

APPENDIX C.5: Pig farming sector technology assessment

Contents

Technology assessments.....	Error! Bookmark not defined.
Covered anaerobic lagoons (CAL) (biogas capture)	1
Effluent solid separation (flocculation)	4
Short Hydraulic Retention Time (HRT)	7
Minimum solids stockpiling.....	9
Manure slurry acidification (and other additives)	12
Abatement Potential – Economic/Feasible:	13
Deep litter housing	14
Low-protein diet (amino acid supplementation).....	17
Probiotic and plant-based feed additives.....	19
Dietary organic acids	21
Pig breeding programs.....	23
References.....	25

Covered anaerobic lagoons (CAL) (biogas capture)

Summary:

A covered anaerobic lagoon (CAL) is an anaerobic pond covered with a gas-tight membrane that captures methane-rich biogas produced from piggery effluent. Methane (CH₄) is captured and either flared or used for energy, preventing its release into the atmosphere. Methane capture and destruction (e.g., flaring or energy use) can reduce emissions from effluent treatment by 62–80% (Australian Government, 2025; McGahan et al., 2013). CALs are considered one of the most mature and effective technologies for Scope 1 emission reduction in the piggery sector.

Annual Abatement Potential (Technical):

CALs trap pond biogas and either flare it or use it for heat/power, destroying methane and sharply lowering the largest on-farm emission source in conventional systems. Multiple Australian assessments show ~62–80% emission cuts versus uncovered ponds, consistent with the ACCU “Animal Effluent Management” method. Energy use can further improve economics (APL, 2022). This is the most mature, proven abatement for piggeries in Australia. One 2,000-sow piggery can abate ~8,500 tonnes CO₂-e/year.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Abatement Potential – Economic/Feasible:

We estimate feasible abatement by starting with the verified FY2022 Scope 1 baseline and isolating the uncovered-pond methane pool within the manure-management subtotal. Using the national MMS split and system intensities, uncovered ponds still dominate MMS emissions, yielding a mid-pool of $\sim 641 \text{ kt CO}_2\text{-e yr}^{-1}$ (about 65% of Scope 1). Applying the documented 62–80% destruction efficiency for CAL/CAP and constraining to sites currently using uncovered ponds, then assuming upper-end adoption around 70–90% under strong incentives (capex + ACCUs), feasible national abatement concentrates in the low-to-mid hundreds of kilotonnes per year, with a central value near $\sim 360 \text{ kt CO}_2\text{-e yr}^{-1}$. Key uncertainties are the precise uncovered-pond share, cover performance (leaks/downtime), and adoption pace on smaller units.

Breadth of application:

Ranking: Low-Medium

Only large piggeries, e.g., 1,500 pigs or more have adopted CAL, $\sim 13.5\%$ of pork production (McGahan et al., 2013). There is potential for increasing adoption within the sector if the high initial capital cost can be addressed through financial support and regulatory factors are addressed.

Co-Benefit Potential

Ranking: High

Delivers substantial co-benefits such as biogas captured from CALs that can be used for on-site electricity generation, heating (e.g., water or housing), replacing LPG or grid electricity. Revenue from excess biogas: Some piggeries produce more biogas than needed and can export electricity to the grid or flare excess gas (McGahan et al., 2013). Eligible under the ACCU Scheme, generating ACCUs that can be sold for revenue. Digestate can offset the need for synthetic fertilisers. Reduced solids entering the lagoon can lower desludging frequency and costs. CALs can reduce odour emissions by up to 95%, improving air quality for workers and surrounding communities, digestate (treated sludge) can be used as a nutrient-rich soil amendment, enhancing soil organic matter and fertility.

Barriers and Knowledge Gaps

Ranking: Medium

Justification: There is not many reliable suppliers of pond biogas technology operate in Australia. High logistics costs are involved to transport the technology to Australia. Very high capital costs to establish pond systems which reduces the economic feasibility, specifically for smaller piggeries (see cost overview below). High costs of retrofitting (see cost overview below), typically reaching cost recovery after 10 years. Several regulatory approvals are needed from different authorities across jurisdictions, which is considered a burden for producers. More broadly, barriers reflect system-level coordination challenges, including lack of standardised designs, fragmented project development pathways, and limited shared engineering capability, all of which increase cost and execution risk.

Stacking Potential

Ranking: High

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Justification: Strong compatibility with multiple strategies. CALs can be effectively combined with solids separation (to reduce sludge and improve gas yield), composting (for nutrient reuse), energy systems (combined heat and power unit (CHP), boilers, grid export) - can also be combined with lowering Scope 2 emissions.

Technology Readiness Level (TRL)

Ranking: 9

Justification: Fully mature technology ready for deployment. Actual system completed and qualified through test and demonstration, proven system in operational environment. Fully operational in Australia.

Commercial Readiness Level (CRL)

Ranking: 3-4

Justification: Adopted by several large piggeries and meat processors, not yet widely adopted across small to medium piggeries, largely due to capital costs and operational complexity. There is a limited number of reliable commercial suppliers of CAL technology in Australia. The technology mostly imported from trusted suppliers (reliability and quality) in Europe. Reliance on imported components and external expertise, increases costs and contributes to delivery risk and limited scalability.

Enabling Potential

Ranking: Low

Justification: CALs are primarily considered a standalone intervention for reducing Scope 1 emissions, but they can also act as a catalyst for broader system transformation under certain conditions. They are often installed independently of other systems. However, CALs can enable or complement broader system changes when integrated thoughtfully:

1. Energy generation from biogas can support on-farm electrification and reduce reliance on fossil fuels, aligning with broader sustainability goals.
2. Carbon accounting: CALs provide measurable methane capture data, which can be incorporated into carbon footprint assessments and reporting frameworks.
3. Infrastructure upgrades: Implementing CALs may prompt improvements in manure handling, sludge management, and wastewater pre-treatment systems.
4. Co-digestion potential: CALs can be adapted to digest other organic wastes, which may require new logistics and infrastructure, thereby expanding their role in circular waste management.

Estimated Cost Range:

Economically feasible, with payback periods ranging from 1.8 to 7.2 years depending on size and system design (McGahan et al., 2013). Capital costs vary based on pond size and design (retrofit vs. new), type of cover (HDPE, LDPE, etc.), and biogas use system (flare, boiler, generator). Additional costs may include sludge management, gas conditioning, and safety and compliance infrastructure. A 2,000-sow piggery can generate 280 kWe of electricity and reduce emissions by 8,500 t CO₂-e/year. Cost-effectiveness comes largely through business operations (energy costs saving through biogas generated energy use). Currently less feasible for smaller piggeries (<1,500 standard pig units (SPU) - 1 SPU is equivalent to the manure output of one standard grower pig) due to very high capital costs. Need for approximately 5,000 SPUs to make it feasible biogas system. The estimated cost range for installing CALs with biogas digesters in Australian piggeries varies depending on the scale, site conditions, and system complexity. Cost estimates include:

5. Small to medium piggeries (5,000 SPU):

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

- CAL+CHP system construction: ~\$2 million
- Large piggeries (20,000+ SPU):
 - CAL + CHP system: ~\$3.4 million
- Site specific factors can increase or decrease these estimates.
- Additional cost components may include:
 - Biogas conditioning (e.g., H₂S scrubbers)
 - Storage systems
 - Grid connection or export infrastructure
- Retrofitting existing lagoons:
 - Cover installation: \$300,000 – \$600,000
 - Gas collection and flare system: \$300,000 – \$400,000
 - Total retrofit cost: \$300,000 – \$1 million
 - In addition, logistics costs for the import of replacement parts

These estimates may underestimate the true cost due to recent cost spikes for earthworks, piping, stainless steel, and logistics services.

Estimated Financial Benefits:

CAL projects typically offset 30–70% of electricity and a portion of heat demand, with additional ACCU revenue for verified abatement under the Animal Effluent Management method. Well-matched systems deliver strong energy savings and odor reduction, lifting social license and resilience to grid price shocks. Returns scale with herd size, VS load, and site energy tariffs. Cost savings: Reduces reliance on LPG or grid electricity, lowering operational costs.

Investment in R&D and Commercialisation (expanded)

Range: \$1.5-\$3 million+ (see table below)

Ongoing R&D focus areas include cover durability, gas handling systems, integration with nutrient reuse and energy systems, improved methods for managing and removing sludge under covers without disrupting operations, development of low-cost sensors and automation for gas flow, pressure, and emissions monitoring. Table 1 lists the estimated cost for a small-medium CAL and CHP system trial sites:

Table 2: Estimated cost for a small-medium CAL and CHP system trial sites

Cost area	Estimated range
Pilot-scale CAL system trials	\$250,000–\$500,000 per site
Cover material testing & development	\$100,000–\$300,000
Biogas handling R&D (flare, CHP, storage)	\$150,000–\$400,000
Monitoring and automation systems	\$50,000–\$150,000
Nutrient recovery integration	\$200,000–\$500,000
Total program (multi-year, multi-site)	\$1.5–\$3million+

Effluent solid separation (flocculation)

Summary:

Treating liquid manure (effluent) to remove organic solids, which reduced methane formation in storage ponds. A process that removes solids from piggery effluent using mechanical (e.g., screw press, Z-Filter) or chemical (e.g., flocculants) methods. Removing 25% of volatile solids before effluent enters the anaerobic pond can lead to 23% reduction in pond methane emissions and 23% reduction in overall manure-related greenhouse gas emissions (Poada et al., 2010).

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Annual Abatement Potential (Technical):

Output: 25% removal of volatile solids can result in 25% reduction in methane emissions from anaerobic ponds, 23% reduction in overall manure-related GHG emissions. For a medium-sized piggery, this could translate to 200–500 tonnes CO₂-e per year in abatement potential, depending on herd size, effluent volume, and system efficiency. Technical abatement is significant when solids separation is used upstream of anaerobic ponds or in pond-less systems. Removal of 75% of volatile solids can reduce pond size by 60%, indirectly reducing methane emissions and infrastructure costs. This is a relatively common practice on many larger pig farms, not so at smaller farms. There is a varying level of solids removal depending on separation method used.

Abatement Potential – Economic/Feasible:

We estimate feasible abatement by taking the uncovered-pond methane pool and scaling it by the proportional reduction when upstream volatile solids are removed. Australian engineering work indicates about 23% pond-CH₄ reduction with ~25% VS removal, which we use as a representative technical effect. We then restrict the application domain to operations that feed liquid effluent to ponds, and—so as not to double count benefits with CAL projects—assign abatement only to the uncovered-pond subset. With adoption at ~50–80% in suitable sites (chemicals, maintenance, operator capability), feasible abatement aggregates to several tens of kilotonnes per year, centralising around ~50 kt CO₂-e yr⁻¹. Uncertainties are day-to-day capture efficacy (screen vs DAF/floc), bypass events and sludge management.

Breadth of application:

Ranking: Medium

Justification: Adoption is not yet widespread among small to medium-sized operations. Larger piggeries, are more likely to implement solids separation as part of integrated waste management strategies.

Co-Benefit Potential

Ranking: High

Justification: Less organic load in ponds reduces odour. Solids can be composted or reused as fertiliser. Smaller/slower sludge buildup reduces pond maintenance need. It supports water quality protection through lower nutrient runoff risk.

Barriers and Knowledge Gaps

Ranking: Moderate

Justification: Capital costs for flocculation systems and associated infrastructure can be prohibitive for smaller producers. Technical expertise and operational complexity may limit uptake without external support. Lack of awareness or access to feasibility studies and demonstration projects may also hinder adoption. Limited availability of standardised system designs and experienced integrators slows adoption beyond early adopters.

Stacking Potential

Ranking: High

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Justification: Effluent solid separation can be effectively combined with covered anaerobic lagoons (CALs) – improves gas yield and reduces sludge, enables composting – for nutrient reuse, irrigation systems – cleaner effluent improves reuse options.

Technology Readiness Level (TRL)

Ranking: 7-8

Justification: System prototype demonstration in an operational environment, actual system completed and qualified through test and demonstration. These technologies have been successfully demonstrated in operational piggeries, including integration with biogas systems and nutrient recovery process.

Commercial Readiness Level (CRL)

Ranking: 6-7

Justification: Commercial availability by early adopters and in trial stage for advanced systems – the technology not yet widely adopted. Adoption is limited to larger, more advanced piggeries, and broader uptake is constrained by capital costs, technical complexity, and lack of awareness.

Enabling Potential

Ranking: Medium-high

Justification: Effluent solid separation using flocculation in the Australian pig production sector can be viewed both as a standalone intervention and as a catalyst for broader system transformation, depending on how it is implemented and integrated. As standalone intervention flocculation is primarily used to:

1. Remove suspended solids from piggery effluent, improving the quality of liquid waste.
2. Reduce organic loading, odours, and nutrient concentrations in lagoons.
3. Improve handling and transport of separated solids, which can be composted or used for biogas generation
4. Enhance the efficiency of effluent treatment systems and can reduce the size and frequency of lagoon maintenance.

When integrated into a more comprehensive waste management strategy, flocculation can:

5. Enable infrastructure upgrades by reducing reliance on anaerobic ponds and allowing for more compact, modular treatment systems like the Z-Filter.
6. Support nutrient recovery and reuse, contributing to circular farming systems and reducing environmental impact.
7. Improve carbon accounting by quantifying reductions in methane emissions and nutrient losses.
8. Facilitate adoption of complementary technologies, such as biogas capture, advanced filtration, and precision nutrient application.

Estimated Cost Range:

The estimated cost range for installing effluent solid separation (e.g., flocculation) systems are (Poat et al., 2010):

- Small to medium piggeries:
 - Basic solids separation systems (e.g., screens, flocculants, pumps): \$100,000–\$300,000
 - Includes installation, basic infrastructure, and chemical dosing systems.
- Large-scale piggeries:
 - Systems integrated with anaerobic digesters or aerobic treatment: \$400,000–\$1 million.
- Additional Costs:

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

- Engineering and design: \$20,000–\$100,000
- Monitoring and automation: \$40,000–\$200,000
- Maintenance and training: ongoing operational costs

Estimated Financial Benefits:

Estimated payback periods and financial returns are not available. Some avenues that contribute to financial benefit include:

- Fertiliser value: Nutrient value of separated solids can offset ~20% of operating costs.
- Reduced pond costs: Smaller ponds = lower capital investment.
- Carbon credits: Potential if integrated with aerobic treatment or biogas systems. The Animal Effluent Management Method under the ACCU Scheme supports solids separation as an eligible activity for methane avoidance. Projects must treat separated solids aerobically and meet specific eligibility criteria.

Investment in R&D and Commercialisation (expanded)

Range: \$200,000 - \$400,000 including lab scale, pilot scale and full-scale testing of available products. Medium investment needs focusing on flocculation, integration with biogas and composting, automation and monitoring systems. Requires commercialisation support, technology is still being developed (refined, e.g., chemical trials) and may require demonstration projects, co-investment, capacity building and training.

Short Hydraulic Retention Time (HRT)***Summary:***

Short HRT systems reduce the time effluent is stored (typically <30 days), limiting anaerobic conditions that produce methane. Unlike traditional ponds with retention times >100 days, short HRT systems are designed to minimise methane formation and improve nutrient recovery.

Annual Abatement Potential (Technical):

Output: Short-HRT tanks/channels keep effluent from turning anaerobic. Australian trials measured ~50-79% lower GHG versus a conventional pond—consistent across seasons—with extremely low CH₄ and NH₃ from the short-HRT stage (McGahan, 2024).. System design and hydraulics are critical; downstream land application must be well managed.

Justification: This approach is validated through field trials and modelling using tools like PigBal and MEDLI in Australia led by APL, which simulate effluent flow and emissions under different treatment scenarios (McGahan, 2024).

Abatement Potential – Economic/Feasible:

We estimate feasible abatement by focusing on storage-stage methane emissions that arises when effluent is held anaerobically for months in ponds. Australian field trials show ~79% lower GHG for short-HRT units relative to conventional ponds, which we adopt as the technical rate for the portion of the estate where hydraulic conversion is realistic. Recognising space, hydraulics and pumping constraints, we limit the technical domain to roughly a quarter of the uncovered-pond estate and assume upper-end adoption of ~50–70% where economics and engineering stack up. Under these conditions, the feasible abatement consolidates at about ~80 kt CO₂-e yr⁻¹, with uncertainty dominated by site retrofitability and sustained retention control.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Breadth of application:

Ranking: Medium

Justification: Currently limited adoption, but technically feasible across all pig production regions. Particularly suited for larger operations with existing effluent infrastructure and high nutrient reuse potential.

Co-Benefit Potential

Ranking: High

Justification: Up to 50% reduction in required separation distances due to lower odour emissions. For nutrient recovery, higher concentrations of nitrogen and phosphorus in effluent improve fertiliser value. Smaller or no anaerobic ponds are needed. Effluent can be directly applied to land with better nutrient availability.

Barriers and Knowledge Gaps

Ranking: Medium

Justification: Lack of awareness and technical guidance, approval requirements, nutrient management complexity, and limited demonstration projects. Need for sufficient land area to apply nutrients, and can be labour-intensive. Requires careful nutrient application planning, and adoption is constrained by a lack of packaged system designs and advisory capability, requiring bespoke engineering for each site.

Stacking Potential

Ranking: High

Justification: Short HRT can be combined with solids separation (pre-treatment), pH modification (to inhibit methanogenesis), additives like polymeric sulphate or calcium-cyanamide (up to 99% methane reduction) (McGahan, 2024).

Technology Readiness Level (TRL)

Ranking: 8-9

Justification: Proven in operational settings.

Commercial Readiness Level (CRL)

Ranking: 3-4

Justification: Early commercial adoption, not yet mainstream.

Enabling Potential

Ranking: Low (primarily)

Justification: HRT systems in the Australian pig production sector are best understood as both a standalone intervention and a potential enabler of broader system transformation, depending on how they are implemented. Short HRT systems are primarily designed to:

- Reduce methane emissions by limiting the time effluent remains in anaerobic conditions, thereby disrupting methanogenesis.
- Lower capital costs compared to methane capture systems like covered anaerobic lagoons or digesters.
- Improve nutrient retention (e.g., nitrogen and phosphorus), which enhances the value of effluent for land application.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

As a standalone technology, short HRT systems are effective in reducing Scope 1 emissions from manure management and are particularly suitable for farms where methane capture is not economically viable. Short HRT systems can also catalyse broader changes when integrated into a more comprehensive strategy:

- Infrastructure upgrades: They require different effluent storage and irrigation systems, such as slurry tanks or direct injection spreaders, which can modernise farm operations.
- Carbon accounting: Their impact on methane reduction is quantifiable and can be incorporated into carbon footprint assessments. For example, Scope 1 manure emissions can be reduced by up to 95% compared to traditional ponds.
- Complementary technologies: Short HRT systems can be combined with solids separation, nutrient recovery, and precision irrigation, enhancing overall environmental performance.
- Energy efficiency: In broader wastewater treatment contexts, short HRT systems (e.g., in high-rate activated sludge processes) have been shown to improve energy recovery and reduce operational costs.

Estimated Cost Range:

Short-HRT retrofits generally cost A\$0.3–1.2 m depending on hydraulic reconfiguration, tanks, pumping and controls. Operating costs are largely pumping and maintenance. Projects often pair with solids removal to protect pumps and to reduce downstream emissions further.

Estimated Financial Benefits:

Economic returns come from odour reduction, smaller/slimmer pond assets, and regulatory risk reduction—rather than energy sales. Where project proof demonstrates methane avoidance per the Animal Effluent Management method, ACCUs may be claimable, improving ROI.

Investment in R&D and Commercialisation (expanded)

Range: N/A

R&D needs include technical modelling (PigBal, MEDLI – ongoing through APL (McGahan, 2024)), emission factor validation, development of ERF methodologies, industry engagement and feasibility studies.

Minimum solids stockpiling

Summary:

Minimum solids stockpiling involves separating and storing the solid fraction of piggery effluent to reduce the organic load entering anaerobic ponds, thereby reducing methane generation (APL, 2022; Phillips et al., 2016). By diverting volatile solids from anaerobic ponds and treating them aerobically (e.g., composting), methane emissions are significantly reduced. Minimum solids stockpiling is considered a supporting technology in reducing GHG emissions, particularly methane, by diverting volatile solids from anaerobic treatment systems (e.g., effluent ponds) and managing them aerobically. While not the most impactful standalone solution, it plays a critical role in integrated manure management systems.

Annual Abatement Potential (Technical):

Output: Up to 10-30% reduction in methane emissions from effluent systems when solids are effectively separated and managed aerobically (Wiedemann et al., 2021).

Justification: This technology is already used at Australian pig farms. Varies by farm size and system but can be hundreds of tonnes CO₂-e per year for large piggeries. Technical abatement

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

potential for the sector is not published as a single figure for minimum solids stockpiling alone, but it is included in broader manure management strategies under the ERF.

Abatement Potential – Economic/Feasible:

We estimate feasible abatement by treating pond methane as the target and scaling by the volatile-solids fraction kept out of ponds. Evidence indicates that aerobic diversion/stockpiling of a meaningful VS share can trim pond CH₄ by ~10–30%; we take ~20% as a planning value. We limit the technical domain to liquid systems with practical pads, handling and drainage, and assume mid-range adoption (~50–80%) under stronger odour/compliance drivers. On this basis, feasible abatement settles in the low-tens of kilotonnes per year, with a central estimate near ~40 kt CO₂-e yr⁻¹ and sensitivity to the consistency of pre-pond capture and pad management (moisture/aeration).

Breadth of application:

Ranking: Medium

Justification: Applicable to most conventional and deep litter piggeries. Particularly suited to medium to large-scale operations with effluent treatment systems.

Co-Benefit Potential

Ranking: High

Justification: Separated solids can be composted and reused as organic fertiliser, enhancing soil organic carbon (SOC) and microbial activity. By managing solids separately, nutrient leaching into waterways is reduced, improving water quality. Aerobic treatment of solids (e.g., composting) produces significantly less odour than anaerobic decomposition in effluent ponds. Reducing solids load in ponds decreases sludge buildup and overflow risk during heavy rainfall. Compost from solids can replace or supplement synthetic fertilisers. Eligible under ERF for generating ACCUs. When stacked with covered anaerobic ponds, solids separation improves methane yield and reduces maintenance costs.

Barriers and Knowledge Gaps

Ranking: Medium

Justification: Capital investment and uncertainty about return. Regulatory complexity and varying state-level requirements. Knowledge gaps in best practices for solids handling and composting. Labour and management intensity for stockpile monitoring and maintenance. Manure as a product is classed differently in different jurisdictions, e.g., as industrial waste in Victoria and New South Wales, while considered an agricultural product or soil amendment in Queensland, South Australia and Western Australia. Differences affect licensing, transport, and reuse requirements. Consistency in the classification of manure as a product across jurisdictions is needed.

Stacking Potential

Ranking: Medium

Justification: Minimum solids stockpiling is not typically implemented as a standalone solution but is highly effective when combined with other emission abatement technologies. This makes it a valuable component in integrated manure and effluent management systems. High potential to stack with a) covered anaerobic ponds (CAPs) for biogas capture, b) composting systems for nutrient recovery, c) effluent reuse systems for irrigation. Stacking enhances both abatement and economic returns.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Technology Readiness Level (TRL)

Ranking: 9

Justification: Fully developed and demonstrated in operational environments across Australia.

Commercial Readiness Level (CRL)

Ranking: 6

Justification: Commercially available and adopted by early movers, but not yet widespread across the industry.

Enabling Potential

Ranking: Low

Justification: Minimum solids stockpiling in the Australian pig production sector is generally considered a complementary or standalone intervention, but it can support broader system transformation when integrated strategically. Minimum solids stockpiling typically involves:

- Separating and storing manure solids for later use (e.g., composting, land application).
- Reducing methane emissions by removing solids from anaerobic lagoons, which limits methanogenesis.
- Improving nutrient management, especially nitrogen and phosphorus retention.

Minimum solids stockpiling can contribute to system-wide change when integrated with:

- Infrastructure upgrades: It may require new storage facilities, composting areas, or transport logistics.
- Integrated farming systems: Solids can be reused in crop production, fish farming, or bioenergy systems, enhancing circularity.
- Breeding and management programs: Improved waste handling can support higher stocking densities or more intensive production systems without increasing environmental impact.

Estimated Cost Range:

No overall cost ranges are available. Capital: \$50,000–\$150,000+ depending on solids separation system (e.g., screw press, sedimentation), scale and technology.

Ongoing: Labour, maintenance, and monitoring costs.

Estimated Financial Benefits:

Standalone: The return on investment (ROI) is moderate, primarily from avoided methane emissions and nutrient reuse.

Stacked: ROI improves significantly when combined with covered anaerobic ponds, composting, or nutrient recovery systems.

- Eligibility for ACCUs: Farms can earn carbon credits under the Animal Effluent Management Method if solids stockpiling is part of a broader methane abatement strategy.
- Grant Opportunities: Funding may be available through programs like the Carbon Farming Outreach Program, ARENA, or state-based sustainability grants.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

- Market Differentiation: Farms adopting sustainable practices may gain access to premium markets or certification schemes (e.g., Climate Active).

Investment in R&D and Commercialisation (expanded)

Range: N/A

Australian Pork Limited (APL) and the Department of Agriculture have funded multiple projects under the Low Carbon Emission Roadmap and Pork CRC. Focus areas include:

- Solids separation efficiency.
- Composting and nutrient recovery.
- Integration with biogas and energy systems.

Continued research into low-cost solids separation, odour control, and nutrient recovery can improve performance and reduce costs.

Manure slurry acidification (and other additives)

Summary: Acidification directly targets methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3) emissions from stored manure, which are major contributors to on-farm GHG emissions. Acidification lowers slurry pH, inhibiting methanogens and reducing CH_4 and NH_3 emissions. Sulfuric acid (H_2SO_4) is the most effective agent. While acidification remains the most established approach, and the focus of this assessment, there is a growing suite of alternative and complementary additives that operate via different mechanisms being developed by industry. These are worthy of future inclusion in this STA.

These include:

- Oxidising agents (e.g. hydrogen peroxide or oxygen-releasing formulations) that suppress anaerobic microbial activity and inhibit CH_4 formation;
- Surfactants and chemical inhibitors (e.g. sodium dodecyl sulfate) that disrupt methanogenic microbes and can achieve very high CH_4 reductions;
- Biological additives (microbial consortia or enzymes) that alter microbial community dynamics, with stronger and more consistent effects on NH_3 and variable effects on CH_4 ;
- Mineral amendments and adsorbents (e.g. biochar, zeolite, gypsum) that reduce NH_3 emissions through adsorption and can also moderate CH_4 production by altering slurry physicochemistry;
- Nitrogen-cycle modifiers (e.g. nitrification inhibitors) that primarily target N_2O emissions by shifting nitrogen transformation pathways; and
- Emerging multi-functional proprietary additives that combine oxidation, microbial suppression, and nutrient stabilisation.

Annual Abatement Potential (Technical):

Output: ~20–60% of CH_4 from acidified slurry storage (central ~40%), via pH suppression of methanogens; also strongly reduces NH_3 volatilisation. Technical effect varies with slurry chemistry and dosing control (NIWA, 2025). Technical abatement potential is high, especially when combined with frequent slurry removal and residual acidification.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Abatement Potential – Economic/Feasible:

We estimate feasible abatement by combining storage-stage emissions with methane suppression at lower pH. Literature supports meaningful CH₄ reductions (often 20–60%) at low-dose acidification; we use a ~40% central effect. Because dosing logistics and OHS considerations limit where this is practical, we restrict the application domain to tank/pre-pond settings (rather than large open ponds) and assume moderate adoption (~40–60%) where safe systems and supply chains exist. Under these guardrails, feasible abatement is in the order of ~10–20 kt CO₂-e yr⁻¹, with uncertainty driven by slurry alkalinity and sustained dosing control.

Breadth of application:

Ranking: Low

Justification: Limited but growing in Australia. Most common in Denmark and Europe; pilot trials underway in Australia.

Co-benefit potential

Ranking: High

Justification: Odour reduction (e.g., significant suppression of hydrogen sulfide (H₂S)) and other odorants; enhancement of the fertiliser value of pig manure slurry through improving retention of ammonium nitrogen.

Barriers and Knowledge Gaps

Ranking: Moderate-High

Justification: High capital cost for automated systems. Safety concerns with acid handling. Need for frequent slurry transfer (not feasible in deep pit systems).

Stacking Potential

Ranking: High

Justification: Potential stacking with biogas systems, dietary interventions, e.g., low-protein diets, frequent slurry removal.

Technology Readiness Level (TRL)

Ranking: 8-9

Justification: Proven in pilot and commercial settings, especially in Europe. Australian trials are ongoing.

Commercial Readiness Level (CRL)

Ranking: 8

Justification: Commercial technologies exist, but adoption in Australia is still emerging. Contractors offer acidification services.

Enabling Potential

Ranking: Medium

Justification: Manure slurry acidification—particularly using sulfuric acid—is primarily considered a standalone or complementary intervention for reducing Scope 1 greenhouse gas emissions in pig production. However, it can enable broader system transformation when integrated strategically.

Slurry acidification is mainly used to:

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

- Reduce methane (CH₄) and ammonia (NH₃) emissions during manure storage. Studies show reductions of 46–96% for methane and 33–78% for ammonia, depending on acid dose.
- Suppress odour emissions, particularly sulfur-containing compounds like hydrogen sulfide (H₂S) and 4-methylphenol.
- Improve nitrogen retention, enhancing the fertiliser value of slurry.

When integrated into a wider manure management strategy, slurry acidification can catalyse system-level changes:

- Infrastructure and operational changes
- Acidification requires specialised equipment for safe handling and mixing, which may prompt upgrades in slurry storage and transfer systems.
- It encourages frequent slurry transfer from barns to storage tanks, which can improve overall manure management efficiency.
- Carbon accounting and emissions reporting
- Acidification can complement solids separation, nutrient recovery, and biogas systems.
- It may also reduce the need for other chemical treatments or odour control technologies.
- Influence on nutrient management and crop systems
- Acidified slurry has improved nitrogen availability and better alignment with crop nutrient needs, supporting more efficient fertiliser use.

Estimated Cost Range:

Acid: \$50–\$100/tonne slurry depending on dose and frequency.

Equipment: Variable; automated systems are costly.

Estimated Financial Benefits:

No estimates of financial benefits are available. Reduced fertiliser costs. Emission reductions from acidification are quantifiable, making it suitable for inclusion in carbon accounting frameworks and sustainability certifications.

Investment in R&D and Commercialisation (expanded)

Range: N/A

R&D focus on low-dose acidification, residual slurry treatment, and automated systems.

Deep litter housing

Summary:

In deeper litter housing systems pigs are housed on a bed of straw or sawdust that absorbs manure which then decomposes aerobically in situ (Copley et al., 2024). This system emits less methane than conventional liquid slurry handling, since manure is managed as a drier aerated solid, reducing anaerobic conditions that produce methane. An alternative to CAL in cooler (southern) regions.

Annual Abatement Potential (Technical):

~55% of GHG from the converted conventional flushed production (e.g., ~4.4 → ~2.0 kg CO₂-e/kg LW), reflecting much lower CH₄ formation when manure is managed as drier, aerated litter rather than slurry to ponds (Copley et al., 2024).

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Abatement Potential – Economic/Feasible:

We estimate feasible abatement by contrasting conventional flushed + uncovered ponds with deep-litter systems that keep manure more aerated in-shed. The FY22 benchmarking shows much lower intensity for deep-litter/outdoor compared with 100% conventional (e.g., ~2.0 vs ~4.4 kg CO₂-e/kg LW), implying ~55% abatement on the converted production share. We then restrict the technical domain to operations realistically convertible (shed design, climate, litter supply) and assume upper-end adoption ~40–60% of that domain over a decade. Under these constraints, feasible abatement aggregates to ~70–100 kt CO₂-e yr⁻¹, with the spread reflecting conversion capex, litter availability and management of NH₃ in deep-litter.

Breadth of application:

Ranking: Medium

Justification: Widely adopted in multi-site and outdoor-bred systems in cooler regions. Not applicable in tropics. Increasing uptake in regions like NSW, VIC, WA, and TAS (ALP, 2025). Deep litter housing is not universally feasible for all types of piggeries in Australia. Its suitability depends on several factors, including production scale, climate, shed type/design (ventilation systems), management capacity, and regulatory requirements. For example, the climate in Queensland is too hot and humid for deep litter housing while it works well in the cooler South Australian climate. It is often more cost-effective and easier to manage small and medium-scale farms. Aligns well with outdoor-bred or free-range production models. Commonly used in grower-finisher sites where pigs are moved from breeding facilities.

Co-benefit potential

Ranking: High

Justification: Better health status, reduced stress. Odour Reduction - Less liquid effluent, lower ammonia emissions. Compostable Bedding - Used litter can be repurposed as fertiliser.

Barriers and Knowledge Gaps

Ranking: Moderate

Justification: Bedding supply and cost can be limiting, specifically during droughts. High management requirements (e.g., in-shed, manure, area for composting). Labour-intensive management. Regulatory requirements for shed base and drainage. Limitations to retrofit certain shed types with ventilation systems that would support deep litter housing.

Stacking Potential

Ranking: High

Justification: Split-sex and phase feeding. Composting systems. Biogas capture from composted litter.

Technology Readiness Level (TRL)

Ranking: 9

Justification: Fully commercial and widely implemented across Australia (temperate regions).

Commercial Readiness Level (CRL)

Ranking: 9

Justification: Commercially viable, with widespread adoption and industry support.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Enabling Potential

Ranking: Medium

Justification: Deep litter housing in the Australian pig production sector is a complementary intervention that can enable broader system transformation when integrated with other technologies and management practices.

- Use bedding materials (e.g., straw, sawdust) to absorb manure and urine, reducing the need for liquid effluent systems.
- Lower capital costs by 60–70% compared to conventional housing, making them attractive for smaller or expanding operations.
- Reduce odour and water use and produce compostable litter that can be used as fertiliser.
- These features make deep litter housing a practical, lower-emission alternative to conventional housing, especially in systems without access to biogas infrastructure.

Deep litter housing can support system-wide change in several ways:

Infrastructure and operational shifts

- Deep litter housing in supports multi-site, all-in-all-out (AIAO) management, split-sex feeding, and phase feeding strategies, which are key to modern, efficient pig production.
- It enables expansion with lower capital investment, making it suitable for marginal producers or those transitioning from outdoor systems.

Carbon accounting and emissions reduction

- Deep litter housing in systems produce less methane than anaerobic lagoons and allow for in-situ composting, which can reduce Scope 1 emissions.
- Used litter can be quantified for nutrient recovery and included in carbon accounting frameworks.

Integration with other technologies

- Deep litter housing in complements:
 - Low-protein diets (by reducing nitrogen excretion into bedding).
 - Solid separation and composting systems.
 - Breeding programs focused on pigs suited to group housing and bedding environments.

Support for circular farming systems

- Compost from deep litter housing in can be reused on-farm or sold, supporting nutrient cycling and reducing reliance on synthetic fertilisers.

Estimated Cost Range:

Capital costs: Deep litter sheds cost typically 60–70% less to build than conventional sheds. Approx. \$50–\$60 per pig for weaners; \$100–\$120 for growers; up to \$250 for dry sows.

Estimated costs: Weaner sheds: \$50–\$60 per pig place. Grower-finisher sheds: \$100–\$120 per pig place. Dry sow sheds: up to \$250 per sow place.

Operating costs: Labour costs may be 20–30% higher due to bedding management.

Feed conversion ratio (FCR) may be 5–10% worse, affecting feed costs.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Offsetting benefits: Improved animal health and welfare. Potential for composting and selling used litter.

Estimated Financial Benefits:

Lower capital costs:

- Deep litter housing sheds cost less to build than conventional sheds.

Reduced production costs:

- Potential for lower overall production costs, depending on bedding and feed prices.
- Deep litter housing supports large group housing, which can reduce labour and sorting costs.

Compostable bedding:

- Used litter can be composted and sold or reused as fertiliser, creating a secondary revenue stream.
- Improved pig marketing:
- Automatic sorters in deep litter housing systems help increase the proportion of pigs marketed in the prime weight range, improving returns.

Reduced odour and effluent:

- Deep litter housing produces little or no liquid effluent, reducing odour and environmental contamination risks.

Improved resource efficiency:

- Deep litter housing contributes to reduced water use and improved nutrient cycling.
- Bedding absorbs manure, reducing runoff and leaching into soil and groundwater.

Animal welfare and health:

- Deep litter housing supports 'all-in, all-out' management, improving herd health and reducing disease transmission.
- Better health status leads to higher feed intake and growth performance.

Investment in R&D and Commercialisation (expanded)

Range: N/A

Focus on optimising bedding use, ventilation, and nutrient recovery.

Low-protein diet (amino acid supplementation)

Summary:

Low-protein diets supplemented with essential amino acids are considered a nutritional-based emission mitigation strategy. There are formulated pig diets with reduced crude protein (CP) content (while adding synthetic amino acids to meet nutritional needs) which can markedly lower nitrogen excretion.

Annual Abatement Potential (Technical):

About 22–36% of manure-N-related emissions (proxied by N excretion, with ~11–12% less N per 1% CP reduction; typical 2–3 pt CP cuts). Consistently reduces NH₃ (and downstream N₂O potential) when AA are properly balanced

We estimate feasible abatement by isolating manure-related emissions tied to nitrogen excretion and applying effects observed with 2–3 percentage-point CP reductions (balanced with crystalline amino acids). Large-scale trials indicate ~11–12% less N excretion per 1% CP drop and ~20–35% NH₃ reduction with properly phase-balanced AA. Given that most Australian grow-finish herds can implement phase feeding and AA logistics, we set a broad technical domain (~90%) and high

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

but not universal adoption (~60–80%) over 10 years. Resulting feasible abatement consolidates around ~30–90 Kt CO₂-e yr⁻¹, driven mainly by diet discipline and ingredient price dynamics, with co-benefits in odour and nutrient loading.

Abatement Potential – Economic/Feasible:

We estimate feasible abatement by isolating manure-related emissions tied to nitrogen excretion and applying effects observed with 2–3 percentage-point CP reductions (balanced with crystalline amino acids). Large-scale trials indicate ~11–12% less N excretion per 1% CP drop and ~20–35% NH₃ reduction with properly phase-balanced AA. Given that most Australian grow-finish herds can implement phase feeding and AA logistics, we set a broad technical domain (~90%) and high but not universal adoption (~60–80%) over 10 years. Resulting feasible abatement consolidates around ~30–90 Kt CO₂-e yr⁻¹, driven mainly by diet discipline and ingredient price dynamics, with co-benefits in odour and nutrient loading.

Breadth of application:

Ranking: High

Justification: applicable in most or all settings.

Co-Benefit Potential

Ranking: High

Justification: Improved gut health, e.g., reduced fermentation and pathogenic bacteria. lower odour emissions, e.g., less ammonia and volatile compounds. Improved nitrogen efficiency, e.g., better nutrient utilisation and reduced pollution.

Barriers and Knowledge Gaps

Ranking: Medium

Justification: Formulation complexity, e.g., requires precision in balancing amino acid profiles. Risk of welfare issues, e.g., poorly balanced diets may lead to tail biting or reduced performance (Minussi et al., 2023). Trying to maintain feed conversion ratios when changing feed types can be a risk.

Stacking Potential

Ranking: High

Justification: Can be combined with effluent management systems (e.g., short HRT, CALs), manure treatment (e.g., composting, biofilters), and precision feeding technologies.

Technology Readiness Level (TRL)

Ranking: 9

Justification: Widely tested and implemented globally (Duarte et al., 2024).

Commercial Readiness Level (CRL)

Ranking: 8

Justification: Commercially available and adopted by mainstream producers in Australia.

Enabling Potential

Ranking: Medium

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Justification: Low-protein diets with amino acid supplementation in the Australian pig production sector are primarily considered a standalone or complementary intervention, but they can support broader system transformation when integrated strategically.

Low-protein diets aim to:

- Reduce nitrogen excretion, thereby lowering greenhouse gas emissions (particularly nitrous oxide).
- Maintain growth performance by supplementing essential amino acids such as lysine, methionine, threonine, tryptophan, and valine.
- Lower feed costs by reducing reliance on high-protein ingredients like soybean meal.

These diets are often implemented independently or alongside other nutritional strategies and do not require major infrastructure changes. When integrated into a larger sustainability or production strategy, low-protein diets can:

- Support carbon accounting: Reduced nitrogen excretion and improved feed efficiency can be quantified and reported as part of Scope 1 emission reductions
- Influence breeding and management: Nutritional strategies may align with genetic selection for pigs that perform well on lower-protein diets, promoting more efficient nutrient use.
- Enable adoption of complementary technologies: For example, reduced nitrogen in effluent may improve the performance of downstream waste treatment systems like short HRT or solids separation.
- Improve gut health and reduce environmental impact: Lower crude protein diets reduce antinutritional factors and pathogenic bacteria, contributing to better animal welfare and reduced emission.

Estimated Cost Range:

Cost range can be variable depending on amino acid prices, feed formulation software, and nutritionist support.

Potential for up to 20–30% reduction in feed costs when soybean meal is replaced (de Almeida et al., 2024).

Estimated Financial Benefits:

No formal assessments are available. Our rough estimate suggests

- Improved feed efficiency.
- Reduced nitrogen-related penalties or compliance costs.
- Potential for carbon credits if integrated into broader emission reduction strategies.

Investment in R&D and Commercialisation (expanded)

Range: N/A

Research in Australia and globally on optimal amino acid profiles, gut health impacts, integration with manure management.

Probiotic and plant-based feed additives

Summary:

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Probiotic and plant-based feed additives are considered emerging and complementary technologies for reducing Scope 1 emissions in pig production (Hossain et al., 2024; Lewis et al., 2015). While not as impactful as manure management systems, they contribute to lower nitrogen excretion, reduced methane generation, and improved gut health, which indirectly reduces GHG emissions. Probiotics improve gut microbiota balance, reducing nitrogen excretion and methane precursors. Plant-based additives (e.g., essential oils, flavonoids, saponins) enhance digestion and reduce ammonia and methane emissions.

Annual Abatement Potential (Technical):

About 5–15% of manure-related emissions via improved digestibility and microbiome effects that modestly lower N losses and odour/CH₄ precursors; effects are product- and context-specific.

Abatement Potential – Economic/Feasible:

We estimate feasible abatement by targeting the manure-emissions share susceptible to digestibility and microbiome improvements and applying a modest technical effect (~5–15%) from multi-issue reviews. Because such products are broadly usable, but outcomes are product- and context-specific, we allow a wide domain (~80%) but hold adoption to ~40–60% in an upper-end, incentive-rich scenario. On these inputs, feasible abatement lies in the single- to low-tens of kilotonnes per year, with variability driven by real-world FCR/N-excretion responses at commercial scale

Breadth of application:

Ranking: N/A

Justification: N/A

Co-Benefit Potential

Ranking: High

Justification: Gut health & immunity, improved feed efficiency, e.g., reduced feed waste and cost, odour reduction, welfare, e.g., reduced stress and improved meat quality (PWC, 2025).

Barriers and Knowledge Gaps

Ranking: Medium

Justification: Costs sensitivity, requires technical knowledge, regulation varies by region.

Stacking Potential

Ranking: High

Justification: Can be combined with low-protein diets, effluent management systems, biofilters and composting.

Technology Readiness Level (TRL)

Ranking: 9

Justification: Widely used and validated in commercial livestock system

Commercial Readiness Level (CRL)

Ranking: 8

Justification: Commercially available and adopted in mainstream pig production globally and increasingly in Australia.

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Enabling Potential

Ranking: Moderate

Justification: Probiotic and plant-based feed additives in the Australian pig production sector are generally considered complementary or standalone interventions, but they can support broader system transformation when integrated strategically. Probiotics and plant-based additives are primarily used to:

- Improve gut health, feed conversion efficiency, and immune function.
- Reduce reliance on antibiotics, addressing antimicrobial resistance concerns.
- Lower environmental impact, such as reduced ammonia emissions from manure.
- These additives are typically incorporated into feed without requiring major changes to infrastructure or breeding programs, making them accessible and scalable.

When strategically integrated, these feed additives can catalyse wider changes:

- Carbon accounting: Improvements in feed efficiency and reduced nitrogen excretion can be quantified and included in Scope 1 emissions reporting.
- Infrastructure and management: Enhanced gut health and nutrient absorption may reduce the load on effluent treatment systems, complementing technologies like short HRT or solids separation.
- Breeding programs: Probiotic use may align with genetic selection for pigs with improved gut microbiota responsiveness or feed efficiency.
- Sustainable farming systems: Plant-based additives, especially those with antimicrobial or anti-methanogenic properties, support natural resource use and circular farming models.

For example, tannin-rich plant additives have shown potential to reduce methane emissions and improve nutrient utilization, which could support broader sustainability goals.

Estimated Cost Range:

8–15% higher than conventional diets.

Estimated Financial Benefits:

Improved feed conversion.

Investment in R&D and Commercialisation (expanded)

Range: N/A

Dietary organic acids**Summary:**

Dietary organic acids reduce emissions by improving nutrient digestibility, reducing manure nitrogen excretion, and lowering methane and hydrogen sulfide (H₂S) emissions from faeces.

Annual Abatement Potential (Technical):

Estimated at 5–15% of manure-related emissions where acids enhance digestibility and reduce N excretion/NH₃; magnitude depends on acid type, inclusion rate, and base diet.

Abatement Potential – Economic/Feasible:

We estimate feasible abatement using the same N-pathway lever as probiotics, applying a ~5–15% technical effect where digestibility and N excretion benefits materialise. Given wide usability but variable responses, we assume a broad domain (~80%) and mid-range adoption (~50%) under ambitious rollout. These settings yield feasible abatement in the single- to low-tens of

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

kilotonnes per year, with variance mainly across acid types, inclusion rates and interactions with basal diets.

Breadth of application:

Ranking: Medium

Justification: More common in AGP-free systems and farms focused on sustainability.

Co-benefit potential

Ranking: High

Justification: Improved gut health, reduced diarrhoea, better immunity. Performance increase, e.g., higher weaning weights, better nutrient digestibility. Reduced odour and faecal gas emissions.

Barriers and Knowledge Gaps

Ranking: Medium

Justification: Cost of high-quality acid blends. Lack of awareness or training. Need for tailored formulations.

Stacking Potential

Ranking: High

Justification: Low-protein diets. Enzyme supplementation. Biogas systems (due to reduced manure emissions).

Technology Readiness Level (TRL)

Ranking: 9

Justification: Fully commercial and widely validated in research and practice.

Commercial Readiness Level (CRL)

Ranking: 8-9

Justification: Commercially available, with multiple suppliers and proven on-farm benefits.

Enabling Potential

Ranking: Low

Justification: Dietary organic acids in pig production are primarily considered a complementary or standalone intervention, but they can support broader system transformation when integrated strategically. As a complementary or standalone intervention organic acids are widely used to:

- Improve gut health and digestion by lowering gastric pH, enhancing enzyme activity, and modulating intestinal microbiota.
- Reduce nitrogen and phosphorus excretion, which contributes to lower manure-related emissions.
- Enhance feed efficiency and growth performance, particularly in weaned piglets and fattening pigs.
- Replace in-feed antibiotics, supporting antimicrobial stewardship.
- These benefits make organic acids a practical and scalable intervention for reducing Scope 1 emissions related to feed and manure management.
- When integrated into a broader sustainability strategy, organic acids can catalyse system-wide changes:

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Infrastructure and feed system efficiency

- Organic acids are used not only in feed but also for grain preservation, offering an energy-efficient alternative to fossil fuel-based drying methods.
- This supports on-farm autonomy and reduces reliance on external feed processing infrastructure.

Carbon accounting

- Their impact on nutrient digestibility and reduced excretion can be quantified in life cycle assessments (LCA), making them suitable for inclusion in carbon accounting frameworks.

Integration with other technologies

- Organic acids complement other feed-based strategies such as:
 1. Low-protein diets
 2. Probiotics and prebiotics
 3. Maternal nutrition programs.
- They also enhance the performance of manure treatment systems by reducing nutrient loads and odorous compounds.

Support for breeding and health programs

- Improved gut health and nutrient absorption may align with breeding goals for pigs with better feed conversion and resilience.

Estimated Cost Range:

The estimated cost range approx. \$20–\$40/tonne of feed depending on blend and supplier.

Estimated Financial Benefits:

Improved FCE (up to 10.9%). Reduced bodyweight loss in sows (up to 28.5%). Increased piglet weaning weight (up to 23.4%). Improved rate of investment through performance benefits that carry through the market weight (exact estimates are unavailable)

Investment in R&D and Commercialisation (expanded)

Range: N/A

Limited research has been conducted on dietary organic acids, particularly in Australia. Research is conducted by companies like Selko®, Novus International, and universities. Focus areas include protected acid blends, dual delivery systems, and gut microbiota modulation.

*Pig breeding programs**Summary:*

Pig breeding programs are considered a foundational and enabling technology for GHG reduction. While they do not directly reduce emissions like effluent management systems, they enhance productivity, feed efficiency, and animal health, which indirectly lowers emissions per unit of pork produced (Dekkers, 2025; Ewaoluwabgemiga et al., 2025). Genetic selection improves traits such as feed conversion ratio (FCR), growth rate, litter size, and survivability. Better FCR means less feed per kg of pork, reducing emissions from feed production and manure.

Annual Abatement Potential (Technical):

~5–15% of whole-of-industry emissions intensity over near-term selection cycles, by reducing feed required and manure produced per kg LW (compounding gains across the herd)

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

Abatement Potential – Economic/Feasible:

We estimate feasible abatement at whole-of-industry scale, since genetic progress reduces intensity across all processes (less feed and manure per kg LW). Long-run analysis shows large historical intensity improvements, and current programs suggest ~5–15% further reductions are realistic over coming selection cycles. Assuming industry-wide technical suitability and upper-end adoption ~60–80% (recognising diffusion lags and G×E interactions), feasible abatement reaches the low-hundreds of kilotonnes per year, with the range depending on correlated responses and herd health.

Breadth of application:

Ranking: High (among commercial producers).

Justification: ~48% of national herd influenced by structured breeding programs like PIGBLUP (AGBU, 2025).

Co-benefit potential

Ranking: High

Justification: Improved feed efficiency, better health & welfare, enhanced meat quality, enhanced meat quality, e.g., less manure and nutrient load.

Barriers and Knowledge Gaps

Ranking: Medium

Justification: Cost of genetic tools (all genetics done in Australia, due to biosecurity concerns do not import of pig genetic material), technical expertise, limited collaboration among large pig breeder/producers.

Stacking Potential

Ranking: High

Justification: Breeding programs complement low-protein diets, feed additives, effluent management, precision feeding systems.

Technology Readiness Level (TRL)

Ranking: 8-9

Justification: Fully developed and widely implemented.

Commercial Readiness Level (CRL)

Ranking: 8-9

Justification: Commercially mature with widespread adoption and support from providers like Myora Genetics (2025) and AGBU (2025).

Enabling Potential

Ranking: High

Justification: Pig breeding programs in the Australian pig production sector are increasingly recognised as technologies that enable broader system transformation, rather than just standalone interventions. Here's how they contribute across different dimensions:

- Environmental impact reduction

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

- Breeding programs that focus on traits like feed efficiency, growth rate, litter size, and survivability directly reduce greenhouse gas emissions, particularly methane and nitrous oxide from manure and feed production.
- Life cycle assessment (LCA) studies show that genetic improvements can lead to 7–9% reductions in environmental impact over a decade, including lower emissions, resource use, and waste generation.

Integration with carbon accounting

- These improvements are quantifiable and verifiable through ISO-compliant LCA methodologies, making them suitable for inclusion in carbon accounting frameworks and sustainability reporting.
- This opens pathways for certification and monetisation of emission reductions, aligning breeding with climate goals.

Infrastructure and operational efficiency

- Genetic progress often requires or enables investment in breeding infrastructure, data systems, and precision management tools.
- It supports more efficient production systems, reducing the need for inputs like feed and water, and lowering the environmental footprint of infrastructure.

Catalysing adoption of other technologies

- Improved feed conversion and animal health can enhance the performance of complementary technologies like: Low-protein diets, probiotic feed additives, effluent treatment systems.
- Breeding programs also support resilience to environmental stress, which is critical for adapting to climate variability and integrating with sustainable farming systems.

Estimated Cost Range:

Performance testing costs are approx. \$12/pig for a single generation (Queensland Government, 2022).

Estimated Financial Benefits:

Increased pig value by \$12–\$30 per pig over time (Queensland Government, 2022). Reduced feed costs and improved herd health.

Investment in R&D and Commercialisation (expanded)

Range: N/A

Ongoing research into genomic selection, feed efficiency, and survivability traits

References

- AGBU. (2025). *PIGBLUP - A PC based genetic evaluation system*. AGBU. Retrieved from https://agbu.une.edu.au/pig_genetics/pigblup.html
- ALP. (2025). *PigGas studies*. Australian Pork Limited (APL). Retrieved from <https://australianpork.com.au/environmental-practices/greenhouse-gases/piggas-studies>
- APL. (2022). *Reducing greenhouse gas (GHG) emissions from piggeries*. Australian Pork Limited (APL). Retrieved from <https://australianpork.com.au/sites/default/files/2022->

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

- [04/033022%20-%20APL%20-%20Reducing%20GHG%20emissions%20from%20piggeries.pdf](#) (Accessed 18/08/2025)
- Australian Government. (2025). *Animal effluent management method*. Canberra, Australia: Australian Government, Department of Climate Change, Energy, the Environment and Water. Retrieved from <https://www.dcceew.gov.au/climate-change/emissions-reduction/accu-scheme/methods/animal-effluent-management>
- Copley, M. A., McGahan, E. J., McCormack, K., & Wiedemann, S. G. (2024). Environmental impacts of Australian pork in 2020 and 2022 determined using lifecycle assessments. *Animal Production Science*, 64(8). doi:<https://doi.org/10.1071/AN23352>
- de Almeida, A. M., Latorre, M. A., & Alvarez-Rodriguez, J. (2024). Productive, Physiological, and Environmental Implications of Reducing Crude Protein Content in Swine Diets: A Review. *Animals*, 14(21), 3081. Retrieved from <https://www.mdpi.com/2076-2615/14/21/3081>
- Dekkers, J. C. M. (2025). Opportunities to improve environmental sustainability of pork production through genetics. *Journal of Animal Science*, 103. doi:<https://doi.org/10.1093/jas/skaf042>
- Duarte, M. E., Parnsen, W., Zhang, S., Abreu, M. L. T., & Kim, S. W. (2024). Low crude protein formulation with supplemental amino acids for its impacts on intestinal health and growth performance of growing-finishing pigs. *Journal of Animal Science and Biotechnology*, 15(1), 55. doi:<https://doi.org/10.1186/s40104-024-01015-6>
- EwaoluwaGbemiga, E. O., Lloret-Villas, A., Nosková, A., Pausch, H., & Kasper, C. (2025). Single-variant genome-wide association study and regional heritability mapping of protein efficiency and performance traits in Large White pigs. *Genetics Selection Evolution*, 57(1), 45. doi:<https://doi.org/10.1186/s12711-025-00993-z>
- Harrington, D. (2023). *Improving the profitability of fattening pigs*. Feed Additive - International Magazine for Animal Feed & Additives Industry. Retrieved from <https://www.feedandadditive.com/improving-the-profitability-of-fattening-pigs/>
- Hossain, M. M., Cho, S. B., & Kim, I. H. (2024). Strategies for reducing noxious gas emissions in pig production: a comprehensive review on the role of feed additives. *Journal of Animal Science and Technology*, 66(2), 237-250. doi:<https://doi.org/10.5187/jast.2024.e15>
- Lewis, K. A., Tzilivakis, J., Green, A., & Warner, D. J. (2015). Potential of feed additives to improve the environmental impact of European livestock farming: a multi-issue analysis. *International Journal of Agricultural Sustainability*, 13(1), 55-68. doi:10.1080/14735903.2014.936189
- McGahan, E. (2024). *Guidance and Operation of Short Hydraulic Retention Time Systems - Technical review and modelling Project 2022/0015* Australian Government, Department of Agriculture and Water Resources; Australian Pork Limited. Retrieved from https://australianpork.com.au/sites/default/files/2024-05/1470%20-%20Short%20HRT%20-%20Technical%20Review%20Final_0.pdf
- McGahan, E., Valentine, J. V., Heubeck, S., & Murphy, C. (2013). *Five Piggery Biogas Capture and Energy Generation Feasibility Studies - Report prepared for the Co-operative Research Centre for an Internationally Competitive Pork Industry* Pork Co-operative Research Centre. Retrieved from <https://porkcrc.com.au/wp-content/uploads/2013/08/4C-102-Final-Report-130420.pdf>
- Minussi, I., Gerrits, W. J. J., Jansman, A. J. M., Gerritsen, R., Lambert, W., Zonderland, J. J., & Bolhuis, J. E. (2023). Amino acid supplementation counteracts negative effects of low

APPENDIX C.5: Priorities for Low Emissions Agricultural Solutions Investment

- protein diets on tail biting in pigs more than extra environmental enrichment. *Scientific Reports*, 13(1), 19268. doi:<https://doi.org/10.1038/s41598-023-45704-0>
- Myora Genetics. (2025). *Myora's High Performance Breeds*. Myora Genetics . Retrieved from <https://myora.com.au/>
- NIWA. (2025). *Biogas from pig farms*. Retrieved from <https://niwa.co.nz/renewable-energy/biogas-pig-farms>
- Phillips, F. A., Wiedemann, S. G., Naylor, T. A., McGahan, E. J., Warren, B. R., Murphy, C. M., . . . Wilson, J. (2016). Methane, nitrous oxide and ammonia emissions from pigs housed on litter and from stockpiling of spent litter. *Animal Production Science*, 56(9), 1390-1403. doi:<https://doi.org/10.1071/AN15650>
- Poad, G., McGahan, E., & Redding, M. (2010). *Low Cost Options for Reducing Effluent Pond Methane - Final Report APL Project 2009/2299*. Australian Government, Department of Agriculture; Australian Pork Limited. Retrieved from https://era.dpi.qld.gov.au/id/eprint/8431/1/2009_2299%20FINAL%20REPORT.pdf
- PWC. (2025). *Probiotics for Animal Feed Market*. PW Consulting (PWC) Health Care Research Center. Retrieved from <https://pmarketresearch.com/hc/probiotics-for-animal-feed-market/>
- Queensland Government. (2022). *Using performance-testing programs in piggeries*. Queensland Government. Retrieved from <https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/animal/industries/pigs/breed/genetics/program>
- Wiedemann, S., McGahan, E., McCormack, K., & Muller, T. (2021). *Low Carbon Emission Roadmap for the Australian Pork Industry* Australian Government, Department of Agriculture and Water Resources; Australian Pork Limited. Retrieved from <https://australianpork.com.au/sites/default/files/2021-12/Pig%20Industry%20Low%20Emission%20Roadmap%20final%20report.pdf>