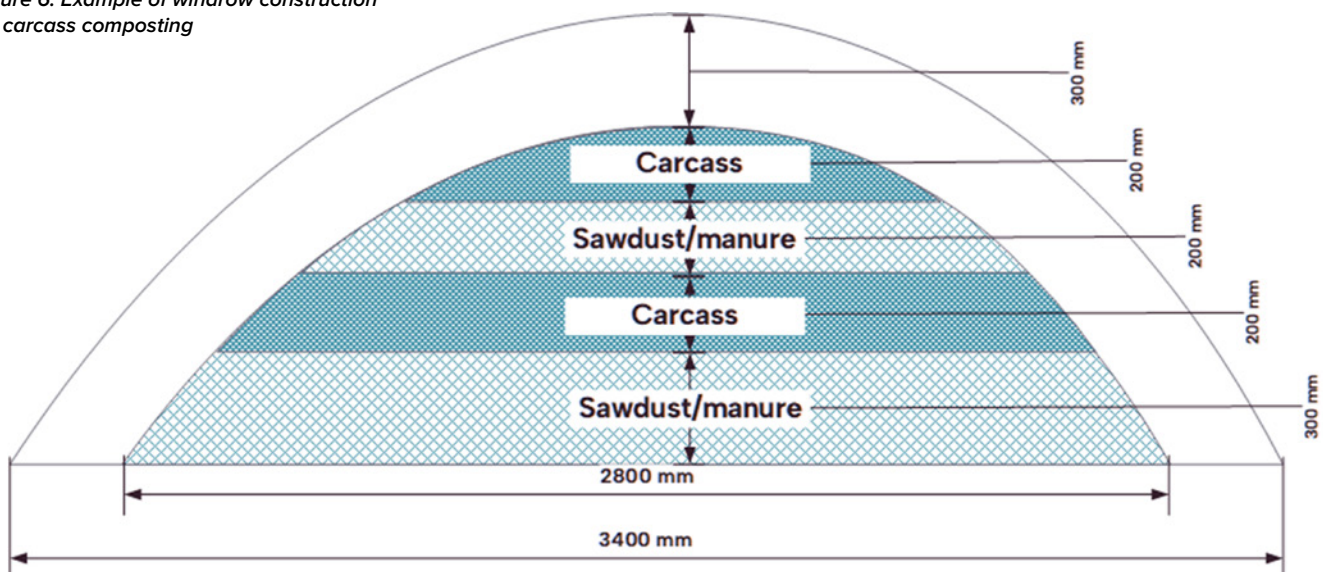
The initial decomposition phase (carcasses largely decomposed) can be completed in approximately 1–2 months. The product will still require further stabilising and curing to be fully pasteurised and matured. As a general rule, hen carcasses are likely to be fully broken down in around 2–3 months after the initial static phase with regular turning (e.g. fortnightly after initial static decomposition).

A general guide to windrow composting of mortalities is as follows:

1. Identify an appropriate site and plan site layout.
 - a. Based on the audit of waste and by-product volumes produced on your farm, determine the size of the area required to accommodate the predicted number and volume of mortalities.
 - i. *To calculate an area, you will need to determine the number/volume of mortalities, and bulking material, and the height, width, and number of windrows.*
 - ii. *As a rough guide, work on about 10 m³ of windrow for every 1,000 carcasses. A small windrow with a 45° side slope, 1.8 m wide, 0.9 m in height, and 12.5 m long would be approximately 10 m³ in volume.*
 - iii. *A 50% contingency (increase) in mortalities (e.g. number, volume) should be allowed for so that sufficient area is available in the event of a high mortality batch or incident. Note that alternative management may be required if mortalities exceed the contingency.*
 - iv. *Allow additional area for machinery to pass between windrows. Note that front-end loaders require more space to operate than tractor-driven straddle turners.*
 - b. It will need to minimise dust, noise, and off-site impacts (odour), e.g. choose a site with appropriate separation distances and (or potential for) vegetative buffers.
 - c. It must be located at a sufficient distance from egg production facilities to minimise the risk of pathogen spread.
 - d. Check if you need a permit to build and operate a composting facility at your preferred location. This might depend on whether or not you are planning to use bulking material from external sources.
2. Build the site or facility. A general list of requirements/specifications include:
 - a. An impermeable surface or compacted clay pad. This will ensure that the pad is trafficable in all weather conditions and prevent leaching to groundwater.
 - i. *The base should be designed to achieve a design permeability of 1x10⁻⁹ m/s over a depth of 300 mm.*
 - ii. *A sealed concrete base is most preferred to minimise leaching.*
 - iii. *Depending on available equipment and expertise, producers may be able to do this themselves, or a contractor could be engaged (e.g. particularly for lime or cement stabilisation).*
 - b. Site drainage to avoid excessive moisture and muddy conditions.
 - c. Where there is potential for a large amount of runoff from the composting pad area (i.e. high rainfall), consider a roof structure to eliminate rain falling on compost. If contaminated water needs to be captured, use a detention basin and vegetative filter area to avoid stagnant water being stored hence reduce biosecurity risks.
 - d. Where surface water risks are present (see Section 2.6.3 and Appendix B of the Egg Industry Environmental Guidelines (McGahan et al. 2018)), water should be excluded from the area through bunding or diversion banks/swales.
 - e. Exclude scavenging animals from carcass composting facilities, with appropriate fencing and gates (e.g. chain wire, electric).
 - f. Obtain quotes for an appropriately sized new/used windrow turner, and purchase/hire preferred machine.
 - i. *Front-end loaders are often the first choice for windrow or pile turning in smaller composting operations, as they may already be available on-farm and can be used for other purposes (ensure Step 7 below is followed). They are, however, slow to operate and care should be taken to ensure that the compost is adequately mixed.*
 - ii. *A variety of windrow compost turners are available, including three-point linkage units, PTO driven trail behind units, self-powered units (driven off a separate engine but attached to a tractor), and self-propelled units.*
 1. The scale of the composting operation is usually the best determiner of the required size of the compost turner. For example, three-point linkage units are available for small- to medium-scale composting, while trailing or self-propelled units are more suited to large-scale operations.
2. Tractor-drawn models can generally turn a windrow less than 3 m high, whilst some self-propelled models can turn windrows up to 4 m high by 4 m wide.

3. Turning rates will vary with the size and type of turner. Three-point linkage turners are limited to a turning rate of 200–400 m³/hr, tractor drawn turners may have a rate of 400–800 m³/hr, and self-propelled turners can turn at rates of 1,200–6,500 m³/hr.
- g. Devise a system of adding water to windrows, and establish required infrastructure/ obtain required equipment.
 - i. Some turners can apply water to windrows using a trailing hose system. Alternatively, some windrow turners can tow a tanker that will supply water during turning or the tanker could be used independently to apply water immediately prior to turning. The latter option may be more appropriate for small to medium operations without water infrastructure.
- h. Check if you own a tractor with creeper gears (to travel at low speed). If not, you need to obtain an appropriately sized tractor with creeper gears. Alternatively, hydraulic assist features are available for turners, removing need for a creeper gear.
- i. Check if you have adequate material handling equipment (e.g. loader), and if not, you need to obtain appropriate equipment.
- j. Obtain suitable bulking material.
- k. If you are aiming to sell compost, you might require a screen.
3. Begin the composting process.
 - a. Put down a 300 mm layer of bulking material (sawdust, straw, or other carbon source) on the bottom of the windrow.
 - b. Add mortalities (1.5 birds deep per layer). To do this, lay the first layer of carcasses side by side. The next set of carcasses should be placed on top of the first layer, so that the torsos of the second layer are on top of the heads, necks, and feet of the first layer. This will create a more level layer of carcasses, with a height roughly equal to about 1.5 birds, ~200 mm high (see **Figure 6**).

Figure 6: Example of windrow construction for carcass composting



- c. If necessary, wet down the feathers of the birds, adding approximately 1 L per 3 carcasses, but note that this is not essential for carcass composting.
- d. Add a layer of bulking material (100–150 mm) at a ratio of approximately 3:1 (v/v) of bulking material to carcass mass before adding further layers of carcasses, ensuring that 100–150 mm of bulking material remains over previous carcasses (see **Bulking material requirements for carcass composting** in Section 7.1).
- e. Ensure that the top layer of carcasses is covered by 300 mm of bulking material.
- f. Windrows are generally 1.0–1.5 m high and 3–4 m wide at the base. The size will be dependent on the equipment used to undertake the turning. A large windrow with a 45° side slope, 3 m wide, 1.5 m in height, and 43 m long would be approximately 100 m³ in volume and could accommodate 10,000 carcasses.
- g. Windrows should be peaked (triangle-shaped) so they can shed rainfall.
- h. Any runoff must be captured (not pool around piles) immediately for reuse in the compost or applied to land.
4. To add additional carcasses, remove some of the top layer of bulking material, leaving 100–150 mm covering the previous layer of carcasses then add the new carcasses following steps 3b–e.



5. It is important to manage the physical and chemical characteristics of the composted material to maintain temperature, moisture, pH, and nutrient ratios within the appropriate ranges, and ensure that the generated product is pasteurised, and its characteristics are within a range of expected values.
6. The composting process needs to be managed and monitored to generate products that meet certain product characteristics for both on-farm and off-farm use:
 - a. The windrow should be left in a static phase (i.e. not turned) for 1–2 months so that the carcasses can begin to breakdown.
 - b. Monitor the temperature and moisture level and turn regularly (e.g. fortnightly) after the initial static stage. Add water as required.
 - i. *After each turn, ensure that no decomposing carcasses are exposed. If carcasses are exposed, cover with a minimum of 300 mm of bulking material.*
 - c. After about 10 weeks into the process, record the temperature before and after turning (next day). If turning does not result in increased temperatures, provided the moisture content is adequate, the material is approaching the maturation stage. Allow to mature for around 4 weeks, i.e. the process will be complete after about 14 weeks.
 - i. *If it does heat, test again, 1–2 weeks later, then allow 4 weeks to cure, i.e. the process will be complete in about 16 weeks.*
 - ii. *Repeat this process until windrow no longer heats above 30–35°C.*
 - d. Ensure that material does not dry out and is adequately dampened during the turning process to reduce risk of aerosolised pathogens. As dry organic materials are hydrophobic, it is difficult to re-wet composted material that has dried out. Exercise caution as excessive application of water can cause nutrient runoff or anaerobic conditions, increasing odour potential.
 - e. Time turning to avoid strong winds blowing toward the production area or sensitive receptors.
 - f. The end-product should no longer resemble the original materials, i.e. it should be a brown/black, earthy material, and any leftover coarse woody material should be easily broken down if rubbed between your fingers. The material should not smell like vinegar or rotting matter but should smell like soil, although composted layer manure tends to retain the smell of ammonia for a long time. If the material smells bad, it should be turned and left to cure further before being tested again.
 - g. Move the finished compost from the composting pad to the storage area, or load onto trucks for immediate land application.
 - h. If the compost is used off-farm, particularly in horticultural production systems, it might be necessary to screen the compost to allow delivery of product with defined particle size (e.g. < 10 mm) and to ensure that the compost does not contain undesirable impurities (e.g. rocks, plastic).
7. Sanitise/quarantine equipment used in moving mortalities or managing compost prior to use in production areas.

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

7.3. Bays and piles

If performed correctly, composting dead birds in regularly turned or mostly static open bays (see **Figure 7**) and piles is an environmentally and biologically safe method of disposal. These bays can have a roof as per Figure 7, which may be required in high rainfall areas. The initial decomposition phase of the process (carcasses largely decomposed) can be completed in approximately 1–2 months. The material will still require further stabilising and curing to be fully matured. Hen carcasses are likely to be fully broken down in around 2–3 months if the composted material is regularly turned (e.g. fortnightly) and watered (if needed) after the initial static phase, and in 6–9 months if the material is not regularly turned and watered (i.e. in mostly static pile). Exact timeframes may vary from location to location.

Figure 7: Example of bay composting facility
Source: McGahan et al. (2018)



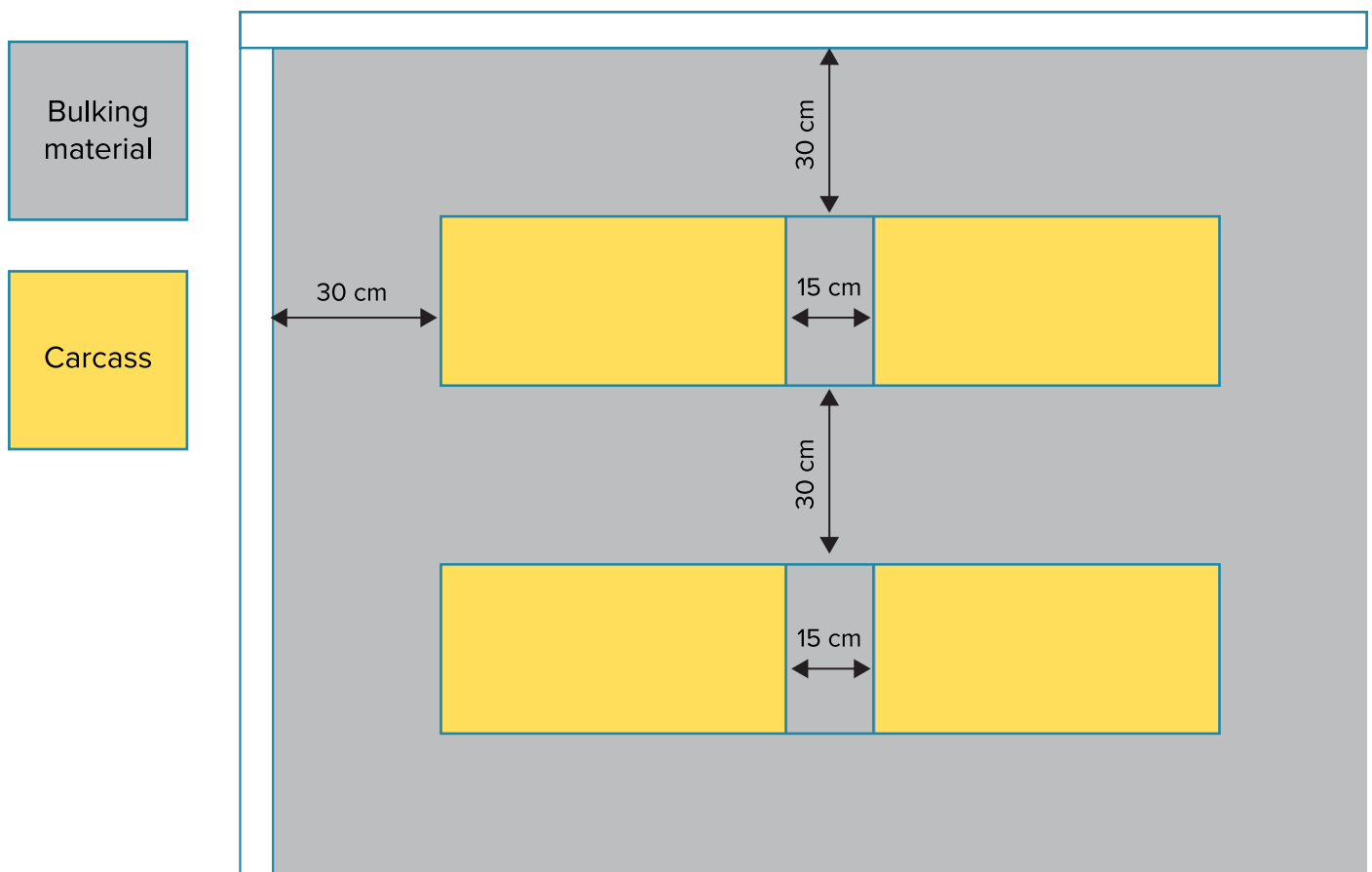


To compost dead birds in bays or piles, follow these steps:

1. Identify an appropriate site and plan site layout.
 - a. Based on the audit of waste and by-product volumes produced on your farm, determine the size of the area required to accommodate more than the predicted number of mortalities so that you have enough capacity in unforeseen circumstances.
 - i. *To calculate an area, you will need to determine the volume of dead birds and bulking material (see **Bulking material requirements for carcass composting** in Section 7.1), and the height, width and number of the piles or bays.*
 - ii. *As a general guide, allow 1 m³ of pile per 100 carcasses, thus a pyramid shaped pile that is 2 m wide, 2.5 m deep and 1 m high would be 1.6 m³ and could accommodate approximately 160 carcasses.*
 - iii. *Account for additional bays for the partially completed material to be moved and mixed into an adjoining bay. The number of bays required will depend on the number of times the material will be moved before the process is complete.*
 - iv. *If the material is to be further stockpiled on-farm, allow additional space for this.*
 - v. *A 50% contingency (i.e. additional space) should be allowed.*
 - b. Choose a site and layout that will also minimise dust, noise, and off-site impacts (odour), e.g. one with appropriate separation distances and (or potential for) vegetative buffers.
 - c. The site must be located at a sufficient distance from production facilities to minimise the risk of pathogen spread.
 2. Exclude scavenging animals from carcass composting facilities with appropriate fencing and gates (e.g. chain wire, electric).
 3. Ensure that you have access to or obtain quotes for a new/used loader, and purchase/hire preferred machine.
 4. Obtain suitable bulking material.
 5. Build the facility. A general list of requirements/specifications include:
 - a. An impermeable surface or compacted clay pad (required for both bays and piles).
 - i. *The base should be designed to achieve a design permeability of 1×10^{-9} m/s over a depth of 300 mm.*
 - ii. *A sealed concrete base is most preferred to minimise leaching.*
 - iii. *Depending on available equipment and expertise, producers may be able to do this themselves, or a contractor could be engaged (e.g. particularly for lime or cement stabilisation).*
 - b. For bays, sidewalls can be timber, concrete or plywood with timber supports or, for a cheaper option, hay/straw bales can also be used as temporary walls.
 - i. *Note that permanent systems (e.g. concrete floor, timber or concrete sidewalls, roof) may provide for easier operation and management but are most suited to large farms with bays filled progressively as mortalities accumulate.*
 - c. Bays are usually about 2 m deep and 2.5 m wide, however, the width is determined by the machinery used for loading, turning, and removal when the process is completed.
 - d. Rain should be excluded in higher rainfall areas, using roofed structures (bays and piles).
 - e. Where surface water risks are present (see Section 2.6.3 and Appendix B of the Egg Industry Environmental Guidelines (McGahan et al. 2018)), water should be excluded from the area through bunding or diversion banks/swales (bays and piles).
6. Begin the composting process.
 - a. Put down a 300 mm layer of bulking material (sawdust, straw, or other carbon source) on the bottom of the bay/pile (see **Figure 6**).
 - b. Add mortalities (1.5 birds deep per layer). To do this, lay the first layer of carcasses side by side. The next set of carcasses should be placed on top of the first layer, so that the torsos of the second layer are on top of the heads, necks, and feet of the first layer. This will create a more level layer of carcasses, with a height roughly equal to about 1.5 birds, ~200 mm high.
 - c. In bays, carcasses should not be placed closer than 300 mm to the walls (see **Figure 8**). If necessary, wet down the feathers of the birds, adding approximately 1 L per 3 carcasses, but note that this is not essential for carcass composting.
 - d. Add further bulking material at approximately 3:1 ratio bulking material to carcass mass, ensuring 100–150 mm of bulking material remains over previous carcasses (see **Bulking material requirements** in Section 7.1)
 - e. Ensure that the top layer of carcasses is covered by 300 mm of bulking material (see **Figure 6**).
 - f. Piles should be peaked (triangle-shaped) so they can shed rainfall, and be no higher than 3 m.
 - i. *Any runoff must be captured (not pool around piles) immediately for reuse in the compost or applied to land.*
 7. To add additional carcasses, remove some of the top layer of bulking material, leaving 100–150 mm covering the previous layer of carcasses, then add the new carcasses following steps 4b–e.

8. It is important to manage the physical and chemical characteristics of the composted material to maintain temperature, moisture, pH, and nutrient ratios within the appropriate ranges, and ensure that the generated product is pasteurised, and its characteristics are within a range of expected values (see [Wiedemann et al. 2008](#) and [Section 7.1 – Composting carcasses \(general information\)](#)).
9. The composting process needs to be managed and monitored in order to generate products that meet certain characteristics for both on-farm and off-farm use:
 - a. Monitor the temperature and moisture level and turn regularly (e.g. fortnightly) after the initial static stage. Add water as required.
 - i. *After each turn, ensure that no decomposing carcasses are exposed. If carcasses are exposed, cover with a minimum of 300 mm of bulking material.*
 - b. After about 10 weeks into the process, record the temperature before and after turning (next day). If turning does not result in increased temperatures, provided the moisture content is adequate, the material is approaching the maturation stage. Allow to mature for around 4 weeks, i.e. the process will be complete after about 14 weeks.
 - i. *If it does heat, test again, 1–2 weeks later, then allow 4 weeks to cure, i.e. the process will be complete in about 16 weeks.*
 - ii. *Repeat this process until the windrow no longer heats above 30–35°C.*
 - c. Ensure that material does not dry out and is adequately dampened during the turning process to reduce risk of aerosolised pathogens. As dry organic materials are hydrophobic, it is difficult to re-wet composted material that has dried out. Exercise caution as excessive application of water can cause nutrient runoff or anaerobic conditions, increasing odour potential.
 - d. Time turning to avoid strong winds blowing toward the production area or sensitive receptors.
 - e. The end-product should no longer resemble the original materials, i.e. it should be a brown/black, earthy material, and any leftover coarse woody material should be easily broken down if rubbed between your fingers. The material should not smell like vinegar or rotting matter but should smell like soil, although composted layer manure tends to retain the smell of ammonia for a long time. If the material smells bad, it should be turned and left to cure further before being tested again.

Figure 8: Example of spacing of carcasses in bay composting





- f. Move the finished compost from the composting pad to the storage area, or load onto trucks for immediate land application.
 - g. If the compost is used off-farm, particularly in horticultural production systems, it might be necessary to screen the compost to allow delivery of product with defined particle size (e.g. < 10 mm) and to ensure that the compost does not contain undesirable impurities (e.g. rocks, plastic).
10. Sanitise/quarantine equipment used in moving birds/managing compost prior to use in production areas.

Hen carcasses are likely to be composted within 2–3 months with regularly turning (e.g. fortnightly) and 6–9 months in mostly static piles after the initial static phase of 1–2 months.

If there is a mass mortality event, the above processes can be used, but more area will be required. Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

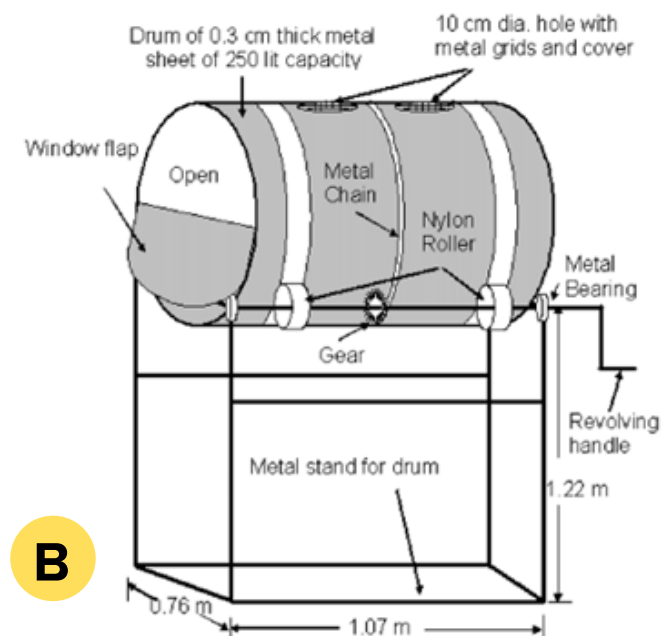
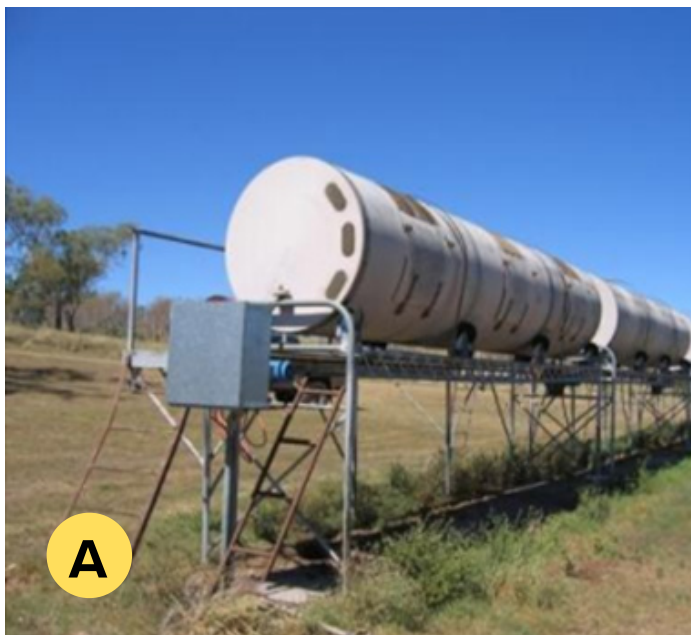
7.4. Rotary drum processing

Mortality processing with a rotary drum is a rapid processing technique, which may be a preferred option where available land is limited (e.g. on small farms). The rotary drum composting system has relatively low labour requirements, creates no leachate or contaminated runoff, requires relatively low quantities of bulking material, and excludes access for rodents and scavengers. It may also be preferred where finding labour is challenging, or as a means of avoiding nutrient loss via runoff.

Disadvantages of the system include the initial cost of purchase (compared with the relatively simple bin design composting systems) and that the systems (particularly automated ones) may also be difficult and costly to manage. It is, however, also possible for farmers to build their own small and inexpensive units (**Figure 9**).

The strategy has been used historically in the egg industry, with employed models ranging from automatic (powered) systems to manual (hand-turned and home-made) designs (see Figure 9). The size and number of units required will depend on the number of mortalities, the volume of the drum, and how long the material is kept in the drum.

Figure 9: Rotary drum processing units for daily mortalities
(A) Powered version (B) Hand-turned version
Source: Kalamdhad and Kazmi (2008)





To establish and operate a rotary drum processing unit, follow these steps:

1. Research the market and purchase a rotary drum processing unit, or research designs and build or commission a unit.
 - a. The material used should be anti-corrosive or at least have an anti-corrosive coating.
2. Identify an appropriate location for the drum (outside the egg production zone, away from sensitive receptors).
3. Based on the type of unit (powered, hand-turned), construct the site accordingly.
 - a. For powered units, these should be installed by a professional. Note that connection to a power supply (grid electricity, solar, etc.) will be required.
 - b. For home-made or lighter units, ensure that the unit is placed on a stable surface (e.g. concrete pad), and that it is not exposed to or is secured against strong winds.
4. Load daily mortalities.
 - a. On small farms, carcasses may be refrigerated or frozen until a sufficient number are available to meet the capacity of the composting unit.
 - b. If using a home-made unit, make sure the unit is sealed securely each time so that scavengers cannot open it.
 - c. For some more advanced units, drums can be loaded continuously (if sized appropriately) so refrigeration or freezing may not be required unless it is for other reasons (e.g. to avoid trips to the unit each day).
5. Add the required bulking material.
 - a. By mass, the carcasses will require about twice as much carbon bulking material. By bulk (volume), this equals about 3 parts bulking material to 1 part carcasses.
6. Commercially available drums are fully automated so that turning frequency and speed, and aeration can be set according to requirements (load, feedstock characteristics). Home-made units need to be turned/agitated at least once per day. If the unit is operated manually, turn several times per day.
7. After the feedstock has been in the drum for 1–2 weeks (moving from one end of the drum to the other), the material should be partly broken down and can be extracted from the drum. The partially composted material should be further composted prior to land application, particularly if pasteurisation is not ensured while the material is in the drum.
 - a. Note that, for small home-made units, if carcasses are added over a few days until the unit reaches capacity, additional bulking material should be added at the same time to maintain the desired ratio, and the materials should be held in the unit for 5–7 days after the last carcass was added.

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.



7.5. Commercial providers

Commercial composting options are available, where mortalities are stored on-farm in aerated bins before being transported off-farm for further processing by third parties. This model is widely used in the meat chicken industry. Once full, the bins are removed for further composting at a commercial composting operation. The bins operate without turning, relying on a forced aeration system to provide oxygen. The exhaust air is filtered before release to the atmosphere, minimising odour. This system may be a particularly advantageous method to handle daily mortalities for producers operating in areas where urban encroachment and odour are an issue. If the bins are operated correctly, they may also reduce biosecurity risks.

A detailed description of how the system should be operated is not provided here. Interested parties should engage directly with their local supplier.

Producers should carefully review the manufacturer's recommendations regarding the maximum loading rate (birds/day). If the recommendation is based on meat chickens, it may be necessary to reduce the loading rate as layer hens may decompose more slowly than meat chicken (as the former are typically much older). Alternatively, the bin may need to be emptied more frequently than the supplier suggests.

Disadvantages of bins include that they are expensive to purchase (approximately AU\$30,000, however, it may be possible to hire rather than purchase), require electricity to operate, may require input of carbonaceous materials (e.g. sawdust) at specific ratios, and must be transported to a commercial composting facility (which may have an additional cost implication, and biosecurity risks from contractors on-site). For these reasons, bins may be a less cost-effective alternative for windrow composting.

Homemade replicas of the system should not be made, nor should mortalities be removed from the bin for land application as, due to the anaerobic conditions observed (Wiedemann et al. 2008), there is distinct pathogen risk with this material. For this reason, it would not be recommended to land apply the material without further composting first.

7.6. On-farm incineration

If carried out appropriately, the risk of odour generation and nutrient runoff from on-farm incineration of mortalities is minimal compared with most other disposal methods. Regarding biosecurity, it is the safest method of disposal for mortalities due to the destruction of common pathogens. It is, however, a 'worst case' scenario from an environmental perspective, as the birds are treated as a waste (generating negative environmental outcomes) and do not contribute to either closed-loop production (on-farm) or a circular economy (used productively off-farm).

While correct incineration is biologically the safest dead bird disposal method, there are several reasons (in addition to investment costs) that it may not be appropriate for your farm, including possible challenges in having the method approved in some jurisdictions. In addition, the process must be performed efficiently and effectively to ensure complete incineration, which can be expensive. By appropriately incinerating carcasses, however, some of the valuable nutrients are also eliminated.

To conduct on-farm incineration of mortalities correctly, producers should follow these steps:

1. Research the market and source a purpose-built poultry-specific incinerator (home-made units should not be used), and have it installed by a qualified professional.
 - a. The unit requires high-temperature incineration capable of reaching appropriate temperatures for safe incineration of potentially pathogenic material, and to destroy a range of pollutants (refer to equipment manufacturer's recommendation for the safe incineration temperature).
 - b. It may require appropriate flue control and emissions management, depending on the risks at the site and/or regulatory requirements. Air pollution devices such as scrubbers may be needed to achieve this outcome.
 - c. Several providers offer poultry incinerators, which may vary in price depending on provider, burning rate (kg/hr), burning time (loads per hour), fuel type, and loading method. These may range from systems with a feed rate of 120 kg/hr at the larger end and 30 kg/hr at the smaller end. **Figure 10** provides examples of some system designs available.
2. Ensure that the incinerator is located at an appropriate site/facility.
 - a. A level concrete base is needed upon which to mount the incinerator.
 - b. Adequate space (e.g. 2 m) should be allowed around each side of the incinerator to ensure easy access and maintenance.



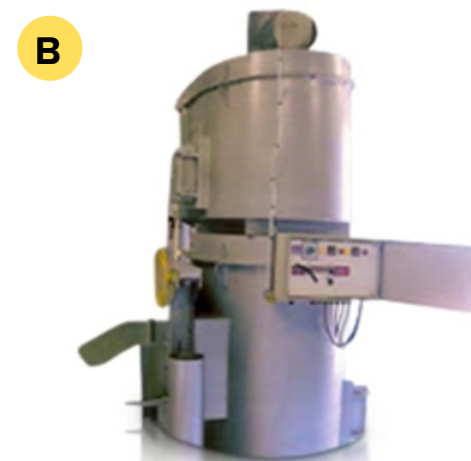
3. Ensure that an appropriate fuel source is available and used (e.g. LPG). Do not use old tyres or sump oil, etc.
4. Load mortalities into the unit.
 - a. If mortalities are not incinerated daily, they need to be appropriately stored (e.g. in a refrigerator/freezer). Note that if incinerated from frozen, additional processing time may be required.
5. Incinerate the material at high temperatures to ensure clean burning and destruction of the entire carcass.
6. Use or dispose of the ash in accordance with the relevant State and local regulations.
 - a. If land applying ash, be aware that whilst it may be a beneficial source of phosphorus and potassium, there is also a risk of high heavy metal content.

Further details on risks and controls associated with on-site incineration are available in the *Egg Industry Environmental Guidelines* (McGahan et al. 2018).

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

Figure 10: Examples of poultry carcass incineration systems available in Australia

(A) Kleenburn Poultry Bio-Security Cremation Unit
(B) A.C.E. Systems MK 5 Incinerator (Dual Chamber)



7.7. Burial

On-site burial of dead birds presents few benefits and several risks that must be managed. This is a 'worst case' scenario from an environmental perspective, as the birds are treated as a waste (generating negative environmental outcomes) and do not contribute to either closed-loop production (on-farm) or a circular economy (used productively off-farm).

To bury mortalities on-site, the following steps must be followed:

1. Construct a purpose-built pit.
 - a. Identify a location that will minimise potential odour and dust impacts off-site. Consider factors such as the location of sensitive receptors, and prevailing meteorological conditions. It should also be located a safe distance from underground and aboveground infrastructure, such as gas lines, water pipes, power lines.
 - i. *Guidance for the burial of carcasses during an EAD outbreak recommends that the pit be located on elevated ground but with a slope of less than 5%.*
 - b. Ensure that the base of the pit will be at least 2 m above the seasonal high water table level, and that it is located at least 200 m from any surface water.
 - c. Ensure that you have access to the appropriate machinery (excavator, loader) or purchase new/used machinery.
 - d. Ensure that you have/will have adequate covering material (sawdust, soil, etc.) on-hand.
 - e. Dig the burial pit, noting that an excavator is the preferred equipment to do so.
 - i. *Pits should be sized appropriately to ensure adequate space for burials and covering materials for each disposal.*
 1. As a general guide, allow 1 m³ of pile per 100 carcasses, thus a burial pit that is 2 m wide, 4 m deep and 1 m long would be 8 m³ and could accommodate approximately 700 carcasses (allowing room for a 500 mm compacted clay seal (see Step 4 below)).
 - f. Where possible, line the pit with a carbonaceous material (e.g. wood shavings, straw) to absorb some of the liquids that will leak out from the carcasses.
 - g. Where risks to the groundwater are present (see Section 2.6.3 and Appendix B of the *Egg Industry Environmental Guidelines* (McGahan et al. 2018)), pits must be lined with an impermeable liner or compacted clay lining. Note that this can be difficult to achieve and may present prohibitive operational and financial challenges in which case alternative options should be considered.



- h. Fence the burial area to prevent entry of pests (e.g. rodents) and feral animals.
- 2. Place mortalities in the pit.
 - a. Burial should take place as soon as possible after the animal has died.
 - i. *Where this is not feasible, carcasses should be stored in freezers/fridges.*
 - ii. *If not stored in a refrigerated unit or collected daily, treat dead birds with chemicals to preserve/disinfect the carcasses, and store in a sealed container to prevent leaching. They should then be buried as soon as possible.*
 - 1. Producers should also be mindful of whether the chemicals used could make alternative disposal methods challenging (e.g. in the event where on-site disposal is required). Hydrated lime (calcium hydroxide, also known as quicklime), for example, is often used to preserve animal carcasses. When exposed to air, hydrated lime releases water and absorbs carbon dioxide, hardening into a calcium carbonate 'crust'. Composting carcasses that have hardened and dried out through quicklime application may require additional water to ensure that the material falls within the preferred moisture range for efficient composting.
 - 2. Regardless of the chemical used, the relevant Safety Data Sheet (SDS) should be followed.
- b. Where possible, a machine (e.g. loader) should be used for burial.
- c. Vehicle movements should be minimised by careful planning of timing of operations. Noise can be minimised through appropriate separation distances and noise reducing screening, such as vegetated buffers (which may also reduce dust).
- 3. Immediately cover the mortalities with appropriate materials (sawdust, soil, etc.) to reduce emissions of odour. Requirements vary between states, however, a minimum of 300 mm of covering material (sawdust, soil, etc.) is recommended.
- 4. Cover the pit when full with at least 500 mm of mounded compacted clay to seal it and account for subsidence. This will minimise the potential of leaching and transmission vectors for pathogens.
- 5. Ensure that the appropriate control measures are in place.
 - a. Where risks to surface water are present (see Section 2.6.3 and Appendix B of the *Egg Industry Environmental Guidelines* (McGahan et al. 2018)), water should be excluded from the burial area through bunding or diversion banks/swales. Rain should be excluded using roofed structures.

- b. Vehicle movements should be minimised by careful planning of timing of operations. Noise can be minimised through appropriate separation distances and noise reducing screening, such as vegetated buffers (which may also reduce dust).

Specific requirements for on-site disposal of mortalities may vary between jurisdictions. Local and State regulators should be contacted in advance to ensure that all requirements are met.

Further details on risks and controls associated with on-site burial are available in the *Egg Industry Environmental Guidelines* (McGahan et al. 2018).

As part of a site management plan, producers should identify a suitable site for burial in a mass mortality incident, e.g. where there is suitable clay material. Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate (e.g. carcasses may need to be buried at least 2,000 mm below the surface), and the relevant guidelines should be consulted and followed.

7.8. Landfill

Off-site disposal of mortalities significantly reduces the risks faced by the producer, by removing the source of the risks off-farm. However, this is the 'worst case' scenario from an environmental perspective, as the birds are treated as a waste (generating negative environmental outcomes) and do not contribute to either closed-loop production (on-farm) or a circular economy (used productively off-farm). Producers are also likely to have to pay to dispose of mortalities.

If off-site disposal is the only viable option available, follow this process:

1. Identify an appropriate landfill facility.
 - a. Check regulatory requirements regarding landfill disposal of animal mortalities in your State.
 - b. Check with the facility to ensure that they can and are willing to accept mortalities.
 - c. Check disposal costs.
 - d. Contractors may be required to collect birds for disposal and transport them to the landfill site.
2. Engage an adequately licensed contractor.
 - a. Ensure that the contractor agrees to regular removals at predicted loads.



3. Ensure that you have appropriate temporary on-site storage in place for dead birds (e.g. sealed refrigeration unit or freezer), as frequency of disposal may depend on the capacity/availability of the waste disposal contractor, and affect transport costs.
 - a. Except for freezers/fridges, storage should only be short-term to minimise decomposition.
 - b. If not stored in a refrigerated unit or collected daily, treat dead birds with chemicals to preserve/disinfect the carcasses, and store in a sealed container to prevent leaching. Check with the destination facility first to ensure that the chemicals are suitable.
 - i. *Producers should also be mindful of whether the chemicals used could make alternative disposal methods challenging (e.g. in the event where on-site disposal is required). Hydrated lime (calcium hydroxide, also known as quicklime), for example, is often used to preserve animal carcasses. When exposed to air, hydrated lime releases water and absorbs carbon dioxide, hardening into a calcium carbonate 'crust'. Composting carcasses that have hardened and dried out through quicklime application may require additional water to ensure that the material falls within the preferred moisture range for efficient composting.*
 - ii. *Regardless of the chemical used, the relevant Safety Data Sheet (SDS) should be followed.*
 - c. Allow for additional storage capacity to cope with fluctuations.
 - d. Dead bird storage should be located close to the access point for the property to minimise the need for disposal contractors to enter the site. Dead bird storage must be located (and site pick up occur) outside the production area.
 - e. Removals should also be timed to minimise noise and impacts on other road users.
 - f. Dust and noise can be further reduced through careful planning of site layout and inclusion of screening such as vegetated buffers.
4. Develop a contingency plan (e.g. additional short-term storage capacity, composting, or burial) in the event of a collection or disposal failure.

Further details on risks and controls associated with on-site storage for off-site disposal are available in the Egg Industry Environmental Guidelines (McGahan et al. 2018).

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

Specific requirements for on-site storage and off-site disposal of dead birds (and classifications of waste) may vary between jurisdictions. Local and State regulators should be contacted in advance to ensure that all requirements are met.



8

Wastewater

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8. Wastewater

Relatively small volumes of wastewater are generated from egg production facilities. Wastewater is produced both regularly (e.g. from grading) and periodically (e.g. at shed cleanout) and viable options for reuse, treatment or disposal of the wastewater may vary according to quality and volume.

To develop a wastewater management plan, you should work through the following steps to identify which options are feasible for your farm.

Step 1:

Audit wastewater volumes and predict likely volumes for a set (e.g. 12-month) period. Where possible, this should be done for each phase of production (e.g. predict wastewater volumes from shed clean-out separately from wastewater from grading). Indicative quality data should be obtained for both wastewater streams.

Step 2:

Review your local and State regulations regarding management and disposal. Identify regulations that determine which wastewater treatment, use, and disposal options are permitted and which are not permitted in your area, and whether there are limitations around the reuse of raw wastewater on-farm.

Step 3:

Research and review available options for your farm. Consider, for example, existing infrastructure, desired/available level of investment for treating wastewater for reuse, expected wastewater quality, whether the catchment is subject to water stress, the availability and cost of clean irrigation water, etc.

Step 4:

Prioritise feasible options for your farm based on the Steps 1–3.

From a waste hierarchy perspective, in order of most to least preferable, the treatment, use, and disposal options are:

1. **Filtration**. This process uses a filter to remove solid particles from wastewater.
2. **Reverse osmosis**. This is a water treatment process that uses a semi-permeable membrane to remove dissolved solids and other impurities from wastewater.
3. **Hot water heaters**. This process (which may require pre-treatment) reuses wastewater productively on-site to heat sheds.
4. **Irrigation**. Wastewater, which may require pre-treatment, is used productively on-farm for irrigating crops or pasture.
5. **Use in on-farm composting**. Where other materials (e.g. spent litter/manure) are composted on-farm, wastewater can be used for maintaining desired moisture levels.
6. **Evaporation**. Wastewater volume is reduced but no productive reuse is made, and high-salt solids need to be managed.
7. **Release to sewer**. No productive reuse is made, and a fee will be charged.

As some of the technologies and strategies in this section are unproven or uncommon in egg production (and may not be viable for small-medium producers), a more realistic hierarchy for implementation is:

1. **Irrigation**
2. **Use in on-farm composting**
3. **Filtration**
4. **Hot water heaters**
5. **Reverse osmosis**
6. **Evaporation**
7. **Release to sewer**



8.1. Filtration

Filtration is an established technique to remove impurities and particles of a certain size from wastewater. There are two main types of system:

1. **particle filtration:**
e.g. **polypropylene filter**
- &**
2. **membrane filtration:**
e.g. **microfiltration, ultrafiltration**

In particle filtration systems, solids are separated from the wastewater using a mechanical or physical means. Membrane filtration is a more advanced technique, usually employed where particle filtration is not sufficient to achieve the desired water quality. The higher (e.g. cleaner) the water must be, the more processes (e.g. steps, filter systems) that must be used. Chemical or ultraviolet disinfection may also be required, depending on end use.

Producers should engage an expert to identify the appropriate filtration system for their wastewater and its intended final use. Key considerations should include: the characteristics of the wastewater including the size of the particles needing removal, the chemical resistance required, and the water quality requirements for the treated wastewater. The appropriate filtration system (and cost and method to operate it) is therefore likely to vary farm to farm. **Table 7** compares the effectiveness of different filtration options.



For general guidance, the chicken meat *Industry best practice manual for water quality management and sterilisation on-farm* (Watson et al. 2020) listed the following as the best practice options for filtration:

- Use of multiple filters in a series, with reducing pore size (i.e. to remove smaller and smaller particles). A series of polypropylene filters, for example, could include 50 micron, 25 micron, 10 micron, and 1 micron filters; or
- Use of biological filtering after primary filtering, e.g. a biologically activated carbon filter; or
- Use of activated carbon filtering.
- Installation of an automated total dissolved solids (TDS), turbidity (cloudiness, from suspended matter) and colour monitoring system on inlet water source pre-treatment, directly after disinfection, and at the endpoint of the system.
- Replacement stocks of disinfectant chemicals, filters, and associated consumables kept on standby.
- Backup power and duplicate facilities available to treat wastewater.

Note that this was for a scenario where treated wastewater was used for drinking water.



Table 7: Effectiveness of filtration treatments

	Polypropylene filter	Ceramic filter	Pleated filter	Rapid sand filters	Semi-rapid sand filters	Slow sand filters	Centrifugal filtration	Nanofiltration	Ultrafiltration	Microfiltration
Sediment	H	H	H	H	H	H	H	H	H	H
Particulate organic matter	LM	LM	LM	LM	LM	LM	LM	H	H	H
Dissolved organic matter	L	L	L	L	L	LM	L	MH	MH	LM
TDS	-	-	-	-	-	-	-	M	L	L
Potassium	-	-	-	-	-	-	-	M	L	L
Sodium	-	-	-	-	-	-	-	M	L	L
Chloride	-	-	-	-	-	-	-	M	L	L
Fluoride	-	-	-	-	-	-	-	M	L	L
Hardness	-	-	-	-	-	-	-	LM	-	-
Calcium	-	-	-	-	-	-	-	LM	-	-
Magnesium	-	-	-	-	-	-	-	LM	-	-
Sulphates	-	-	-	-	-	-	-	LM	-	-
Iron	-	-	-	-	-	-	-	LM	-	-
Manganese	-	-	-	-	-	-	-	LM	-	-
Metal ions	-	-	-	-	-	-	-	-	-	-
Copper	-	-	-	-	-	-	-	-	-	-
Lead	-	-	-	-	-	-	-	-	-	-
Zinc	-	-	-	-	-	-	-	-	-	-

L: Low.
LM: Low to moderate.
M: Moderate.
MH: Moderate to high.
H: High.
- : N/A.

Source: Adapted from Watson et al. (2020)

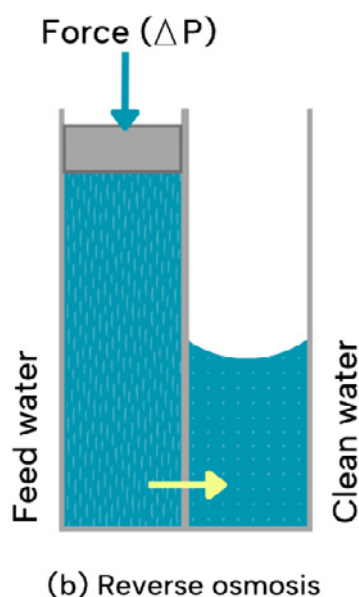
8.2. Reverse osmosis

Wastewater from grading operations typically contains broken shells, egg contents, dirt, cleaning chemicals and manure, which may prevent the raw wastewater from being beneficially reused. Treating the wastewater to remove impurities, as opposed to evaporating it, will allow for the water to be recycled for beneficial use (though not necessarily within the boundaries of the poultry unit).

Reverse osmosis (RO) is a mature and widely used water purification technology that applies significant pressure (energy) to move water molecules against osmotic pressures through a semi-permeable membrane, while most other substances remain on the other side of the membrane, and increase in concentration (see **Figure 11**).

Figure 11: Reverse osmosis process

Source: Adapted from Doble et al. (2023)



The technology is highly effective at removing sediment, particulate organic matter, and dissolved organic matter from wastewater (Watson et al. 2020). It is also a highly effective pre-treatment against salinity (including removal of potassium, sodium, chlorine, and fluoride), hardness (including removal of calcium, magnesium, sulphates, iron, and manganese), and metals (including removal of copper, lead, and zinc ions) (Watson et al. 2020).

Producers interested in adopting RO treatment of wastewater should engage with a dedicated service provider to evaluate the best options for their farm. This process should include:

- Wastewater testing so that the system can be tailored to address the contaminants, etc., specific to the wastewater.
- Customisation of the design to best treat the wastewater for the chosen purpose. This should include consideration of the size of the system to ensure cost-effectiveness.

- For example, if the treated water is to be used as drinking water for birds (e.g. as opposed to irrigation), additional treatment (e.g. ultraviolet disinfection) should be used. Costs are likely to vary based on system size and any additional treatment.
- Development of a procedure for regular maintenance of the RO system to ensure that it operates efficiently. This process should include regular membrane cleaning (this may be automatic in some systems), checking of filters, water quality assessments, and monitoring of the pressure.

RO systems require energy to operate, which may increase cost-of-production, however, ensuring the system is operating efficiently (and potentially considering renewable energy sources as part of the design phase) will limit this.

8.3. Hot water heaters

If wastewater (e.g. from grading) can be appropriately treated and cleaned, it may be feasible to reuse the wastewater in a water heat exchange/hot water convection heater. Several service providers offer water-based heating systems in Australia. These systems, which would also require the addition of an external boiler, are likely to be most cost effective in systems where heat demand is high (e.g. rearing sheds). An added benefit of the system may be the displacement of LPG for heating, reducing on-farm greenhouse gas emissions.

The major barrier to adoption is that the cost of the system per shed may be high, as demand for heating is relatively low compared to other countries, and LPG typically cheaper in Australia. If/when LPG prices rise in future, the viability and attractiveness of this technology will increase and will likely be suitable for small-medium farms, provided there is adequate demand for heating, and investment costs are acceptable.

If producers are interested in using hot water heaters to productively reuse wastewater, a detailed pre-feasibility assessment should be conducted considering:

- Capital and operating costs of hot water heater(s), and current and projected costs for heating using LPG.
- The volume of wastewater produced on-farm (and proximity to the site with the greatest demand for heat).
- Current energy demand and generation potential of the hot water heater(s).
- Water requirements of the hot water heater(s).
- Wastewater characteristics (e.g. solids, salinity, heavy metals), and whether solids separation or pre-treatment is needed, and if/how water quality requirements may differ between models.



8.4. Irrigation

Provided that wastewater is of adequate quality and the irrigation system is managed carefully, this by-product can be a valuable resource for irrigating agricultural land.



Land application of wastewater from grading or from clean-outs (may have to be treated) can allow for nutrient and water usage by crops or pastures without environmental degradation. However, poor management can result in contamination of nearby surface waters and groundwater, along with land degradation.

To develop a sustainable wastewater irrigation system for agricultural land, the following factors need to be considered:

- The volume and composition of the wastewater.
- Availability of agricultural land for crop/pasture production that is suitable for long-term irrigation with wastewater.
- Availability of additional clean water supplies for diluting wastewater (as/if required).
- Irrigation infrastructure, including wastewater storage.
- Water treatment technology (if required).
- Management expertise to run the system.

Key components for the sustainable use of wastewater for irrigating agricultural land are:

- Ensuring that soil properties of the irrigated land and rainfall patterns are conducive to the long-term use of wastewater for irrigation.
- Balancing the addition of nutrients with the off-take of nutrients in agricultural produce, the safe soil storage capacity of phosphorus in the soil, and acceptable nutrient losses.
- Monitoring and managing other contaminants in the water (salts and sodium) to prevent soil degradation.

Nutrients

A representative wastewater sample should be collected and sent for analysis before management decisions are made. This will provide information to estimate the likely applications of nutrients and contaminants. The amount of nutrients contained in wastewater expressed in kg/ML (megalitre) is identical with values expressed in mg/L. Nutrients supplied with irrigation water need to be included in nutrient budgets (see **Appendix 3 – Nutrient budgeting (general information)**).

Since 100 mm depth of irrigation applied to one hectare = 1 ML/ha, calculating the application of nutrients is relatively straight forward. Once the wastewater volume and the total nutrient contents are known, the nutrient application rates per hectare can be determined. Ideally,

wastewater with high salt content should be mixed with clean irrigation water ('shandied') to lower the concentration of salts, to prevent potential issues such as leaf burn and accumulation in the soil. Agronomic advice should be sought on this, based on the soil and crop type. If clean water is not available, application of wastewater will need to be carefully managed to avoid soil and plant damage. If it is not possible to shandy the waste with 'clean' irrigation water and rainfall is low, crop yield and nutrient uptake can be put at risk. This means that wastewater will need to be applied to larger areas (i.e. at a lower application rate) to avoid over applying nutrients.

If there is a limited amount of land that is suitable for irrigation with wastewater, nutrient removal becomes an important consideration, to keep nutrient levels within an acceptable range. High rates of nutrient removal will ensure that the irrigation area does not become overloaded with nutrients and a threat to the environment. Potential nutrient imbalances in the wastewater need to be considered, which can be done by means of a 'rolling' nutrient budget for each paddock. If the nutrient imbalance is severe, wastewater should be applied at rates that satisfy nutrient demand for the most limiting nutrient.

Crops with maximum nutrient removal capacity are typically high yielding fodder plants, for example maize or forage sorghum. Pasture or lucerne for hay production can also remove a significant amount of nutrients (see **Table 20**). When aiming to maximise nutrient off-take, the key is to maximise plant yield and harvest the whole plant as hay or silage.

Grazing will remove very few nutrients from the system (see **Table 20**), as a large percentage of the fodder that livestock consume is returned to the paddock in the form of manure and urine. This is why pasture for grazing is not generally a sustainable option for irrigation with wastewater, unless the applied wastewater has low concentrations of nutrients.

Another way of managing nutrient application per hectare is to rotate applications to different paddocks in different years. This will reduce the overall amount of nutrients applied over time, but increases the area required for irrigation infrastructure and crop management.

Specific requirements for irrigation of wastewater may vary between jurisdictions. Local and State regulators should be contacted in advance to ensure that all requirements are met.

Managing contaminants

Wastewater can contain undesirable elements and pathogens. Of particular concern are elevated levels of sodium (Na) and chloride (Cl) found in some wastewater. Chloride toxicity varies between different plant species. Many horticultural species are sensitive to soil chloride



levels of < 300 mg/kg whilst broadacre crops are more tolerant, with critical levels for wheat in the order of 600 mg/kg and 700 mg/kg for sorghum (Wiedemann & Gould 2018). For cotton, however, the critical soil chloride toxicity concentration is 1,600 mg/kg (Wiedemann & Gould 2018). If chloride toxicity levels approach the toxic thresholds, and no action is taken to reduce the chloride toxicity, crop yields will decline.

Sodium ions attach to clay in soil, which can cause the soil to become more dispersive, or 'sodic'. Sodic soils are commonly associated with reduced water availability, susceptibility to wind and water erosion as a result of soil dispersion, crusting or sealing of the soil surface, and poor productivity, all increasing management requirements (Wiedemann & Gould 2018). Sodicty is commonly measured by the exchangeable sodium percentage (ESP) of the soil, which is the relative amount of sodium ions present in the soil, reported as a percentage of the total exchangeable cations in the soil (Wiedemann & Gould 2018). The general criteria for classifying sodicty in soils are outlined in **Table 8**.

Table 8: General criteria for classifying sodicty in soils
Source: Adapted from Northcote and Skene (1972)

Criteria	Description
ESP < 6	Non-sodic
ESP 6–15	Sodic
ESP >15	Strongly sodic

If the wastewater available has high levels of Na and Cl, this can be managed by:

- Determining the tolerable/maximum amount of wastewater (salt) that can be applied per ha and year on irrigated paddocks.
- Diluting wastewater with 'clean' water. This will result in less salt being applied per hectare but may require an increased irrigation area to utilise the available wastewater.
- Rotating the land used for irrigation from one season to the next.
- Applying and incorporating gypsum if the soil becomes sodic and dispersive.
- Flushing salt accumulation with clean water after wastewater application.
- Growing salt tolerant plants if levels rise.

Wastewater that is not purified and disinfected should not be irrigated onto crops that enter the human food supply chain and are eaten raw (e.g. leafy vegetables) or with minimal processing within a month of harvest. Refer to Freshcare standards for guidance (Freshcare 2020). A minimum withholding period of 21 days for livestock is recommended for paddocks that have been irrigated with wastewater to protect animals from pathogen risks.

Irrigation of range areas may also pose a biosecurity risk (beyond the potential for Salmonella in untreated wastewater) as verdant ranges can attract wild birds.

8.5. Composting

Wastewater can be used for maintaining desired moisture levels in composted material. However, wastewater should only be used in the initial stages of active managed on-farm composting. Disposing of wastewater via evaporation during the composting process is not necessarily a good idea, as this approach will not only require additional bulking material and additional turning to ensure that the moisture level does not become too high, but it is also likely that relatively high quantities of leachate will be generated, which need careful management.

Composting facilities will presumably be located at a distance from wastewater sources meaning that a tanker/slurry tanker may be needed to move wastewater from holding ponds or the source to the composting site. The wastewater holding pond can also be located at the composting site. If transported to an off-site composting operation, additional permissions and approvals may be required, including being transported by an approved transporter. Biosecurity protocols (e.g. covering loads, sanitising equipment) must also be observed if moving solids removed in the treatment process or from evaporative ponds to composting facilities.

Where solid organic material is separated from wastewater streams on-farm (e.g. from grading floor wastewater), the material can be co-composted on-farm with manure/spent litter, etc. If organic solids separated during the wastewater treatment process or gathered from evaporative ponds are moved to external composting facilities, biosecurity protocols (e.g. covering loads, sanitising equipment) must also be observed.

8.6. Evaporation

Evaporative basins are a wastewater disposal method in dry regions where evaporation rates greatly exceed rainfall. This is less preferred to irrigation (where it can be done sustainably) or other forms of wastewater reuse, however, in areas where cropping is not feasible and/or where there is no access to clean irrigation water for shandying, evaporation of wastewater the next best option (from an environmental perspective).

Evaporation ponds can have any shape and size but are typically shallow with a large surface area. A pond should be sized to hold a one in 20-year, 24-hour storm event or not overtop more than once every 20 years on average, whichever is the higher. Local and State regulations may require more stringent design than this and should be consulted before investing in this option. These can be built as long narrow basins along the contour.



A large surface area relative to pond depth will maximise the evaporative rate.

If solids are not removed from the wastewater prior to entry to the pond, they will need to be removed from the bottom of the pond periodically. The gradual buildup of salts in the pond may also require solids removal when dry to lower salt concentrations, as high levels reduce water evaporation rates. However, solids or slurries removed from evaporation ponds may be difficult to use or dispose of due to high salt content.

8.7. Release to sewer

Discharge of wastewater from egg production to sewer is the least preferred option from an environmental point of view, as no productive on-site reuse is made of the wastewater.

Egg producers have to pay to dispose of wastewater (as part of local council levy), based on the quantity and quality of discharged wastewater.

If off-site disposal to sewer is the only viable option available, producers should periodically reassess their options to determine whether an alternative avenue is available.





9

Shells and broken eggs

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9. Shells and broken eggs

Small amounts of egg waste (shells and broken eggs) are generated during laying operations, and on the grading and pulping floors. Effective utilisation or disposal of these materials is needed to avoid disease transfer, hygiene problems, and amenity impacts (odour) and contamination of surface water and groundwater.

Eggs with unsuitable cracks, leakers, and heavy dirt that are not suitable for packing should be effectively contained in a sealed container for transfer to an appropriate facility (a licensed and approved egg processor) for pasteurisation. Where this is not possible (e.g. due to location), or where the condition of the eggs or bacterial load does not allow it, alternative management is needed.

To develop a waste management plan for egg waste, you should work through the following steps to identify which options are feasible for your farm:

Step 1:

Audit egg waste volumes and predict likely volumes for a set (e.g. 12-month) period. These will likely only be a small volume (see [Appendix 2 – Industry baseline](#)), however, where floor eggs are a problem, there may be a significant volume of eggs that end up in waste streams.

Step 2:

Review your local and State regulations regarding management and disposal. Identify which processing and disposal options are permitted and which are not permitted in your area.

Step 3:

Research and review the available options and identify those feasible for your farm. Consider, for example, the level of investment available for managing broken eggs or shells, whether it is possible to source additional labour, etc.

Step 4:

Prioritise feasible options for your farm based on the Steps 1–3.

From a waste hierarchy perspective, in order of most to least preferable, the options are:

1. **Feed to animals.** Utilising broken eggs as animal feed is an environmentally optimal outcome, although this option is not feasible in all jurisdictions due to swill classifications and feeding restrictions.
2. **On-farm co-composting.** Eggshells and broken eggs can be co-composted with other streams (e.g. spent litter/manure). The end product can (generally) either be used productively on-farm or sold for productive use elsewhere in the economy.
3. **Separation** of shells and membranes. Separating eggshells may increase their value and utility, however, capital investment is required.
4. **Burial.** Burial of shells and broken eggs at the farm avoids landfill disposal, but does not make any beneficial use of the by-product and can have environmental and biosecurity impacts if not managed correctly.
5. **Off-site disposal in landfill.** This is the last-resort scenario as it makes no beneficial use of the by-product. Egg producers will have to pay to dispose of the by-products, which will be treated as waste.

Producers should regularly assess whether there are opportunities to reduce the volume of shells and broken eggs produced on-farm, e.g. by keeping up to date with research into opportunities to reduce floor eggs, maintaining equipment at the shed and grading floor to reduce breakage, proactively engaging with nutritionists to manage eggshell quality, and encouraging staff to prioritise appropriate handling of eggs.

Other uses for shells and broken eggs have been investigated (Section 9.6), however, the majority of those not covered in detail here are either advanced technologies not yet applicable at the farm-scale (e.g. blue-sky/potential opportunities) or are minor use options (e.g. on-site garden use).

The list of options in this section is not exhaustive. Depending on the scale of production, it may be possible to use broken eggs with other materials to generate energy (see [Appendix 4 – Anaerobic digestion](#)), in processes to capitalise on the nutrient value of the material (see [Appendix 6 – Rapid composting](#)), or potentially as a feedstock for insects (see [Appendix 6 – Feedstock for insects](#)).



9.1. Animal feed

In some jurisdictions, it is possible to feed broken eggs to animals, while that is not the case in others.



In New South Wales, for example, eggs can be fed to pigs, however, in Queensland this is prohibited.

Producers need to consult the relevant State regulations to determine whether and to what animals eggs can be fed, e.g. ferrets can eat eggs but are prohibited as pets in Queensland and the Northern Territory. There are limited opportunities to use broken eggs as animal feed due to a lack of available options. Pigs are the only really viable option for feeding broken eggs (in states where that is allowed), but their diets are usually specially formulated and biosecurity/animal health risks may prevent this.

If producers do find a suitable market/customer for broken eggs, biosecurity risks associated with transporting eggs or with third parties entering the farm to collect eggs must be managed. If transported off-site, additional permissions and approvals may be required, including transportation by an approved transporter.

This strategy may be most viable for small-scale egg producers operating diversified farms or located near to small-scale piggeries, etc.

9.2. Co-composting

Co-composting broken eggs or shells with other farm materials (e.g. manure/spent litter) is a viable option for managing shells and broken eggs. The end-product can be used productively on-farm, sold off-farm as compost, as an organic fertiliser/soil ameliorant.

These options ensure that the material contributes to either closed-loop production or a circular economy. Note, to be sold as 'AS4454 compliant compost/compost manufactured to AS4454 standards', the requirements of the standard must be met. Check if you need a permit to build and operate a composting facility at your preferred location. This might depend on whether or not you are planning to use bulking material from external sources.

If co-composting broken eggs or shells, the general process outlined in **Section 6.4 – Conventional (windrow) composting** can be followed, however, producers will need to monitor the carbon to nitrogen ratio, oxygen supply, and moisture levels because of the added material. The shells and broken eggs are likely to be a small proportion of the total material composted, however, producers should ensure that characteristics of the initial feedstock mix are within the desired range, and that their established processes are maintained, and be willing to adapt either if necessary to facilitate

the composting process and ensure production of good quality material.

Breaking cracked eggs before co-composting may speed up the rate of decomposition and prevent eggs from rolling away. Producers should also monitor for any increased risk of pests/scavengers and take steps to ensure that eggs are covered by a minimum 300 mm of bulking material and/or strengthen exclusion infrastructure as necessary.

9.3. Separation

A large proportion of shells generated at pulping facilities are sent to landfill or are buried (see **Appendix 2 – Industry baseline**). The primary value of the shells is likely to be their calcium and carbon content.

Many poultry equipment suppliers offer eggshell centrifuges to separate remnant liquid egg from shells. Centrifuges may range in processing capacity from 20,000 shells per hour to 252,000 shells per hour, and should therefore be a scalable technology. The capital cost of a smaller 20,000 shell per hour centrifuge may be in the order of AU\$13,500 and may require 5.5 kW of power to operate.

Producers or facility managers interested in centrifuges should conduct a pre-feasibility assessment, considering the following:

- Broken egg/shell volume and required processing capacity of a centrifuge.
- Capital and maintenance costs of the centrifuge.
- Processing capacity compared with broken egg/shell volume at site.
- Energy requirements (and costs) to operate the centrifuge.
- Labour requirements (and costs) to operate the centrifuge.
- Access to market/end-user(s) willing to pay for separated material(s).

Full separation of eggshell from its membrane may increase the value of the eggshells, opening up alternative strategies for reuse within the egg industry or via the sale of eggshells to other industries. This separation could be done by grinding eggshells into a powder and immersing the powder in water to separate the membrane. The heavier shells sink whilst the lighter membrane will stay suspended in the water. Eggshell membranes are high in collagen and separated membrane may have the potential to be used in the pharmaceutical and cosmetic industries. The separated eggshells can be used in a variety of ways on-farm. These include as a calcium supplement for layers late in the production phase, a calcium supplement to fertilisers, and a soil amendment that can fully or partially replace lime or dolomite.



Shells can potentially be monetised for their calcium and carbon value by selling them to farmers for land application (lime substitute) or as a feed ingredient. It might be possible to sell shells to local fertiliser producers or supply them to a composting operation, although it is doubtful that this option will provide a return. Currently, 5% of shells from pulping facilities are used in composting facilities, although this could be in composting operations run by the pulping facility owners.

9.4. Burial

On-site burial of broken eggs and shells (most likely alongside other by-products, e.g. mortalities) presents few benefits and several risks that must be managed. Burial is a 'worst case' scenario from an environmental perspective, as the by-products are treated as a waste (generating negative environmental outcomes) and do not contribute to either closed-loop production (on-farm) or a circular economy (used productively off-farm).

To bury eggshells and broken eggs on-site, the following steps must be followed (if co-burying with daily mortalities, refer to **Section 7.7 – Burial**, and Step 2 below):

1. Construct a purpose-built pit.
 - a. Identify a location which will minimise potential odour and dust impacts off-site. Consider factors such as the location of sensitive receptors, and prevailing meteorological conditions. It should also be located a safe distance from underground and aboveground infrastructure, such as gas lines, water pipes, power lines.
 - b. Ensure that the base of the pit will be at least 2 m above the seasonal high water table level, and that it is located at least 200 m from any surface water.
 - c. Where risks to the groundwater are present (see Section 2.6.3 and Appendix B of the *Egg Industry Environmental Guidelines* (McGahan et al. 2018)), pits must be lined with an impermeable liner or compacted clay lining. Note that this can be difficult to achieve and may present operational and financial challenges in which case alternative options should be considered.
 - d. Ensure that you have access to the appropriate machinery (excavator, loader) or purchase new/used machinery.
 - e. Ensure that you have/will have adequate covering material (sawdust, soil, etc.) on-hand.
 - f. Dig the pit, noting that an excavator is the preferred equipment to do so.
 - g. Fence the burial area to prevent entry of pests (e.g. rodents) and feral animals.
2. Commence the burial process.
 - a. For broken eggs, a layer of dry material (e.g. sawdust, straw) should be placed at the bottom of the pit to absorb moisture.
- b. Ensure for both burial of shells and broken eggs and co-burial (e.g. with mortalities) that the pit is sized appropriately, to ensure adequate space for all by-products and covering materials for each disposal.
 - i. *If broken eggs cannot be quickly buried (e.g. immediately after detection at grading), they should be safely stored (e.g. at temperatures well below 7°C) and should be appropriately disposed of (even if stored well below 7°C) if burial has not taken place within three days.*
- c. Place broken eggs and shells in the pit.
3. Immediately cover the material with appropriate materials (sawdust, soil, etc.) to reduce emissions of odour. Requirements vary between states, however, a minimum of 300 mm of covering material is recommended.
4. Cover the pit when full with at least 500 mm of mounded compacted clay to seal it and account for subsidence. This will minimise the potential of leaching and transmission vectors for pathogens.
5. Ensure that the appropriate control measures are in place.
 - a. Where risks to surface water are present (see Section 2.6.3 and Appendix B of the *Egg Industry Environmental Guidelines* (McGahan et al. 2018)), water should be excluded from the burial area through bunding or diversion banks/swales. Rain can be excluded using roofed structures.
 - b. Vehicle movements should be minimised by careful planning of timing of operations. Noise can be minimised through appropriate separation distances and noise reducing screening, such as vegetated buffers (which may also reduce dust).

Specific requirements for burial may vary between jurisdictions. Local and State regulators should be contacted in advance to ensure that all requirements are met.

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

9.5. Landfill

Off-site disposal of shells and broken eggs is the ‘worst case’ scenario from an environmental perspective, as the by-products are treated as a waste (generating negative environmental outcomes) and do not contribute to either closed-loop production (on-farm) or a circular economy (used productively off-farm). Producers are also likely to have to pay to dispose of the by-products.

If off-site disposal is the only viable option for dealing with eggshells and broken eggs, producers should periodically reassess their options to determine whether an alternative avenue is available and follow the general principles presented for disposal of day-to-day mortalities in **Section 7.8 – Landfill**.

9.6. Other uses for eggshells

There are various other ways eggshells can be beneficially used (practically and in theory) but a major challenge is that only a relatively small proportion of Australia’s eggs go to pulping (< 5%). In most cases, the usually small volume of shells generated at individual facilities is too small and/or located too far away for commercialised applications beyond those described above. In addition, transport distances may make other centralised processing/utilisation options unviable. On-farm processing of eggshells on a commercial scale (e.g. processing eggshells or membranes into food additives, or purified calcium carbonate) would be a high capital cost project. A previous study estimated that the lowest level of capital investment would be in the order of AU\$750,000 (derived from Quina et al. 2017). As an animal by-product, there may be regulatory restrictions on the re-use of eggshells and membranes in certain capacities and jurisdictions in Australia.





10

Spent hens and off-sex chicks

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10. Spent hens and off-sex chicks

To develop a waste management plan for spent hens, you should work through the following steps to identify which options are feasible for your farm. Hatcheries should follow a similar process.

Step 1:

Audit spent hen volumes and predict likely volumes for a set (e.g. 12-month) period. Consider whether there is likely to be an increase or decrease in numbers in the short- to medium-term (e.g. expanded production).

Step 2:

Review your local and State regulations around spent hen management and disposal. Identify what is permitted and what is not permitted in your area, and whether there are limitations around the use (on and off-site) of end-products.

Step 3:

Research and review the options available for spent hen management and identify those feasible on your farm. Consider, for example, what level of investment is available to manage spent hens, whether it is possible to source additional labour, what land area/facilities are available to dedicate to spent hen treatment, where that land sits in relation to sensitive receptors, etc.

Step 4:

Prioritise feasible options for your farm based on the Steps 1–3.

From a waste hierarchy perspective, in order of most to least preferable, the options are:

1. **Windrow composting**. The end-product can (generally) either be used productively on-farm or sold for productive use elsewhere in the economy.
2. **On-farm processing (bays and piles)**. The end-product can (generally) either be used productively on-farm or sold for productive use elsewhere in the economy.
3. **Burial**. This avoids landfill disposal but does not make any beneficial use of the by-product and can have negative environmental and biosecurity impacts if not managed correctly.
4. **Off-site disposal in landfill**. This is the last-resort scenario as it makes no beneficial use of the by-product, and producers will likely have to pay disposal fees.
5. **Sale to local markets**. This avoids the spent hens being treated as a waste stream (e.g. in on-farm burial or landfill disposal), however, this practice should be avoided due to biosecurity, bird health, and industry social licence risks.

The list of options in this section is not exhaustive. The following sections of Appendices 4–6 provide further information. Established disposal methods are still viable (see **Meat processing**, **Rendering**) and are preferred environmentally. Depending on the scale of production, it may be possible to use spent hens to generate energy (see **Anaerobic digestion**, **Combustion**) or to pre-process birds so they can be handled more easily and processed on-farm (**Spent hen drying**, **Feedstock for insects**). Options that warrant further investigation via industry research include **Maceration/grinding** and **Dedicated spent hen processors**.

For hatcheries, the options described above are generally feasible. **In-ovo technology** (Section 10.6), however, is an emerging technology that may aid in reducing off-sex chick volumes in future.



10.1. Windrow composting spent hens

The method for composting spent hens in windrows is more or less identical to that described in **Windrow composting** mortalities (Section 7.2). However, producers must have access to a much larger composting area than for daily mortalities (e.g. the number of spent hens will be much greater), and much more bulking material will be required (see **Bulking material requirements for carcass composting** in Section 7.1 to estimate this).



Spent hens must be euthanised prior to composting. Once euthanised, the carcasses should be transferred to the composting area, placed in the windrows, and covered immediately.

This means that all necessary preparation needs to have been done (i.e. up to step 6 below), and that enough bulking material must be on hand.

The initial decomposition phase (carcasses largely decomposed) can be completed in approximately 1–2 months. The product will still require further stabilising and curing to be fully pasteurised and matured. As a general rule, hen carcasses are likely to be fully broken down in around 2–3 months after the initial static phase, with regular turning (e.g. fortnightly after initial static decomposition).

A general guide to windrow composting of spent hen carcasses is as follows:

1. Identify an appropriate site and plan site layout.
 - a. Based on the audit of waste and by-product volumes produced on your farm, determine the size of the area required to accommodate the predicted number and volume of spent hens.
 - i. *To calculate an area, you will need to determine the number/volume of spent hens, and bulking material, and the height, width, and number of windrows.*
 - ii. *As a rough guide work on about 10 m³ of windrow for every 1,000 carcasses. A large windrow with a 45° side slope, 4.0 m wide, 1.8 m in height, and 140 m long would be approximately 500 m³ in volume and could accommodate 50,000 spent hens.*
 - iii. *Allow additional area for machinery to pass between windrows. Note that front-end loaders require more space to operate than tractor-driven straddle turners.*
 - b. It will need to minimise dust, noise, and off-site impacts (odour), e.g. choose a site with appropriate separation distances and (or potential for) vegetative buffers.
 - c. It must be located at a sufficient distance from production facilities to minimise the risk of pathogen spread.
- d. Check if you need a permit to build and operate a composting facility at your preferred location. This might depend on whether or not you are planning to use bulking material from external sources.
2. Build the site or facility. A general list of requirements/specifications include:
 - a. An impermeable surface or compacted clay pad. This will ensure that the pad is trafficable in all weather conditions and prevent leaching to groundwater.
 - i. *The base should be designed to achieve a design permeability of 1x10⁻⁹ m/s over a depth of 300 mm.*
 - ii. *A sealed concrete base is most preferred to minimise leaching.*
 - iii. *Depending on available equipment and expertise, producers may be able to do this themselves, or a contractor could be engaged (e.g. particularly for lime or cement stabilisation).*
 - b. Site drainage to avoid excessive moisture and muddy conditions.
 - c. Where there is potential for a large amount of runoff from the storage area (i.e. high rainfall), consider a roof structure to eliminate rain falling on compost. If contaminated water needs to be captured, use a detention basin and vegetative filter area to avoid stagnant water being stored hence reduce biosecurity risks.
 - d. Where surface water risks are present (see Section 2.6.3 and Appendix B of the *Egg Industry Environmental Guidelines* (McGahan et al. 2018)), water should be excluded from the area through bunding or diversion banks/swales (see **Figure 3**).
 - e. Exclude scavenging animals from carcass composting facilities with appropriate fencing and gates (e.g. chain wire, electric).
 - f. Obtain quotes for an appropriately sized new/used windrow turner, and purchase/hire preferred machine.
 - i. *Front-end loaders are often the first choice for windrow or pile turning in smaller composting operations as they may already be available on-farm and can be used for other purposes (ensure Step 6 below is followed). They are, however, slow to operate and care should be taken to ensure that the compost is adequately mixed.*
 - ii. *A variety of windrow compost turners are available, including three-point linkage units, PTO driven trail behind units, self-powered units (driven off a separate engine but attached to a tractor), and self-propelled units.*
 1. The scale of the composting operation is usually the best determiner of the required size of the compost turner. For example, three-point linkage units are available for



small- to medium-scale composting, while trailing or self-propelled units are more suited to large-scale operations.

2. Tractor-drawn models can generally turn a windrow less than 3 m high, whilst some self-propelled models can turn windrows up to 4 m high by 4 m wide.
3. Turning rates will vary with the size and type of turner. Three-point linkage turners are limited to a turning rate of 200–400 m³/hr, tractor drawn turners may have a rate of 400–800 m³/hr, and self-propelled turners can turn at rates of 1,200–6,500 m³/hr.
- g. Devise a system of adding water to windrows, and establish required infrastructure/ obtain required equipment.
 - i. *Some turners can apply water to windrows using a trailing hose system. Alternatively, some windrow turners can tow a tanker that will supply water during turning or the tanker could be used independently to apply water immediately prior to turning. The latter option may be more appropriate for small to medium operations without water infrastructure.*
- h. Check if you own a tractor with creeper gears (to travel at low speed). If not, you need to obtain an appropriately sized tractor with creeper gears. Alternatively, hydraulic assist features are available for turners to negate the need for a creeper gear.
- i. Check if you have adequate material handling equipment (e.g. loader), and if not, you need to obtain appropriate equipment.
- j. Obtain suitable bulking material.
- k. If you are aiming to sell compost, you might require a screen.
3. Begin the composting process.
 - a. Put down a 300 mm layer of bulking material (sawdust, straw, or other carbon source) on the bottom of the windrow.
 - b. Add carcasses (1.5 birds deep per layer). To do this, lay the first layer of carcasses side by side. The next set of carcasses should be placed on top of the first layer, so that the torsos of the second layer are on top of the heads, necks, and feet of the first layer. This will create a more level layer of carcasses, with a height roughly equal to about 1.5 birds, ~200 mm high (see **Figure 6**).
 - c. If necessary, wet down the feathers of the birds, adding approximately 1 L per 3 carcasses, but note that this is not essential for carcass composting.
 - d. Add a layer of bulking material (100–150 mm) at a ratio of approximately 3:1 (v/v) of bulking material to carcass mass before adding further layers of carcasses, ensuring that 100–150 mm of bulking material remains over previous carcasses (see **Bulking material requirements for carcass composting** in Section 7.1).
- e. Ensure that the top layer of carcasses is covered by 300 mm of bulking material.
- f. Windrows are generally 1.5–2 m high and 3–4 m wide at the base. The size will be dependent on the equipment used to undertake the turning. A large windrow with a 45° side slope, 3 m wide, 1.5 m in height, and 43 m long would be approximately 100 m³ in volume and could accommodate 10,000 carcasses.
- g. Windrows should be peaked (triangle-shaped) so they can shed rainfall.
- h. Any runoff must be captured (not pool around piles) immediately for reuse in the compost or applied to land.
4. It is important to manage the physical and chemical characteristics of the composted material to maintain temperature, moisture, pH, and nutrient ratios within the appropriate ranges, and ensure that the generated product is pasteurised, and its characteristics are within a range of expected values.
5. The composting process needs to be managed and monitored to generate products that meet certain characteristics for both on-farm and off-farm use:
 - a. The windrow should be left in a static phase (i.e. not turned) for 1–2 months so that the carcasses can begin to breakdown.
 - b. Monitor the temperature and moisture level and turn regularly (e.g. fortnightly) after the initial static stage. Add water as required.
 - i. *After each turn, ensure that no decomposing carcasses are exposed. If carcasses are exposed, cover with a minimum of 300 mm of bulking material.*
 - c. After about 10 weeks into the process, record the temperature before and after turning (next day). If turning does not result in increased temperatures, provided the moisture content is adequate, the material is approaching the maturation stage. Allow to mature for around 4 weeks, i.e. the process will be complete after about 14 weeks.
 - i. *If it does heat, test again 1–2 weeks later, then allow 4 weeks to cure, i.e. the process will be complete in about 16 weeks.*
 - ii. *Repeat this process until windrow no longer heats above 30–35°C.*
 - d. Ensure that material does not dry out and is adequately dampened during the turning process to reduce risk of aerosolised pathogens. As dry organic materials are hydrophobic, it is difficult to re-wet composted material that has dried out. Exercise caution as excessive application of water can cause nutrient runoff or anaerobic conditions, increasing odour potential.



- e. Time turning to avoid strong winds blowing toward the production area or sensitive receptors.
 - f. The end-product should no longer resemble the original materials, i.e. it should be a brown/black, earthy material, and any leftover coarse woody material should be easily broken down if rubbed between your fingers. The material should not smell like vinegar or rotting matter but should smell like soil, although composted layer manure tends to retain the smell of ammonia for a long time. If the material smells bad, it should be turned and left to cure further before being tested again.
 - g. Move the finished compost from the composting pad to the storage area, or load onto trucks for immediate land application.
 - h. If the compost is used off-farm, particularly in horticultural production systems, it might be necessary to screen the compost to allow delivery of product with defined particle size (e.g. < 10 mm) and to ensure that the compost does not contain undesirable impurities (e.g. rocks, plastic).
6. Sanitise/quarantine equipment used in moving mortalities or managing compost prior to use in production areas.

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

10.2. Bays and piles

The method for composting spent hens in bays and piles is more or less identical to that described in **Bays and piles** (Section 7.3) for day-to-day mortalities. However, producers must have access to a much larger composting area and more/larger bays or piles than for daily mortalities (e.g. the number of spent hens will be much greater) and much more bulking material will be required (see **Bulking material requirements for carcass composting** in Section 7.1 to estimate this).

Spent hens must be euthanised prior to processing in bays or piles. Once euthanised, the carcasses should be transferred to the processing area, placed in the bays or piles, and covered immediately. This means that all necessary preparation needs to have been done (i.e. up to and including step 5e below), and that enough bulking material must be on hand.

The initial decomposition phase of the process (carcasses largely decomposed) can be completed in approximately 1–2 months, where they remain in an unmixed static pile. The material will still require further stabilising and curing to be fully matured. Hen carcasses are likely to be fully broken down in around 2–3 months if the composted material is regularly turned (e.g. fortnightly) and watered (if needed) after the initial static phase, and in 6–9 months if the material is not regularly turned and watered (i.e. in a mostly static pile). Exact timeframes may vary from location to location.



A general guide to bay and pile processing of spent hens is as follows:

1. Identify an appropriate site and plan site layout.
 - a. Based on the audit of waste and by-product volumes produced on your farm, determine the size of the area required to accommodate more than the predicted number of spent hens.
 - i. *To calculate an area, you will need to determine the volume of dead birds and bulking material (see **Bulking material requirements for carcass composting** in Section 7.1), and the height, width and number of the piles or bays.*
 - ii. *As a general guide, allow 10 m³ of pile per 1,000 carcasses, thus a pyramid shaped pile that is 10 m wide, 10 m deep and 1.5 m high would be approximately 50 m³ and could accommodate approximately 5,000 spent hens. The number of bays/piles will be dependent on the time interval between spent hen culling events and the total length of the composting period.*
 - iii. *Consider whether it is prudent to allow for additional area/bays (e.g. due to planned new sheds/increase in production).*
 - b. Choose a site and layout that will also minimise dust, noise, and off-site impacts (odour), e.g. one with appropriate separation distances and (or potential for) vegetative buffers.
 - c. The site must be located at a sufficient distance from production facilities to minimise the risk of pathogen spread.
2. Exclude scavenging animals from composting facilities with appropriate fencing and gates (e.g. chain wire, electric).
3. Ensure that you have access to or obtain quotes for a new/used loader, and purchase/hire preferred machine.
4. Obtain suitable bulking material.
5. Build the facility. A general list of requirements/specifications include:
 - a. An impermeable surface or compacted clay pad (required for both bays and piles).
 - i. *The base should be designed to achieve a design permeability of 1x10⁻⁹ m/s over a depth of 300 mm.*
 - ii. *A sealed concrete base is most preferred to minimise leaching.*
 - iii. *Depending on available equipment and expertise, producers may be able to do this themselves, or a contractor could be engaged (e.g. particularly for lime or cement stabilisation).*
 - b. For bays, sidewalls can be timber, concrete or plywood with timber supports or, for a cheaper option, hay/straw bales can also be used as temporary walls.
 - i. *Note that permanent systems (e.g. concrete floor, timber or concrete sidewalls, roof) may provide for easier operation and management but are most suited to large farms, with bays filled progressively as mortalities accumulate.*
6. Begin the composting process.
 - a. Put down a 300 mm layer of bulking material (sawdust, straw, or other carbon source) on the bottom of the bay/pile (see **Figure 6**).
 - b. Add hens (1.5 birds deep per layer). To do this, lay the first layer of carcasses side by side. The next set of carcasses should be placed on top of the first layer, so that the torsos of the second layer are on top of the heads, necks, and feet of the first layer. This will create a more level layer of carcasses, with a height roughly equal to about 1.5 birds, ~200 mm high.
 - c. In bays, carcasses should not be placed closer than 300 mm to the walls (see **Figure 8**).
 - d. If necessary, wet down the feathers of the birds, adding approximately 1 L per 3 carcasses, but note that this is not essential for carcass composting.
 - e. Add further bulking material at approximately 3:1 ratio bulking material to spent hen mass, ensuring 100 to 150 mm of bulking material remains over previous carcasses (see **Bulking material requirements for carcass composting** in Section 7.1)
 - f. Ensure that the top layer of spent hens is covered by 300 mm of bulking material (see **Figure 6**).
 - g. Piles should be peaked (triangle-shaped) so they can shed rainfall and no higher than 3 m.
 - i. *Any runoff must be captured (not pool around piles) immediately for reuse in the compost or applied to land.*
7. It is important to manage the physical and chemical characteristics of the material to maintain temperature, moisture, pH, and nutrient ratios



within the appropriate ranges, and ensure that the generated product is pasteurised, and its characteristics are within a range of expected values (see [Wiedemann et al. 2008](#) and [Section 7.1 – Composting carcasses \(general information\)](#)).

8. The composting process needs to be managed and monitored in order to generate products that meet certain characteristics for both on-farm and off-farm use:
 - a. Monitor the temperature and moisture level and turn regularly (e.g. fortnightly) after the initial static stage. Add water as required.
 - i. *After each turn, ensure that no decomposing carcasses are exposed. If carcasses are exposed, cover with a minimum of 300 mm of bulking material.*
 - b. After about 10 weeks into the process, record the temperature before and after turning (next day). If turning does not result in increased temperatures, provided the moisture content is adequate, the material is approaching the maturation stage. Allow to mature for around 4 weeks, i.e. the process will be complete after about 14 weeks.
 - i. *If it does heat, test again, 1–2 weeks later, then allow 4 weeks to cure, i.e. the process will be complete in about 16 weeks.*
 - ii. *Repeat this process until windrow no longer heats above 30–35°C.*
 - c. Ensure that material does not dry out and is adequately dampened during the turning process to reduce risk of aerosolised pathogens. As dry organic materials are hydrophobic, it is difficult to re-wet composted material that has dried out. Exercise caution as excessive application of water can cause nutrient runoff or anaerobic conditions, increasing odour potential.
 - d. Time turning to avoid strong winds blowing toward the production area or sensitive receptors.
 - e. The end-product should no longer resemble the original materials, i.e. it should be a brown/black, earthy material, and any leftover coarse woody material should be easily broken down if rubbed between your fingers. The material should not smell like vinegar or rotting matter but should smell like soil, although composted layer manure tends to retain the smell of ammonia for a long time. If the material smells bad, it should be turned and left to cure further before being tested again.
 - f. Move the finished compost from the composting pad to the storage area, or load onto trucks for immediate land application.
 - g. If the compost is used off-farm, particularly in horticultural production systems, it might be necessary to screen the compost to allow delivery of product with defined particle size (e.g. < 10 mm) and to ensure that the compost does not contain undesirable impurities (e.g. rocks, plastic).

9. Sanitise/quarantine equipment used in moving birds/ managing material prior to use in production areas.

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

10.3. Burial

On-site burial of spent hens presents few benefits and several risks that must be managed. It is also not a long-term option. This is a 'worst case' scenario from an environmental perspective, as the birds are treated as a waste (generating negative environmental outcomes) and do not contribute to either closed-loop production (on-farm) or a circular economy (used productively off-farm). On-site burial of spent hens also requires a large area, meaning it is not a viable long-term solution, particularly for farms with a large number of birds.

To bury spent hens on-site, the following steps must be followed:

1. Construct a purpose-built pit.
 - a. Identify a location that will minimise potential odour and dust impacts off-site. Consider factors such as the location of sensitive receptors, and prevailing meteorological conditions. It should also be located a safe distance from underground and aboveground infrastructure, such as gas lines, water pipes, power lines.
 - i. *Guidance for burial of carcasses during an EAD outbreak recommends that the pit be located on elevated ground but with a slope of less than 5%.*
 - b. Ensure that the base of the pit is at least 2 m above the seasonal high water table level, and that it is located at least 200 m from any surface water.
 - c. Ensure that you have access to the appropriate machinery (excavator, loader) or purchase new/ used machinery.
 - d. Ensure that you have/will have adequate covering material (sawdust, soil, etc.) on-hand.
 - e. Dig the burial pit, noting that an excavator is the preferred equipment to do so.
 - i. *Pits should be sized appropriately to ensure adequate space for burials and covering materials for each disposal.*
 1. As a general guide, allow 1 m³ of pile per 100 carcasses, thus a burial pit that is 2 m wide, 5 m deep and 1 m long would be 10 m³ and could accommodate approximately 900 carcasses (allowing room for a 500 mm compacted clay seal (see Step 4 below)).



- f. Where possible, line the pit with a carbonaceous material (e.g. wood shavings, straw) to absorb some of the liquids that will leak out from the carcasses.
 - g. Where risks to the groundwater are present (see Section 2.6.3 and Appendix B of the *Egg Industry Environmental Guidelines* (McGahan et al. 2018)), pits must be lined with an impermeable liner or compacted clay lining. Note that this can be difficult to achieve and may present operational and financial challenges in which case alternative options should be considered.
 - h. Fence the burial area to prevent entry of pests (e.g. rodents) and feral animals.
2. Euthanise birds on-site following the relevant protocols and guidance. See, for example, **Best Practice for on Farm Euthanasia of Spent Layer Hens** (Scott 2015).
 3. Place spent hens in the pit.
 - a. Burial should take place as soon as possible after euthanasia.
 - b. Where possible, a machine (e.g. loader) should be used for burial.
 4. Cover the pit when full with at least 500 mm of mounded compacted clay to seal it and account for subsidence. This will minimise the potential of leaching and transmission vectors for pathogens.
 5. Ensure that the appropriate control measures are in place.
 - a. Where risks to surface water are present (see Section 2.6.3 and Appendix B of the *Egg Industry Environmental Guidelines* (McGahan et al. 2018)), water should be excluded from the burial area through bunding or diversion banks/swales.
 - b. Vehicle movements should be minimised by careful planning of timing of operations. Noise can be minimised through appropriate separation distances and noise reducing screening, such as vegetated buffers (which may also reduce dust).

Specific requirements for on-site disposal of spent hens may vary between jurisdictions. Local and State regulators should be contacted in advance to ensure that all requirements are met.

Further details on risks and controls associated with on-site burial are available in the *Egg Industry Environmental Guidelines* (McGahan et al. 2018).

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate (e.g. carcasses may need to be buried at least 2,000 mm below the surface), and the relevant guidelines should be consulted and followed.

10.4. Landfill

Off-site disposal in landfill of spent hens significantly reduces the risks faced by the producer by removing the source of the risks off-farm.



However, this is the 'worst case' scenario from an environmental perspective, as the birds are treated as a waste (generating negative environmental outcomes) and do not contribute to either closed-loop production (on-farm) or a circular economy (used productively off-farm).

Producers are also likely to have to pay to dispose of spent hen carcasses.

If off-site disposal in landfill is the only viable option available, follow this process:

1. Identify an appropriate landfill facility.
 - a. Check with the facility to ensure that they can and are willing to accept spent hens.
 - b. Check disposal costs.
 - c. Check regulatory requirements for the landfill disposal of animal mortalities in your State.
 - d. Contractors may be required to collect birds for disposal and transport them to the landfill site.
2. Engage an adequately licensed contractor (as required).
 - a. Ensure that the contractor agrees to removals of predicted hen quantities at agreed times (i.e. immediately following on-site euthanasia).
3. Euthanise birds on-site following the relevant protocols and guidance. See, for example, **Best Practice for on Farm Euthanasia of Spent Layer Hens** (Scott 2015).
4. Undertake the removals process, adhering to biosecurity protocols.
 - a. Removals should also be timed to minimise noise, and impacts on other road users.
 - b. Dust and noise can be further reduced through careful planning of site layout and inclusion of screening such as vegetated buffers if required.
5. Develop a contingency plan (e.g. composting or burial) in the event of a collection or disposal failure.

Specific requirements for off-site disposal of spent hens (and classifications of waste) may vary between jurisdictions. Local and State regulators should be contacted in advance to ensure that all requirements are met.



Further details on risks and controls associated with on-site storage for off-site disposal are available in the *Egg Industry Environmental Guidelines* (McGahan et al. 2018).

Note that in the event of an Emergency Animal Disease incident, the steps above may not be appropriate, and the relevant guidelines should be consulted and followed.

10.5. Spent hens to local markets

Some small-scale producers sell spent hens (or keep a number of spent hens to sell) to local markets/customers as layers, as an alternative to rendering or on-farm disposal. Spent hens may sell for AU\$5–\$10 each, and sales may be advertised via social media. This practice is not recommended, however, due to the high degree of risk associated with it, ranging from biosecurity to potential damage to bird health and industry's social licence.

10.6. In-ovo technology

Traditional methods of disposal for male chicks, i.e. culling, are increasingly being subject to scrutiny on animal welfare/ethics grounds. Certain jurisdictions, including the Netherlands and France, have introduced policy to ban or phase-out chick culling on these grounds, whilst some egg supply businesses (particularly in Germany) are introducing 'no-kill' branding for eggs.

The principal alternative to chick culling is in-ovo technology, which allows identification of male chicks before they hatch, and hence prevents the existence of male chicks. In-ovo sexing is a relatively new technology, not yet widely adopted in Australia. As the technology is adopted, there will be an increase in the number of unhatched eggs requiring management. Viable management strategies for these additional unhatched eggs will likely mirror those of other hatchery by-products, including processing for animal feed and potential for composting or anaerobic digestion.



11. Plastic

To develop a waste management plan for plastic associated with egg production and processing, you should work through the following steps to identify which options are feasible for your farm.

Step 1:

Audit plastic volumes, types, and sources for a set (e.g. 12-month) period. Different types of plastic may be generated from:

- Grading: pallet wrap, damaged plastic egg cartons (if used), chemical/cleaning product bottles.
- Biosecurity: packaging associated with PPE, plastic gloves, etc.
- Animal health: outer packaging associated with medications, etc.
- Milling: plastic wrap.

Note that this list is not exhaustive, and producers should identify all sources and types specific to their egg operations.

Step 2:

Identify if/where opportunities exist to avoid plastic volumes entering your farm. This may include, for example, engaging with suppliers to determine whether alternative packaging or products with less packaging are available, or whether it is possible to purchase products in bulk. There are, for example, reusable vinyl or mesh alternatives to plastic pallet wrap, which may help reduce plastic waste streams generated on-farm.

Step 3:

Identify if/where opportunities exist to reuse plastic materials. This may include, for example, repurposing clean plastic crates and containers, etc., for storage.

Step 4:

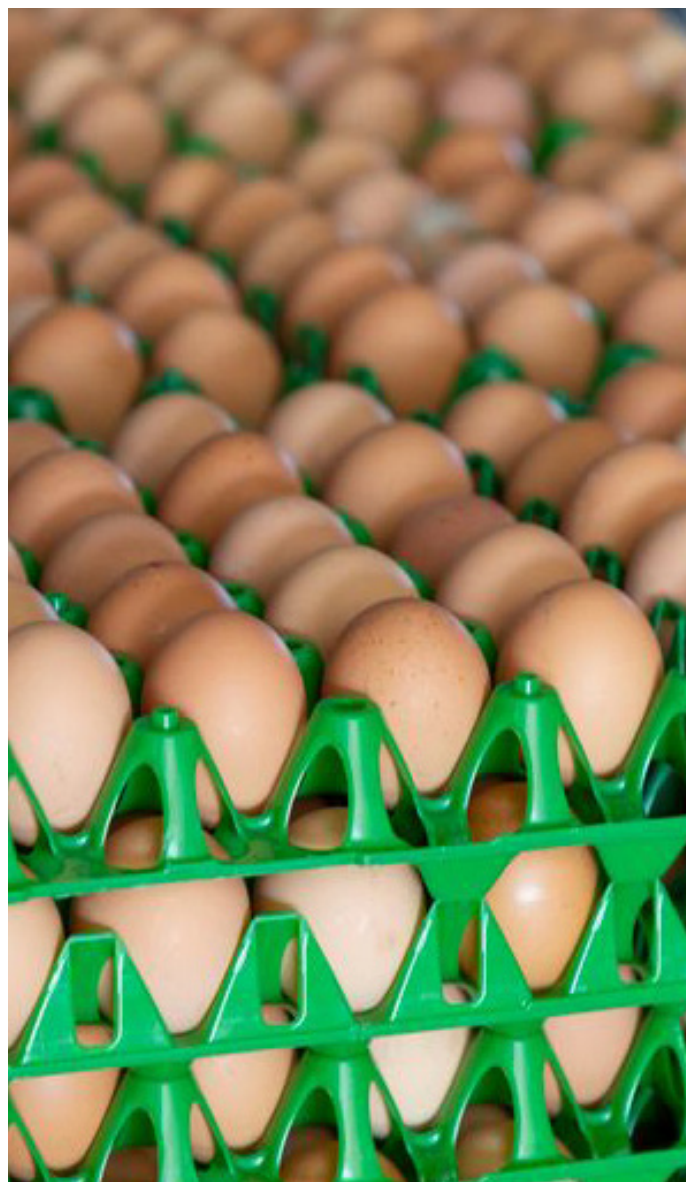
Identify if/where opportunities exist to change to different types of plastic. Plastics can be, for example, certified compostable, which would mean that they can be co-composted on-farm. Some suppliers may offer recyclable alternatives, e.g. pallet wrap.

Step 5:

Where plastic cannot be avoided, recycled, reused, or better alternatives sourced, dispose of the remaining material. Recycling or disposal in landfill is likely to be the only available option, as plastics will not be allowed to be buried or burned on-site in most jurisdictions.

Step 6:

Periodically (e.g. annually) review steps 2–5 to identify whether a more preferred option is now available.





12. Cardboard

To develop a waste management plan for cardboard, you should work through the following steps to identify which options are feasible for your farm.

Step 1:

Audit cardboard volumes and sources for a set (e.g. 12-month) period. Cardboard may be generated from:

- Grading: damaged egg cartons, boxes, damaged packaging in which cleaning products or other purchased products are packaged.
- Biosecurity: boxes in which disposable clothing, footwear, PPE, etc., are packaged.
- Animal health: outer boxes in which vaccinations, syringes, etc., are packaged.

Note that this list is not exhaustive, and producers should identify all sources specific to their farms.

Step 2:

Identify if/where opportunities exist to reduce cardboard volumes entering your farm. This may include, for example, engaging with suppliers to determine whether alternative packing or products with less packaging are available, or whether it is possible to purchase products in bulk. Enquire if reusable packaging is available for some products you purchase.

Step 3:

Review available recycling and disposal options for cardboard and identify those feasible on your farm.

From a waste hierarchy perspective, in order of most to least preferable the options are:

1. **On-farm co-composting.** Cardboard can be composted, used as a high carbon source in poultry composting operations (including windrow, bay and pile, small bin), potentially reducing the need for other carbon sources. Shredding the cardboard first should speed up the rate at which it breaks down. Ensure that packing tape and plastic labels, etc., are removed prior to shredding.
2. **Council recycling.** Cardboard that cannot be used in composting operations (e.g. no on-farm composting) should be recycled, either via commercial cardboard collection (if available at farm location) or via municipal collection/drop-off facilities, or sent to municipal or local recycling facilities.
3. **On-farm burning.** Cardboard should be burnt only if it cannot be productively reused or recycled.
4. **Landfill.** Disposal of cardboard in landfill is the worst-case environmental option.



13. Other solid waste

In addition to plastic and cardboard waste streams on-farm arising directly within the egg business, other inorganic and organic waste streams common to farming operations also require management. To develop a waste management plan for these streams, you should work through the following steps to identify which options are feasible for your farm.

Step 1:

Audit volumes and sources of waste materials not otherwise accounted for, covering a set (e.g. 12-month) period. Solid wastes streams may include (but may not be limited to) the items listed in Table 9:

Table 9: Common organic and inorganic waste materials that may not be categorised elsewhere

Organic				
Waste feed		Dust		Trapped or baited vermin
Inorganic				
Feed bags	Fertiliser bags	Drums	IBCs	Disposable overalls, masks, other PPE
Glass vaccination bottles	Syringes	Pallets	Scrap metal	Old tyres (car, tractor)
Silage wrap	Baling twine	Conveyor belting	Old/broken machinery	Seed bags
Bale netting	Traffic cones	Chemical containers	Old fence posts	Wire cuttings

Step 2:

Identify if/where opportunities exist to reduce or avoid, or manage these products. Dust, for example, can be captured at the ends of sheds with windbreak walls and handled alongside manure or spent litter in stockpiling or compost processes.



Step 3:

Research and identify if/where opportunities exist to recycle these materials, for example:

- Intermediate bulk containers (IBCs) can be collected or delivered to collection centres and, after cleaning, be supplied back into the market. Alternatively, the IBCs can be separated into their constituent parts, which are then recycled.
- Some fertiliser suppliers operate take-back services for fertiliser bags (including one tonne bags).
- **Big Bag Recovery** (into which Farm Waste Recovery was integrated) is the Australian Government Accredited Product Stewardship scheme for recyclable sacks and bulk bags (e.g. fertiliser, seed, feed bags) that are made of woven polypropylene (wPP) and low-density polyethylene (LDPE).
- **drumMUSTER** is a program which collects (at 830+ designated sites) and recycles empty, approved agricultural chemical containers (specifically cleaned AgVet chemical containers) into other products, avoiding on-farm stockpiling, burning, or landfilling. Eligible containers can be identified by the drumMUSTER logo.
- Some scrap metal dealers will purchase old machinery and equipment, or parts thereof, usually including on-site dismantling and removal.

Step 4:

Identify opportunities to reuse these products on-farm.

For example:

- Old tractor tyres can be filled with sand and placed on ranges to provide scratch areas for free range hens. Note that the use and quantity of tyres that can be used may be limited by local and State legislation.
- Pallets or old fence posts can be wired together to create infrastructure for range areas,
- e.g. in an A-frame, providing shade and potentially encouraging birds to range.
- Old conveyor belts can be made into small bins which can be used to compost mortalities.
- 44-gallon drums can be used (i) for small bins for mortality composting, (ii) as water or feed troughs if cut in half, or (iii) for grain storage if the top is cut off and if the drum can be resealed.

- Waste feed can be co-composted. Composting operations that produce certified organic compost products must ensure that the feed does not contain GMO grain or meal. Additionally, where there are large amounts of waste feed, these should be carefully integrated into the compost feedstock mix to ensure that feedstock characteristics are within the desired ranges, and that the composting process is facilitated, particularly as large amounts of waste feed can cause excessive heat and subsequent combustion if not managed correctly.

Step 5:

Identify opportunities to source alternative products/materials with different compositions that increase the options available for management or disposal and/or avoid plastic going to landfill. For example:

- Natural fibre (jute, sisal, etc.) baling twine is available, and it may be possible to replace/avoid use of some plastic baling twine with natural fibre twine, particularly in ad-hoc use of the twine.
- Biodegradable silage cover is available.
- Biodegradable gloves are available. Use of these in some parts of the egg business would reduce the volume of waste that does not breakdown in landfill or after burial.



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Appendix 1 - Farm waste and by-product audit

Table 10: Farm by-product audit template

		Inventory data					
Parameter	Units	Your farm	Cage	Cage-free (barn)	Free range	Rearing	Explanatory notes (as required)
Farm by-products							
Daily mortalities	tonnes						Multiply the number of birds placed (e.g. 100,000) by the average mortality rate for the flock (e.g. 3%) and the average weight of the birds (e.g. 2 kg for layers), and then divide by 1,000 to convert to tonnes. EXAMPLE: <i>(100,000 birds x 3% mortality x 2 kg/mortality)/1,000 = 6 tonnes</i>
Manure/spent litter	tonnes						
Spent hens	tonnes						
Wastewater	kL						
Grading by-products							
Broken/cracked eggs	tonnes						Multiply the number of eggs packed/graded (e.g. 30 million) by the average loss rate (e.g. 2%) and then multiply that by the average weight per egg in kilograms (e.g. 60 grams/1,000), then divide by 1,000 to convert to tonnes. EXAMPLE: <i>(30,000,000 eggs x 2% loss x 60 g/1,000)/1,000 = 36 tonnes</i>
Shells	tonnes						Multiply the number of eggs broken on site (e.g. 2 million) by the average weight per egg in kilograms (e.g. 60 grams/1,000) and then multiply by 14% (roughly 14% of the mass of a whole egg is the shell), and then divide by 1,000 to convert to tonnes. EXAMPLE: <i>(2,000,000 eggs x 60 g/1,000 x 14%)/1,000 = 16.8 tonnes.</i>
Wastewater	kL						



Table 11: Farm waste audit template

Parameter	Units (If blank, enter your own unit)	Inventory data	Explanatory notes (as required)
		Your farm	
Inorganic waste			
Cardboard			
Soft plastic			
Hard plastic			
Total plastic		0.00	Sum the two lines above.
IBCs	No.		
Drums, e.g. 44-gallon	No.		
Chemical containers/ bottles	No.		
Conveyor belting	m		
Lights	No.		
Feed bags	No.		
Fertiliser bags	No.		
Vaccination bottles	No.		
Used syringes	No.		
Bale or silage wrap	m		
Bale netting	m		
Poultry netting	m		
Tractor tyres	No.		
Car tyres	No.		
Old machinery	No.		
Fence posts	No.		
Pallets	No.		
PPE (e.g. disposable overalls)			
Broken feed chain	m		
Broken drinker line	m		
Other			
Other			
Other			
Organic waste			
Waste feed	kg		
Dust	kg		
Baited/trapped rodents	No.		
Other			
Other			
Other			

Appendix 2 - Industry baseline

The industry baseline was modelled for a 12-month period ending on 30 June 2023, and is reported in the following sections. **Table 12** outlines the by-product and nutrient masses and volumes produced by Australian layer and rearing farms, and provides insight into current handling and disposal methods. By-product masses/volumes and handling methods were determined via survey, and nutrient masses were calculated for the by-products generated using standard Australian nutrient composition data (e.g. as reported in the *Egg Industry Environmental Guidelines* (McGahan et al. 2018)).

All by-product masses and volumes (e.g. spent hens, mortalities, spent litter, broken eggs) in the following sections are reported as is, i.e. including moisture, whilst the carbon and major nutrients contained in them are reported on a dry matter basis.

Table 12: Annual raw (pre-treatment) farm by-product and nutrient masses produced by the egg industry in FY2023

		Units	Cage	Cage-free	Free range	Rearing	Total
Spent hens		tonnes	14,657	3,052	12,992	-	30,701
Handling	Rendering or meat processing	% of total	67%	89%	78%	-	74%
	Composting (on and off-site)	% of total	33%	11%	22%	-	26%
Daily mortalities		tonnes	616	234	1,275	91	2,216
Handling	Composting on-farm	% of total	86%	56%	71%	74%	76%
	Burial	% of total	3%	4%	1%	8%	4%
	Landfill	% of total	0%	14%	10%	7%	6%
	Incineration	% of total	6%	0%	0%	2%	2%
	Managed off-farm by contractors*	% of total	6%	26%	18%	9%	12%
Manure/spent litter		tonnes	291,725	39,238	142,121	25,121	498,204
Handling	Sold off-farm direct from shed*	% of total	43%	46%	41%	61%	47%
	Composted on-farm	% of total	42%	45%	41%	26%	37%
	Spread on-farm direct from sheds	% of total	1%	0%	0%	0%	0%
	Biogas on-farm	% of total	0%	0%	0%	0%	0%
	Stockpile on-farm	% of total	14%	9%	19%	13%	15%
Carbon and major nutrients contained in the by-products listed above							
Carbon		tonnes	49,331	9,166	35,256	5,603	99,356
Nitrogen		tonnes	7,672	1,136	4,138	325	13,271
Phosphorous		tonnes	2,846	480	1,796	166	5,288
Calcium		tonnes	13,702	2,626	10,073	270	26,670
Magnesium		tonnes	664	137	534	69	1,405
Potassium		tonnes	2,305	408	1,539	248	4,500

* Producers have limited insight into final handling/use.

By-product nutrient, and waste masses and volumes from grading and pulping operations are reported in **Table 13** alongside an indication of current handling/disposal practices.

Table 13: Annual by-product and nutrient masses and volumes from grading and pulping operations produced by the egg industry in FY2023

		Units	Grading	Pulping
Shells		tonnes	-	2,032
Handling	Landfill	% of total	-	80%
	Composting	% of total	-	5%
	Burial	% of total	-	12%
Losses*		tonnes	10,050	554
Handling	Landfill	% of total	3%	0%
	Composting	% of total	40%	0%
	To wastewater	% of total	58%	100%
Wastewater		ML	350	14
Handling	Released to sewer	% of total	10%	50%
	Reverse osmosis	% of total	20%	0%
	Irrigation	% of total	70%	50%
Plastic waste to landfill		tonnes	839	151
Waste to recycling		tonnes	360	194
Carbon and major nutrients contained in the by-products listed above				
Carbon		tonnes	159	229
Nitrogen		tonnes	199	29
Phosphorous		tonnes	16	3
Calcium		tonnes	501	724
Magnesium		tonnes	6	9
Potassium		tonnes	0.5	1

* Losses at grading and pulping include shells and pulp.



Estimated annual by-product, and nutrient masses and volumes from hatcheries and from parent and grandparent stock are outlined in **Table 14** and **Table 15**.

Table 14: Annual by-product and nutrient masses and volumes from hatcheries associated with the egg industry in FY2023

	Units	Hatcheries
By-products*	tonnes	256
Nitrogen	tonnes	5.8
Wastewater	kL	5,868

*Empty shells, infertile eggs, late hatchings, dead chickens, dead embryos

Table 15: Annual by-product and nutrient masses from production of parent and grandparent stock associated with the egg industry in FY2023

	Units	Parent & grandparent stock
Spent hens	tonnes	111.9
Mortalities	tonnes	8.57
Manure/spent litter	tonnes	1,438
Carbon and major nutrients contained in the by-products listed above		
Carbon	tonnes	335.9
Nitrogen	tonnes	41.6
Phosphorous	tonnes	17.6
Calcium	tonnes	96.2
Magnesium	tonnes	5.0
Potassium	tonnes	14.9

Average annual by-product and nutrient masses produced at the farm level are reported in **Table 16** per 1,000 birds housed.

Table 16: Average annual by-product and nutrient masses produced per 1,000 birds housed in FY2023

	Units	Cage	Cage-free	Free range	Rearing
Spent hens	kg	1,460	1,398	1,353	-
Mortalities	kg	61	107	133	11
Manure/spent litter	kg	29,052	17,975	14,797	3,046
Carbon and major nutrients contained in the by-products listed above					
Carbon	kg	4,913	4,199	3,671	679
Nitrogen	kg	764	520	431	39
Phosphorous	kg	283	220	187	20
Calcium	kg	1,365	1,203	1,049	33
Magnesium	kg	66	63	56	8
Potassium	kg	230	187	160	30

Average by-product and nutrient masses produced at grading and pulping are reported in **Table 17** per 1,000 kg eggs in at each facility.

Table 17: Average by-product, waste and nutrient masses produced per 1,000 kg of eggs to grading and pulping in FY2023

	Units	Grading	Pulping
Shells	kg	-	110
Losses*	kg	25	30
Wastewater	L	888	732
Plastic waste to landfill	kg	2	8
Waste to recycling	kg	1	10
Carbon and major nutrients contained in the by-products listed above			
Carbon	kg	0.4	12
Nitrogen	kg	0.5	2
Phosphorous	kg	0.04	0.2
Calcium	kg	1.3	39
Magnesium	kg	0.02	0.5
Potassium	kg	0.00	0.00

*Losses at grading and pulping include shells and pulp.

Appendix 3 - Nutrient budgeting

Nutrient budgeting (general information)

Nutrient budgeting is a way to account for nutrient movements at the paddock and farm-scale to observe nutrient imbalances (deficiencies/surpluses) and maximise efficiency. By understanding the nutrient demands of a crop or pasture, an appropriate application rate for by-products can be determined. This reduces the need for mineral fertiliser use and saves money, and can improve long term performance. Nutrient budgeting can also reduce the risk of losing nutrients to the environment (atmosphere, surface water, or groundwater) due to nutrient surpluses. The following details how to do a nutrient budget for raw manure, however, the same principles can be applied to other by-products, such as spent litter, wastewater, and digestate.

Setting up a nutrient budget

Nutrient budgets require knowledge of:

- Soil nutrient status (e.g. fertility levels).
- Nutrient requirements for individual crops and a crop rotation (i.e. outputs – removal through plant harvest, export of livestock).
- Nutrient inputs and availability (i.e. from manure, fertiliser).
- Maximum recommended soil nutrient levels.

These can be calculated on a per hectare basis for any area where the same basic management is occurring. A nutrient budget can be calculated using information from previous years to help make predictions for the coming season. The first step is to assess the level of nutrients in the soil.

What nutrients are in the soil?

Soil nutrient status can be determined by soil testing, and this is particularly important in paddocks with a history of fertiliser or manure application. Refer to the *Egg Industry Environmental Guidelines* (McGahan et al. 2018) or other information on soil sampling and testing recommendations.

Once a soil analysis has been done, there are two approaches to assessing soil nutrient levels:

1. Calculating the total quantity of nutrient per hectare (this may require agronomic advice); or
2. Comparing soil analysis results (reported in mg/kg) with 'standard' soil nutrient concentrations considered adequate for growing different crops or pastures (these are often available in reference books for most crops and regions). Nutrient contents usually vary with depth (e.g. 0–20 cm, 20–40 cm, > 40 cm), which need to be accounted for.

It is important to realise that standard nutrient target levels are influenced by individual property soil types and management practices. For example, phosphorus requirements are based on multiple factors including the crop type, time since previous phosphorus application, and sorption capacity of the soil. Phosphorus sorption (reactivity) relates to the capacity of the soil to immobilise phosphorus. Two tests are required to understand P availability in soil: a measure of the soil's sorption capacity (one example being the phosphorus buffering index – PBI) and available P. There are numerous tests for available P in Australia, with the most popular being the Colwell P test and the Olsen P test. In some instances, other tests may be used but Colwell P is recommended as the benchmark for agronomic and environmental guidance in most regions. Different target levels exist for each test and for different crops and pastures. As phosphorus availability is very responsive to soil pH modification, pH management should be part of the standard approach to phosphorus management. In simple terms, the PBI measures the extent to which a particular soil type can adsorb P that is applied to it. The higher the PBI value, the more ability the soil has to adsorb (fix) the applied P. For effluent and manure application areas, soils with a high P sorption capacity can store phosphorus with lower risks of losses in runoff or via leaching.

To interpret Colwell P levels, they must be based on a relative value of PBI, as the critical value of Colwell P required increases as the PBI increases. Some example phosphorus (P) levels for soils in manure application areas are given in **Table 18**. It shows low, medium and high soil P levels relative to crop P demand. As can be seen, grains, and vegetable crops have higher requirements than pastures.

Table 18: Soil Colwell P level requirements relative to crop demand and sorption ability

Source: Adapted from Moody and Bolland (1999).

Soil P status	Soil P sorption	Crop P demand (mg/kg)		
		Low (e.g. pasture)	Moderate (e.g. grains)	High (e.g. vegetables)
Low	Low	< 10	< 15	< 20
	Moderate to high	< 20	< 30	< 50
Medium	Low	10–30	15–45	20–60
	Moderate to high	20–60	30–90	50–150
High	Low	> 30	> 45	> 60
	Moderate to high	> 60	> 90	> 150

Soil nitrogen levels are generally measured as mineral nitrogen, i.e. nitrate (NO₃). Desirable soil nitrate-N levels for planting/growing a crop depend on season, crop, and mineralisation. They are best determined by an agronomist. However, rough estimates can be made using standard target levels from a reference book, such as Interpreting Soil Test Results (Hazelton & Murphy 2007). Nitrate is highly mobile and easily lost from the root zone, reducing plant availability, and potentially

causing negative impacts to groundwater. Recommended soil nitrate-N concentrations at the bottom of the root zone are shown in **Table 19**, which outlines nitrate-N concentrations equivalent to 10 mg/L of nitrate-N in soil solution. These trigger values apply at a depth of 0.6 m, or at base of the root zone. Actual root zone depth depends on soil depth, crop type, climate, and whether the crop is irrigated.

Table 19: Recommended maximum nitrate-N concentrations (equivalent to 10mg/L of nitrate-N in soil solution) at 0.6 m depth

Soil texture	Moisture content at field capacity*	Nitrate concentration**
	<i>g water/g soil</i>	<i>mg NO₃-N/kg soil</i>
Sand	0.12	1.2
Sandy-loam	0.15	1.5
Loam	0.17	1.7
Clay-loam	0.20	2.0
Light clay	0.25	2.5
Medium clay	0.35	3.5
Self-mulching clay	0.45	4.5

Skerman (2000)* Soil gravimetric moisture content at field capacity.

** Limiting soil nitrate-nitrogen concentration.

Source: Adapted from Skerman (2000).

It can also be helpful to measure total nitrogen and or organic matter content in paddocks that have received manure because this will give an idea of the total reserves of nitrogen, and quantities of nitrogen that can mineralise and provide nitrogen for crop or pasture growth.



Outputs

The amount of nutrients removed from a paddock, either through crop removal or grazing, or through environmental losses, can be used to estimate required annual fertiliser or manure application rates.

Once the major system inputs (i.e. what is applied) have been determined, similar calculations are needed for the main outputs. Nutrients are removed primarily through agricultural produce, including hay, grain, or livestock products (liveweight, milk, or wool). For livestock, the

nutrient content of live beef is approximately 2.4 kg N, 0.7 kg P, and 0.18 kg (potassium) K/100 kg live weight. For milk production, 1,000 L of milk will remove about 5 kg of N, 1 kg of P and 1.5 kg of K. Grazing properties export relatively small amounts of nutrients in the livestock. For example, selling 100 beef steers weighing 500 kg/head in liveweight gain, exports about 1,200 kg N, 350 kg P and 90 kg K per year. Crops generally remove much larger amounts of nutrient per hectare than livestock as shown in **Table 20**.

Table 20: Yield and nutrient off-take for selected crops
Source: Adapted from Reuter and Robinson (1997).

Crop	Yield	N	P
	t/ha	kg/ha/yr	kg/ha/yr
Dryland pasture hay	1–4	20–80	3–12
Irrigated pasture hay	8–20	160–400	24–60
Lucerne hay	5–15	150–450	15–45
Dryland winter cereal (grain only)	2–4	40–80	6–20
Dryland winter cereal (grain + straw)	2–4 grain (+ 2–5 t straw)	59–239	9–20
Grain sorghum	2–8	40–160	6–24
Forage sorghum	10–20	200–400	30–60

Nutrient inputs – fertiliser and manure

Once nutrient availability in the soil and the nutrient requirement of the crop are known, the required nutrient input, supplied through manure or fertiliser can be calculated.

Fertiliser nutrient inputs are calculated by multiplying the application rate (kg/ha) by the nutrient content to give a mass of nutrients applied per hectare. For example, the phosphorous input of single superphosphate (9% P) applied at 125 kg/ha to grazing land is calculated as follows:

$$0.09 \times 125 = 11 \text{ kg/ha of P}$$

The standard analysis for fertiliser is printed on the bag or is readily available from the manufacturer.

For nutrient inputs from manure, a similar calculation is needed to estimate the amount of nutrients per tonne of manure 'as spread', but the key difference is that moisture content must be taken into account, as analytical results are presented on a dry weight basis. The first step is to obtain an analysis for the manure from a laboratory or to use standard analysis data (refer to the fact sheet **Manure Sampling Procedure**).

Manure analysis results are generally provided on a 'dry weight basis' (db), however, all manure contains moisture at the time of spreading. To calculate the amount of phosphorus in a tonne of fresh layer manure with a dry matter content of 70% (or a moisture content of 30%) and a total phosphorus content of 2.3%, use the following process:

$$1,000 \text{ kg} \times 0.7 \text{ (70\% dry matter)} \\ = 700 \text{ kg dry matter.}$$

$$700 \text{ kg} \times 2.3\% \text{ db (average phosphorus} \\ \text{content in layer manure)} \\ = 16.1 \text{ kg P/tonne}$$

This same process can be applied to other nutrients in layer manure.

Nutrient availability

When using manure and compost, not all nutrients are immediately available to the plant, and this must be taken into account when setting application rates. Plant nutrient uptake occurs when nutrients are present in an inorganic form. Some nutrients need to be converted from the organic to the inorganic form by microbial decomposition before they become available for plant uptake. Of the



macro nutrients in layer manure, N and P availability can vary widely, while K is highly available from the time of application.

Generally, about 10% of the N in fresh layer manure is present in the form of ammonium, though this may range from 6–30% (Griffiths 2011). This N rapidly becomes available to the plant after application, but it is also easily lost to the atmosphere via ammonia volatilisation, if the manure is not incorporated into the soil. Losses are highest where manure is applied to the surface and allowed to dry out. The remaining N is contained in an organic form and will mineralise over time, releasing N for plant growth. Between 30 and 80% of the total N is likely to become available in the first year. However, the mineralisation rate depends upon several factors including soil health, temperature, and moisture. See the factsheet [Spreading Layer Manure](#) for more information.

Immediately available P may be around 20% in fresh layer manure, and up to 60% may become available in the first year. The availability of P depends on soil characteristics, such as buffering capacity and the mineralisation and demineralisation of P by soil microbes. P will be more easily accessed by plants where manure is incorporated into the soil, but this is not essential.

The nutrient balance

Once soil nutrient levels, outputs, and inputs have been calculated, the overall nutrient budget is:

$$\text{Final soil nutrients} = \text{initial soil nutrients} + \text{inputs} - \text{outputs}$$

The result will show if more or less nutrient inputs are required to balance the equation. Where the final soil nutrient level is higher than the initial level, nutrients will be stored in the soil or lost to the environment. Losses should be avoided wherever possible, as these are both a financial cost and a risk to the environment. In particular, N and P are harmful to water and in some cases air quality, and need to be minimised by balancing the nutrient budget as much as possible without compromising yields.

Poultry manure/compost is not typically a balanced fertiliser, and to avoid oversupplying nutrients, it should be applied to optimise the most limiting nutrient whilst considering nutrient availability, storage, and loss rates. For example, if N and P are imbalanced, creating a risk that soils (particularly topsoils) could be overloaded with P, this could then lead to losses via erosion, potentially posing a risk to water quality.

Nutrient budgets are a useful tool for managing fertiliser and manure applications, providing greater efficiency within the system, saving money, and helping to protect the environment, giving a win-win situation. They should not, however, be used in isolation from ongoing monitoring.

Both the nutrient composition of the by-product, and soil where by-products are applied to land, should be monitored.' This helps confirm the theoretical nutrient budget and assess trends in nutrients in the soil over time. This will enable correct management decisions on further applications, and minimise potential overloading and environmental risks.

Appendix 4 - Advanced processing technologies

Anaerobic digestion

Capital cost	Labour requirement	Financial return/cost-saving potential	Suitable for small- to medium-sized layer farms
 High	 Medium	 Yes (reduced demand for grid electricity/LPG, etc.)	 Unlikely at this time

Biogas production using wet anaerobic digestion is suited to high moisture materials, like manure removed from layer sheds with belts. Wet anaerobic digesters range from simple covered anaerobic pond (CAP) designs (see **Figure 13**) to advanced, in-ground or above-ground engineered tanks with heating and mixing capacity. The process for all systems works by capturing biogas, which is generated during the anaerobic (without oxygen) breakdown of the feedstock. After purification, the produced biogas can be burnt to generate electricity and/or heat.

For the egg industry, the most applicable type of anaerobic digestion is likely to be an engineered wet digester (see **Figure 12**). These systems handle manure (and other digestible by-products) with much lower moisture contents than CAPs. The feedstock and digested material must be pumpable. Therefore, considerable additional water would be required to get layer manure to a suitable moisture content to load it in and out of the digester. The liquid digestate (output from the digester) is odorous and needs to be stored prior to land application. Virtually no plant nutrients are lost during the digestion process, which makes digestate a valuable liquid fertiliser with high nitrogen availability. Risk of high ammonia volatilisation requires special land application technology.

Figure 12: Example of an engineered above-ground digester
Source: BettaPork



How much biogas is produced and its quality depend on a large number of factors, including the concentration of volatile solids, methane potential of the feedstock, its pH, the loading rate and residence time, temperature, design of the system, and the carbon to nitrogen (C:N) ratio.

After purification, biogas can be combusted in a generator to produce electricity, but the electrical energy efficiency of methane generators is generally only 30–35%. A more efficient option is a combined heat and power unit that generates electrical energy (30–35% efficiency) and heat energy (50–55% efficiency). The heat can then be used as a replacement for LPG or natural gas.

Co-digestion of other organic waste streams (e.g. mortalities, spent hens) may be possible and may increase the methane generation potential. External feedstock rich in methane potential (e.g. piggery effluent) is ideal for increasing biogas production but there may be biosecurity considerations that need to be managed if feedstock is brought onto site.

Potential benefits

- Odour reduction.
- Use of wastewater.
- Reduced demand for grid electricity.
- Reduced demand for LPG/natural gas.
- Digestate may be utilised as a nutrient-rich fertiliser.
- No need for bulking material (if composting is the alternative).

Potential barriers to adoption

- High capital costs.
- Scale (due to high capital cost only suitable to large farms or centrally located to ensure sufficient feedstock).
- Suitable location (i.e. digester needs to be near to feedstock and near to facility/building that will use the energy generated – particularly heat).
- The use of the by-products (e.g. digestate) may require additional approval in some jurisdictions.
- Special application technology required to minimise ammonia volatilisation.

Key considerations

- Digestate is classified as industrial waste in Victoria, and as compost in Queensland and New South Wales, i.e. it may be difficult to use/dispose of it.
- High ammonia levels in feedstock/digester pose a significant operational problem.
- High levels of ammonia and ash in layer manure generally necessitate additional steps/technologies (ammonia stripping and ash removal).
- Eggshells and grit in manure can become an operational problem, as they settle on the base of the digester.
- Funding may be available through certain programs/bodies, e.g. the Australian Renewable Energy Agency (ARENA).
- Heat energy cannot be stored so it would either need to be used immediately (i.e. digester is located next to facility with high heat demand), or transformed into electricity (which will result in some energy being lost) and used or stored (e.g. in a battery).

Examples of the inputs, outputs, costs, and revenues associated with anaerobic digestion and energy generation are provided in **Table 21**. Example A is for a 1,000,000 bird farm with the lowest cost digester (covered anaerobic pond) and highest possible energy potential, and Example B is for a 1,000,000 bird farm with a mid-range capital cost and mid-range energy potential.

Table 21: Example of costs and benefits for anaerobic digestion options with a combined heat and power unit at a 1,000,000 bird farm

	A – CAP with highest possible energy potential	B – Engineered digester with mid-range energy potential	Notes/assumptions
Costs			
Capital	\$5 million	\$10 million	Based on range of \$5–15 million. Depends on system type and whether purchased off-the-shelf
Operating/maintenance (per year)	\$200,000	\$400,000	Based on OPEX to CAPEX ratio from Watts & McCabe (2015)
Production data			
Volatile solids (VS) in feedstock (tonnes/year)	7,600	7,600	Based on 20.8 g VS/hen/day
Methane yield range (m ³ /year)	1,900,000	1,520,000	Based on methane yield of 0.5–0.25 L/g of VS
Total energy (GJ/year)	71,800	57,450	Based on methane energy content of 37.8 MJ/m ³
Electricity production (kWh/year)	5,985,000	4,788,000	At 30% electrical energy efficiency
Heat production (GJ/year)	35,900	28,725	At 50% heat energy efficiency
Benefits			
Avoided grid electricity (kWh/yr)	5,568,400	4,579,700	Relative to base demand of 5,568,400 kWh/year (average of range in total electricity demand of 3,186,800–7,950,00 kWh/year for 1,000,000 bird farm reported in Copley et al. (2023))
Avoided LPG (MJ/yr)	2,648	2,207	Based on total heat demand of grading floor of 0.0727–0.109 MJ/kg eggs, derived from Wiedemann and McGahan (2012)
Avoided grid electricity (\$/yr)	\$1,113,680	\$915,940	Based on unit price of \$0.20/kWh
Avoided LPG (\$/yr)	\$36,536	\$30,049	Based on unit price of \$0.83/L

Anaerobic digestion is a high-cost technology where the viability is heavily dependent on both the capital cost (see **Table 22**) and the methane potential of the feedstock. Producers interested in anaerobic digestion should conduct a competitive tender process and a detailed feasibility of the potential energy generation.

Table 22: Partial benefit cost analysis for anaerobic digestion with combined heat and power unit, based on a 10-year project life and a discount rate of 4%

	Total benefits (present value)- AUD	Total costs (present value)- AUD	Net present value of investment-AUD	Internal rate of return
1,000,000 bird farm with low- est capital cost and highest energy potential (A – CAP)	\$7,672,815	\$6,622,179	\$1,050,636	8%
1,000,000 bird farm with mid-range capital cost and mid-range energy potential (B – Engineered digester)	\$9,329,280	\$13,244,358	-\$3,915,078	-5%

Third party build-own-operate

Build-own-operate models are a possible alternative to direct financing, ownership and operation of high cost, high maintenance energy projects like anaerobic digesters. Some energy providers operate build-own-operate models where they may finance, design, construct, own and operate the facility, selling power back to the client (usually at a reduced rate). The Goulburn Bioenergy Project, for example, saw an energy provider partner with Southern Meats to design, construct, own and operate a biogas facility at the abattoir (**Figure 13**), accessing funding through the Australian Renewable Energy Agency (ARENA).

Figure 13: Covered anaerobic pond with renewable energy generation constructed under a third party build-own-operate model
Source: Google Earth.



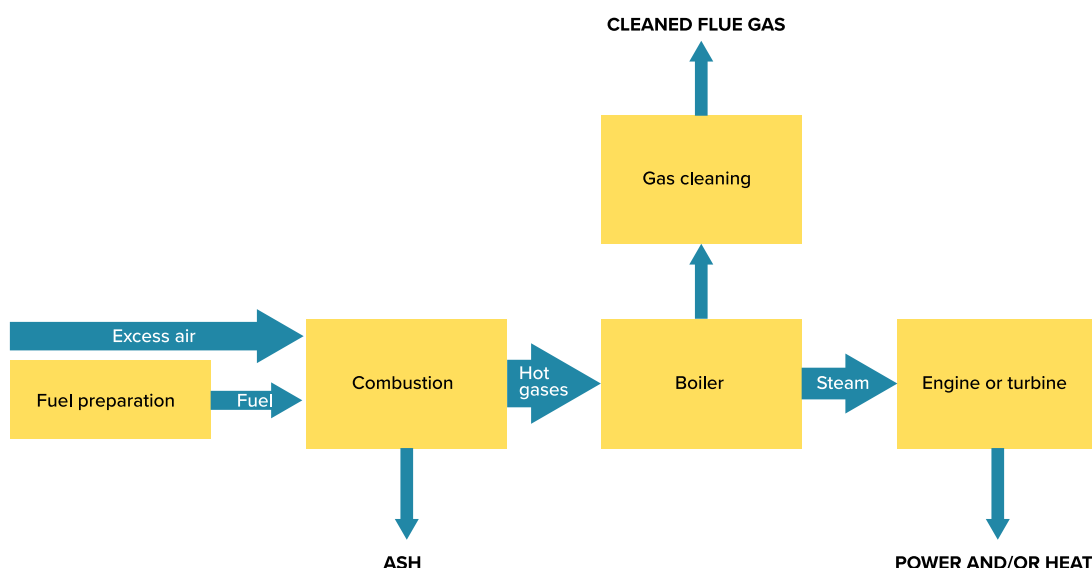
Combustion

Capital cost	Labour requirement	Financial return/cost- saving potential	Suitable for small- to medium-sized layer farms
High	Moderate	Unlikely to be high enough to earn a net return on investment.	No

Combustion involves burning biomass to generate heat energy (see **Figure 14**), which can then be transformed into electricity or used as heat. To operate efficiently, the biomass must have a low moisture content (e.g. spent litter, rather than fresh manure). Combustion may, however, be challenging to undertake using spent litter

from layer operations as the long flock length (compared with meat chickens) and the grit fed to birds means that the litter/manure has high ash levels, which can create issues when burnt. This would require additional technology and investment to overcome.

Figure 14: Diagram of combustion process for energy generation



Potential benefits

- High energy potential (reduced demand for grid electricity, LPG, etc.).

Potential barriers to adoption

- High capital costs (~AU\$8 million).
- Scale – large volumes of biomass needed.
- Carbon and nitrogen will be lost when spent litter is burnt.
- May be difficult to obtain regulatory approval.

Key considerations

- Heat energy cannot be stored so it would either need to be used immediately (i.e. combustion occurs next to facility with high heat demand) or transformed into electricity (which will result in some energy being lost) and used or stored (e.g. in a battery).

Based on the high capital costs associated with the technology, the partial benefit cost analysis (see **Table 23**) indicates that this technology is not a viable strategy for producers at this time. A detailed example of system

requirements, costs, and benefits has not been provided as the costings are only available as a pre-feasibility for a specific farm (which did not proceed to a project), and reporting them may reveal confidential information.

Table 23: Partial benefit cost analysis for combustion, based on a 10-year project life and a discount rate of 4%

	Total benefits (present value)- AUD	Total costs (present value)- AUD	Net present value of investment-AUD	Internal rate of return
Very large farm	\$9,038,019	\$9,297,743	-\$259,724	3%

Pyrolysis

Pyrolysis is a thermal energy production system that converts materials (e.g. spent litter) into heat energy in the absence of oxygen. By-products from this process are syngas, oil, and biochar.

To operate efficiently, a low moisture and low ash feedstock is required. Raw layer manure is unsuitable due to its high moisture levels. Spent litter (or dried layer manure) may be slightly closer to optimal moisture levels but still has high ash levels. The ash (combined with potassium in the manure) can lead to the fusion of char, which can adversely affect operational efficiency and maintenance costs. The greater issue is that the syngas must then be cleaned of impurities (tar, dust, ammonia, etc.), a process which is cost prohibitive at present.

If these issues could be overcome, there may be potential for the technology to be applied in the egg industry (likely only, or at least initially, on very large farms due to capital costs). There may then be opportunities to land apply the biochar (burnt remains) as part of a soil carbon project (note that other activities would also be required) to generate carbon credits, which could then be sold as an alternative revenue stream for the business. Depending on the feedstock and the temperature at which the system operates, however, biochar may either have minimal value or be unsuitable for some plant species, particularly horticulture, limiting the potential use of the by-product if a soil carbon project is not feasible.

Pelletisation

Capital cost	Labour requirement	Financial return/cost-saving potential	Suitable for small- to medium-sized layer farms
Moderate-High	Moderate-High	Yes	Unlikely

Pelletisation of raw or composted manure may be one way to convert by-products into an alternative revenue stream and to add value. Advantages over other handling/processing strategies include that the final product has a low moisture content, is easier/cheaper to transport and likely to be easier to store, has low odour, and may be able to be applied with current cropping equipment, such as air seeders. Disadvantages include very high capital costs (could be in the order of AU\$5–\$10 million for a one million bird farm) and that there are high energy requirements, as manure must be dried to reduce the moisture content to less than 20%. For sheds with belt removal, raw manure may range in moisture from 32.4–73.7% depending on whether the sheds have manure drying. It may be possible to generate compost moisture content around 20%.

Examples of the inputs, outputs, costs, and revenues associated with pelletisation of raw manure are provided in **Table 24**. Example A is for a 1,000,000 bird farm with manure belts and drying in shed, Example B is for a 1,000,000 bird farm with manure belts and no drying in shed, and Example C is for a 500,000 bird farm with manure belts and no drying in shed. As such a high-cost technology, it is not likely to be suited to farms of less than one million birds (see **Table 25**). Producers of one million birds or more should conduct detailed feasibility assessments before committing to the technology.



Table 24: Example of pelletisation requirements, production, costs, and benefits for 1,000,000 and 500,000 bird farms with and without manure drying in shed

Scenarios	A	B	C	Notes/assumptions
Farm size (bird numbers)	1,000,000	1,000,000	500,000	
Manure belts	Yes	Yes	Yes	
Manure belt drying in shed	Yes	No	No	
Costs				
Capital cost	\$7.5 million	\$7.5 million	\$5 million	Based on range of AU\$5–10 million
Electricity cost (per yr)	\$81,170	\$158,096	\$79,048.25	Based on unit price of \$0.20/kWh. A, B & C costs differ according to moisture content of raw manure and manure quantity for drying.
Labour cost (per yr)	\$80,000	\$80,000	\$80,000	1 FTE
Maintenance costs (per yr)	\$750,000	\$750,000	\$500,000	Estimated at 5% of CAPEX
Supplies & consumables (per yr)	\$75,000	\$75,000	\$50,000	Estimated at 1% of CAPEX
Production				
Total manure available for composting (t/yr)	14,034	18,412	9,206	
Initial moisture content of raw material (%)	32.4%	73.7%	73.7%	A: 32.4% moisture content for manure from sheds with belt removal and manure drying. B & C: 73.7% moisture content for manure from sheds with belts and no drying. All from Wiedemann et al. (2008).
Final moisture content required for pelletising (%)	15%	15%	15%	
Energy to dry one tonne wet manure to 15% moisture (kWh/t)	13	45	45	
Energy to operate pelletiser (kWh/t)	20	20	20	
Energy required – drying and pelletising (kWh/t)	33	65	65	
Total energy required (kWh/yr)	405,849	790,482	395,241	
Pellet mass produced (t/yr)	11,592	7,604	3,802	At 15% moisture
Benefits				
Pellet sales (per yr)	\$1,680,900	\$1,102,615	\$551,307	Based on selling price of AU\$145/t



Table 25: Partial benefit cost analysis for on-farm pelletisation of manure, based on a 10-year project life and a discount rate of 4%

	Total benefits (present value)	Total costs (present value)	Net present value of investment	Internal rate of return
1,000,000 bird farm with manure belts and drying in shed (A)	\$13,633,605	\$12,556,747	\$1,076,858	7%
1,000,000 bird farm with manure belts and no drying in shed (B)	\$8,943,192	\$13,735,612	-\$4,792,420	-13%
500,000 bird farm with manure belts and no drying in shed (C)	\$4,471,596	\$9,050,559	-\$4,578,963	-28%

Spent hen drying

Capital cost	Labour requirement	Financial return/cost- saving potential	Suitable for small- to medium-sized layer farms
 Moderate	 Moderate-High	 No	 No

Strategies to manage (and make an earning from) spent hens are of great interest to many producers. On-farm euthanasia and drying are a possibility, although most likely suited only to large farms (one million+ birds) due to high capital costs.

This form of spent hen treatment involves use of engineered drying technology to dry hens to very low moisture before further processing. Once treated, it may be possible (depending on location/ regulation) to use the dried spent hens in compost land applied, or theoretically used to generate energy (see **Combustion**).

Potential benefits

- Production of dry sterilised product with multiple potential applications.
- Alternative to rendering (i.e. avoided transport cost, some limited financial return).

Potential barriers to adoption

- High capital cost.
- High energy demand to operate.
- Regular supply of spent hens required to operate efficiently, or appropriate interim storage facility needed.

Key considerations

- Additional labour required to operate the system.
- Technology not commercially available in Australia.

Examples of the inputs, outputs, costs, and revenues associated with drying spent hens are provided in **Table 26**. Example A is for a 1,000,000-bird farm, and Example B is for a centralised processing facility (equivalent to supply from 2,000,000 birds per year).

Table 26: Example of spent hen drying requirements, production, costs in AUD, and benefits for 1,000,000 and 2,000,000 bird facilities

Scenario	A	B	Notes/assumptions
Farm size	1,000,000	2,000,000	
Centralised system	No	Yes	
Costs			
Capital	\$1,100,000	\$1,100,000	
Operating (per year)	\$22,000	\$22,000	
Labour (per year)	\$80,000	\$120,000	A: Equivalent to 1 FTE. B: Equivalent to 1.5 FTE.
Energy (per year)	\$81,636	\$163,271	
Production			
Feed rate (t/hr)	0.5	0.5	
Mass of spent hens available (t/yr)	1,385	2,769	At 53.5% moisture
Operating time required (hrs/yr)	2,769	5,538	
Load (kW)	147	147	
Electrical energy required (kWh)	408,178	816,355	
Product produced (t/yr)	644	1,288	
Benefits			
Sale of product (per year)	\$23,339	\$46,679	Based on theoretical selling price of \$35.25/t (approx. half compost selling price)

The partial cost-benefit analysis indicates that at neither scale is the technology viable (**Table 27**). The major limitation is that annual operating costs are always greater than annual revenue (even where stabilised spent hens are assumed to sell for the same price as compost).

Table 27: Partial benefit cost analysis for spent hen drying, based on a 10-year project life and a discount rate of 4%

	Total benefits (present value)- AUD	Total costs (present value)- AUD	Net present value of investment-AUD	Internal rate of return
1,000,000 bird farm (A)	\$189,304	\$2,589,449	-\$2,400,145	N/A
2,000,000 bird centralised processing facility (B)	\$518,993	\$4,494,122	-\$3,975,129	N/A

Appendix 5 - Offsite processing

Meat processing

Processing spent hens for human consumption is an environmentally optimal strategy, but the practical potential is limited due to the lack of meat processing facilities dedicated to or receptive of spent hens, and the retail preference for meat from dedicated meat chicken breeds.

Toowoomba Poultry is a dual processing facility, covering locally grown meat chickens and spent layer hens, producing products mostly for the domestic market. Supreme Poultry in NSW processes spent hens and it has a great deal of exposure to international markets. For small-medium producers, the emergence of more dedicated spent hen processors would be particularly beneficial.

Rendering

One of the most common methods for disposal of spent hens, is sale to renderers for processing into meat and bone meal, feather meal, poultry meal, etc. Although some vertically integrated chicken meat companies own and operate their own rendering facilities, this is not the case in the egg industry. Egg producers are 'price-takers' and, in addition to low prices for spent hens, must often bear the cost of transporting birds to rendering facilities.

Rendering is environmentally preferable to several other disposal methods, especially landfill, contributing to the development of a circular economy where products are retained and repurposed rather than sent to an end-of-life waste disposal process. Despite the low return on rendering, it is likely to be less costly (and better perceived by consumers) than having to pay to dispose of euthanised spent hens in landfill.

Appendix 6 - Potential opportunities

The following sections describe on- and off-farm processing opportunities that are relevant to by-products from the Australian egg industry, but that are yet to become available and applied commercially or are not yet widespread.

Dedicated spent hen processors

The major barriers to sending spent hens for processing for human consumption in Australia include a lack of processing facilities willing to take spent hens, since meat chicken breeds are preferred and dominate the market. As described in **Appendix 5 – Meat processing**, however, overseas markets exist for meat from spent Australian layer hens (particularly organics), and some domestic consumers may have a preference for it (as opposed to meat from broilers) as spent hens may have a lower fat content.

A blue-sky opportunity is the development of centrally located (e.g. in key production regions) spent hen processing facilities either owned and operated by producer(s) or by third parties who purchase and process spent hens from local producers. To be financially viable, however, producers may still receive little to no return for sending hens to meat processing. The benefit would instead be the avoided cost of sending birds for rendering or the reduction of risks and costs associated with on-farm disposal. The emergence of centralised facilities like this would be of great benefit to small-medium producers.

Biosecurity would be a key consideration for spent hen processing facilities, however, this could be managed similarly to meat chicken processing facilities, e.g. with clear demarcation and adherence to input/output areas (dirty vs clean) and on-site decontamination of trucks.

Centralised organic fertiliser production

The primary barrier to adoption of pelletisation as a means of processing and value adding of manure is that, for the overwhelming majority of egg producers, the scale of production (and available manure quantity) is too low to generate a high enough return on the original capital investment. Similarly to centrally located spent hen processing, it may be possible to establish centralised organic fertiliser businesses operating on a similar model (cost and biosecurity) to that described in the Dedicated spent hen processor section.

Similar to a model operated by an Australian lotfeeder, the business operator (if affiliated with an egg business) could provide a line of credit (at 0% interest) for the sale of pelletised products to grain growers from whom the egg business purchases feed commodities, and then deduct this from the final grain bill. This benefits both the grain grower and the egg producer, as it might result in reduced greenhouse gas emissions from grain production if synthetic fertiliser use is reduced in line with nutrient supply from pellets. Whilst this would not necessarily work towards closed-loop production on-farm, such a scenario would contribute to the development of a broader circular economy. Likewise, if operated as a separate business (but still affiliated with an egg business), manure/spent litter could be 'sold' at very low cost to the fertiliser business and the final product then 'sold' back for on-farm use also at a low price.

To fully evaluate the feasibility of a centralised organic fertiliser facility, consideration and controls would need to be in place to manage odour, transport, and biosecurity.

Feedstock for insects

Capital cost	Labour requirement	Financial return/cost-saving potential	Suitable for small- to medium-sized layer farms
 Moderate	 Yes	 Possibly	 Possibly

Insects have increasingly been discussed as an alternative protein source for poultry, but they may also be an emerging strategy for by-product management and conversion. Principally, the insects would be used to process (and breakdown) poultry by-products, particularly manure and spent litter. There may be potential to sell the frass or insect meal/oil to other markets, however, opportunities may be limited at the present time due to the potential for Restricted Animal Materials (RAM) classification, and that the products could not be fed to ruminants, or generally to pigs or poultry if reared on animal wastes, nor could they be sold to human supply chains.

A trial conducted by the University of Western Australia found that optimised black soldier fly larvae grown on manures could reduce the volume of layer manure by 80%, producing 200 kg of frass from 1 tonne of manure (Katzin et al. 2022). Mixed streams, containing shells, feathers etc., were found to have a lower waste reduction potential (Katzin et al. 2022).

Whilst insects may be an efficient strategy to reduce the volume of farm by-products and generate new revenue streams, the strategy is not currently likely to be viable at a broad scale for industry given the limited opportunities to sell or reuse insect meal, etc., in poultry diets (e.g. to achieve a circular production system) and prohibitively high production costs compared to currently available feed products. Consistency in the composition of the product and volume are other significant barriers to widespread adoption.

Maceration/grinding

Capital cost	Labour requirement	Financial return/cost-saving potential	Suitable for small- to medium-sized layer farms
 Moderate	 Yes	 Possibly	 Possibly

Maceration/grinding (similar to the process used for day-old male chicks) may be one strategy to process spent hens on-site and then incorporate the end product into traditional composting systems. In a trial in Canada, strong negative pressure ('vacuum') was used to feed spent hens into a grinder with blades running at 500+ rpm, causing instant death. Other designs may see birds placed in a hopper that then feeds them into a grinder. One limitation to widescale adoption may be how consumers perceive the technology, i.e. birds may need to be euthanised first.

Macerated spent hens will breakdown faster than if composted as whole birds, due to the increase in the surface area to volume ratio. As with composting of whole birds, it would require careful management to ensure that excessive odour is not generated, by covering partially composted material with an inert material (carbon source) following turning. The compost piles/windrows also need to be managed to avoid waterlogging and anaerobic conditions that can generate excessive odour and the formation of *Clostridium botulinum* toxins.

Depending on the availability and capital cost of the systems in Australia, this may be a viable option for small-medium farms.

Potential benefits

- Increased nitrogen content of compost (if spent hens would otherwise have been sold off-farm).
- Alternative disposal method to rendering (avoided transport costs, no uncertainty regarding market for spent hens, reduced biosecurity risk by eliminating the presence of vehicles on-site that have visited a centralised facility').
- Less co-composting material required (relative to composting whole carcasses).
- Potential option in the event of a mass disposal event or emergency animal disease.

Potential barriers to adoption

- Purchase of additional technology required.
- Additional labour/identification of willing labourers may be required.
- May be biosecurity risk if aerosols are created in the grinding process.

Key considerations

- Macerating live birds may not be perceived well by consumers. Euthanising birds prior to maceration may address some animal welfare concerns.

Rapid composting

Some poultry equipment providers now market systems that are called rapid composting units for poultry manure, although some appear to be rapid drying technology. These systems are enclosed engineered structures with connection to a power supply, which mimic the natural composting process but at a much faster speed. Depending on the model and processing time, the end-product may still require further composting (e.g. in windrows) to generate a stable, storable product. Note that the material may need to be re-wetted prior to further composting.

The moisture content of layer manure, and possibly spent litter, means that an additional drying step (and associated infrastructure) may be required. In addition, layer manure can cause significant ammonia emissions, which may require the additional purchase and installation of an air-scrubber. All this means that engineered rapid composting systems are likely to be high capital cost technologies.

Potential benefits

- Odour reduction (relative to conventional composting).
- Accelerated rate of composting (e.g. could potentially store product and time peak production to align with peak demand from local users).
- No slowing of rate of composting (e.g. from cold weather).
- May have a small footprint.
- No or little bulking material required

Potential barriers to adoption

- High investment costs.
- Additional infrastructure (drying, ammonia scrubbers) adds significant costs.
- Site works and labour required.
- May need further composting, depending on intended use.

Key considerations

- The relatively low selling price of composted poultry manure/spent litter (rapid composted or otherwise), and the high capital and operating costs, makes achieving a viable return on investment in rapid composting technology difficult at the current prices.

Examples of the inputs, outputs, costs, and revenues associated with engineered rapid composting units are provided in **Table 28** for a 1,000,000 bird farm. Based on the high capital costs associated with the technology, the partial benefit cost analysis (**Table 29**) indicates that this technology is not a viable strategy for industry at this time.

Table 28: Example of an engineered rapid composting unit requirements, high-level costs, and annual benefits for a 1,000,000 bird farm

	Value-AUD	Notes
Costs		
Capital	\$5 million	Includes drying unit and site works (concrete slabs, etc.)
Operating/maintenance	\$750,000	Includes repairs and maintenance, labour, electricity
Production		
Total material to drying (t/yr)	12,636	Includes manure, mortalities, cardboard, and egg waste
Average dry matter content (%)	64%	
Total material to drying (t dry matter/yr)	8,135	
Dry matter content required for composting	45%	
Product out (t/yr)	7,403	At 15% moisture content
Benefits		
Product sales	\$536,687	Based on selling price of \$72.50/t

Table 29: Partial benefit cost analysis for an engineered rapid composting unit, based on a 10-year project life and a discount rate of 4%

	Total benefits (present value)- AUD	Total costs (present value)- AUD	Net present value of investment-AUD	Internal rate of return
1,000,000 bird farm	\$4,353,016	\$11,083,172	-\$6,730,156	N/A



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