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AUSTRALIAN Pork®

Guidance and Operation of Short Hydraulic Retention Time Systems

Technical review and modelling
Project 2022/0015

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Executive Summary

Emissions associated with manure management are a key contributor to greenhouse gas (GHG) emissions from animal production systems. Methane is the primary GHG released from piggery manure systems and is predominantly generated from the anaerobic decomposition of carbon in effluent treatment ponds at conventional (effluent based) piggery systems. With around one third of all manure currently managed in uncovered anaerobic ponds in Australia, there is an opportunity for the pig industry to adopt technologies such as short hydraulic retention time (HRT) systems to reduce GHG emissions. Short HRT systems reduce methane generation by decreasing the opportunity for the development of anaerobic conditions created by the traditional long HRT (often >100 days) ponds. The main advantages of short HRT systems when compared to methane capture and destruction systems such as covered anaerobic pond (CAPs) or engineered digesters are the lower construction and operation costs. Short HRT systems also have the benefit of utilising more of the valuable resources in piggery manure (carbon, nitrogen and phosphorus) as soil additives to improve both health and fertility.

Emission factors for short HRT systems (< 1 month storage) are included in the latest NIR (Commonwealth of Australia, 2023b) as a 3% methane conversion factor (MCF) for all states and provides a pathway for the adoption of short HRT systems into the Animal effluent management method under the ERF. The updated IPCC Guidelines (2019), from the 2006 version also include provision for short HRT systems as liquid/slurry systems. Interestingly, these updated IPCC guidelines include additional retention times of 1, 3, 4, 6 and 12 months, instead of the current more or less than 1 month storage. Also, the guide proposes that 5 percent of VS is retained in storage after emptying, rather than 0 percent (i.e. completely clean) assumption implied in the original IPCC 2006 calculations. The IPCC (2019) guideline now have higher reported MCF values for pig production regions in Australia, ranging from 13 to 42%, depending on the climatic zone. These would represent significantly higher methane emissions than are currently adopted 3% in Australia for all climatic zones.

Solids separation can be used in conjunction with other treatment technologies, such as CAPs or as a standalone GHG abatement system under the Emission Reduction Fund. It also would be a beneficial pre-treatment process before short HRT systems for several reasons as it would:

- Remove coarse material that is difficult to irrigate and causes clogging.
- Reduce settled solids in storage tanks to allow easier total removal.
- Remove significant amounts of nutrients to reduce the size of effluent irrigation areas.
- Convert a proportion of the liquid waste stream to a solids fertiliser/soil amendment that can be readily removed/sold off-farm.

pH modification is a potential method that could be utilised with short HRT, as the theory of short HRT is that fresh effluent will undergo pH reduction naturally when left in a storage tank for less than 30 days. pH has a significant effect on the performance of the anaerobic digestion process, as methanogenic bacteria are very sensitive to pH and do not thrive at pH levels < 6 and methane generation is almost zero at pH < 5 or > 8.

Some additives have also proven to have a significant reduction in GHG emissions. These include polyferric sulphate, with a 99% reduction in methane emissions from dairy effluent over 42 days and calcium-cyanamide that had methane reductions of 81% and 99% for pig effluent when added at rates of 300 and 500 ppm of effluent.

Modelling of these systems has shown that a relatively high percentage (between 61 and 99%) of the effluent can use utilised from short HRT systems depending on the location of the system in Australia. Generally, higher percentages of effluent can be used in areas with higher mean temperatures and lower rainfall, due to the frequent demand for effluent application by the crop. Effluent application from all piggeries, and in particular short HRT systems due to the higher nutrient concentration must be managed to ensure that nutrient application rates meet with the agronomic demand of the crop. Excess nutrient application can result in surface runoff and leaching of nutrients contributing to downstream eutrophication.

For 2,000 SPU farms operating with a short HRT system, the expected area for effluent application ranged between 80 and 110 ha depending on the climate, soil type and crop type. With the introduction of solids separation, this area was reduced to between 45 and 65 ha. For a 10,000 SPU farms operating with a short HRT system, the expected area for effluent application ranged between 400 and 550 ha depending on the climate, soil type and crop type. With the introduction of solids separation, this area was reduced to between 225 and 325 ha.

The GHG abatement of short HRT systems was shown to be very high when compared to traditional uncovered anaerobic ponds. The four pig production regions that were assessed showed that GHG abatement ranged between regions between 64 and 66%. This was based on modelling that assumed 100% of the effluent was managed via a short HRT system. Abatement, however, would still be high (around 50%) if at least 80% of the effluent was managed via a short HRT system. A detailed analysis of the disaggregated emissions for one location showed that Scope 1 manure emissions (methane and nitrous oxide) reduced from 2.66 to 0.13 kg of CO2-e/kg LW sold, representing a 95% reduction in GHG emissions.

The odour abatement of short HRT systems was shown to be very high when adopted as an alternative to traditional uncovered anaerobic ponds. Assessments were undertaken with different scenarios of the amount of effluent treated in short HRT systems. With 100% of the effluent treated in short HRT, required separation distances using the NEGIP formula were 50% less than for traditional uncovered anaerobic ponds. This means that if a piggery was to adopt short HRT with at least 80% of the effluent produced, it could have ~2.5 times more SPU, with the same required separation distance. The proposed treatment factors used in this study may require further validation, however, before adoption in the NEGIP.

Short HRT storage may offer the potential to be used as a systems approach in reducing overall GHG emissions from effluent treated in uncovered anaerobic ponds. Solids separation prior to short HRT storage would allow greater practical management of the stored effluent. Provided the separated solids are stored/treated in a manner that anaerobic activity is minimised, minimal emissions would occur from the separated component. Where short HRT systems are not viable due to issues with storage time or residual methanogenic bacteria in storage tanks, pH modification or additives to ensure methane generation remains inhibited in the storage tank prior to reuse.

It is recommended that the next stage of the project be undertaken that will include the development of a “how-to” guide and webinar for producers on the operation of short HRT systems in various pig production regions; the advantages and disadvantages of them over traditional uncovered ponds and likely GHG abatement potential. In conjunction with this will be an industry survey to gauge the level of producer interest in short HRT systems.

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1. Background to Research

Emissions associated with manure management are a key contributor to greenhouse gas (GHG) emissions from animal production systems. Significant research and investment over the last few decades have developed a range of viable methods for reducing manure related GHG emissions (methane and nitrous oxide) or improving the utilisation of the resources (including carbon and nitrogen) that are contained within livestock waste streams. Methane (CH_4) is the primary GHG gas generated from piggery manure systems in Australia and its main source is from the anaerobic decomposition of carbon in effluent treatment ponds at conventional (effluent based) piggery systems. In 2022, conventional piggery systems represent 60% of manure management in Australia, with the other 40% managed in deep litter and outdoor systems. Around one third of the manure generated in conventional piggeries (~19% of as all manure) is managed via methane capture and destruction systems and another 8% of all manure is managed via solids separation (Copley et al. *in preparation*). This still leaves almost one third of all the manure from piggeries in Australia generating methane emissions in uncovered anaerobic pond systems.

Short hydraulic retention time (HRT) systems are an alternative method for managing effluent for conventional piggeries. Short HRT systems reduce methane generation by decreasing the opportunity for the development of anaerobic conditions created by the traditional long HRT (often >100 days) ponds. Short HRT systems could be combined or operated in tandem with solids separation systems, to reduce GHG emissions and improve the characteristics of effluent for irrigation.

The main advantages of short HRT systems compared to methane capture and destruction systems, including covered anaerobic pond (CAPs) and engineered digesters, are the lower construction and operation costs. Short HRT also have the benefit of utilising more of the valuable resources in piggery manure (carbon, nitrogen and phosphorus) as soil additives to improve both health and fertility. Short HRT adoption has potential for small to medium sized piggery operations and larger operations where energy capture via anaerobic digestion is not economic due to a lack of energy demand at a site (e.g. large grow-out facility with natural ventilation).

This project aims to provide a solid research foundation to demonstrate the GHG mitigation benefits associated with short HRT effluent management systems in piggeries. Providing the adoption of short HRT proves a viable option for conventional piggeries in Australia, a submission to Commonwealth Energy Regulator could be made to include the methodology in the existing *Carbon Credits (Carbon Farming Initiative - Animal Effluent Management) Methodology Determination 2019* to enable Australian Carbon Credit Units (ACCUs) to be claimed.

2. Objectives of the Research Project

The specific objectives of this project are:

1. Provide evidence that a short HRT methodology can be adopted in both large and small production systems to reduce GHG emissions where covered ponds are not feasible across regions of Australia where pig production is concentrated.
2. Provide a technical review to APL and the CER for application of the methodology for emissions reduction.
3. Working with APL staff to provide content for extension and communications materials based on the project output, including infographics, summaries, and webinars/presentations.

This progress report has been completed to meet Milestone 3 of the project: Technical review of short HRT systems and modelling. The modelling includes nutrient and water balance assessments to investigate the impact of converting to short HRT from conventional larger anaerobic ponds for both small and large piggeries.

3. Technical Review

3.1 Background

Conventional pig farms typically manage effluent from production sheds through treatment in large uncovered anaerobic ponds. As of 2022, a proportion of the industry use solids separation systems prior to anerobic pond treatment (~8%) and around 19% of pig production has the manure managed with either covered anaerobic ponds (CAPs) or engineered digestors (Copley et al. *in preparation*).

Modelling of a short HRT scenario on a 'typical' farm suggests potential GHG emissions could be reduced by 51% (Wiedemann et al., 2012). This emission reduction outcome is based on a scenario where year-round usage of effluent may not be viable for irrigation and assuming that most of the effluent is directed to a short HRT system, while the remainder is treated though a conventional system pond system. The GHG reduction is similar to that achieved using a CAP or digester. Successful operation of short HRT systems will have a positive effect on the GHG emissions at a farm scale and could potentially be part of an overall GHG reduction strategy to minimise emissions for the Australian pork industry.

The short HRT system would effectively be an avoided emission technique, by minimising methane (CH_4) emissions through the avoidance of the complete anaerobic digestion process that occurs with effluent treated in traditional uncovered anaerobic ponds. The effluent is only stored for a short period (e.g. < 30 days) before utilisation to avoid significant methane generation and emission.

Short-HRT systems can be defined as: *a tank/sump outside the animal confinement building used for storing effluent for short periods*. Short-HRT systems are typically combined with direct application of effluent to land by using either a tanker, or a system designed to handle effluent with high solids content.

Short-HRT systems are common practice in European and North American piggery and dairy industries, where they are termed liquid/slurry systems. Manure is stored for short periods before land application with slurry spreaders. These systems do not utilise any treatment/storage pond to treat effluent. In Australia, short HRT systems are not common practice in the pig industry, as effluent is generally managed using anaerobic treatment systems. Around one third of the piggery manure generated at conventional piggeries in Australia currently incorporates methane capture and utilisation/destruction system, and thus is not viable to introduce short HRT systems.

Short HRT systems can be and may be best operated as part of a manure treatment and handling process to make manure handling simpler and to maximise emission reductions. This may include chemically modifying effluent pH and/or removing solids prior to short HRT storage. These processes are also investigated as part of this technical review.

Before exploring the physiochemical pathway to reducing GHG emissions using short HRT, the anaerobic decomposition of organic matter needs to be understood, along with the theory behind GHG emission estimation.

3.2 Anaerobic digestion

Anaerobic digestion (AD) is a series of biological process by which biodegradable organic matter is decomposed by numerous microorganisms that function in the absence of oxygen, producing CH_4, CO_2 and other gases. This process occurs naturally in many anaerobic (oxygen-free) environments, such as mammalian guts and waste sediments. Anaerobic decomposition is a four-stage process, where different groups of microorganisms are involved at each stage These four stages are:

1. Hydrolysis, - during this stage, solid material is broken down by enzymes into soluble molecules,
2. Acidogenesis – this is where soluble molecules are degraded by acid forming bacteria into acetate, hydrogen and CO_2,
3. Acetogenesis - here, volatile fatty acids are converted into acetic acid, CO_2, and hydrogen, and
4. Methanogenesis – in the final stage, the two groups of methanogens produce methane from either acetate or hydrogen plus CO_2.

To ensure all four stages are complete and methane is generated, an anaerobic environment and sufficient retention times are needed. Anaerobic digestion occurs naturally in uncovered effluent treatment ponds, with the resulting biogas released directly to the environment.

The yield of biogas and the resulting methane composition produced from anaerobic decomposition is highly dependent on various factors such as the methane potential of feedstock, design of the digestion system (pond of digester), nature of substrate, pH, temperature, volatile solids(VS), loading rate, hydraulic retention time, C:N ratio, volatile fatty acids content, and other trace gases, additions of methane inhibitors or inoculants, all of which can influence methane production (Dhevagi et al., 1992). Some of the more important factors that have a direct influence on short HRT systems are discussed below.

> ***Temperature*** significantly affects methane production due to the sensitivity of methanogenic bacteria to low temperatures (Molloy & Tunney, 1983). The optimum temperature range for satisfactory gas production takes place in the mesophilic range which is between 25 to 35 ° C (Chae et al., 2008; Uzodinma et al., 2007). Temperatures below this range severely limit the production of methane. This was evidenced in a study by Kavuma's (2013), which only obtained a methane yield of 47% for manure, due to digester temperatures below 24 ° C. This temperature explains the difference in methane percent concentrations between Oceania regions (Gavrilova et al., 2019) and other international studies.
>
> ***pH*** can affect the performance of anaerobic digestion, as methanogenic bacteria are very sensitive to pH and do not thrive at pH levels < 6. The optimum methane production is achieved when the pH value of anaerobic digestion is near neutral. The pH evidenced during anaerobic digestion is also a function of the retention time. During the start-up period of anaerobic digestion, large quantities of organic acids are formed by acid producing bacteria, and the pH can drop to <5, and this temporarily inhibits methanogenic bacteria digestion activity. This is a common issue with newly commissioned anaerobic treatment systems in the pig industry if they are not pre-loaded with effluent from a functioning anaerobic system. Over a period of storage time, the concentration of ammonia increases due to the breakdown of organic nitrogen, which then increases the pH values to an optimal methane producing level. When the pH stabilises

between pH 6 and 8, the digestion will produce higher levels of methane. With the treatment of effluent with acidification to reduce methane generation, a pH of around 5.5 is commonly reached (Fangueiro et al., 2015). This has been shown to result in almost complete inhibition of methanogenesis from several studies, as reported by Dalby et al. (2021). Section 3.7 further details the research and application of pH modification to reduce GHG emissions from animal effluent.

Relative proportions of C and N present in an organic material is expressed in terms of the carbon/nitrogen ratio (C:N). A C:N ratio ranging from 20 to 30 is considered optimal for anaerobic digestion (Stevens et al., 1989). At very low C:N ratios, elevated ammonia levels can inhibit digestion, and this mainly occurs with very concentrated manure sources.

Substrate type and characteristics will also have a significant effect on methane generation from both a chemical and physical perspective. Materials with higher levels of readily degradable volatile solids (VS) will have the potential to generate more methane. The removal of coarse manure particles (large surface area to volume ratios) via solids separation can increase potential methane generation rates per kg of organic material in the short-term, partly due to a slower degradability of coarse particles as opposed to finer particles (Sebola et al., 2016). This is observed in piggery CAPs and digesters with HRT of less than about 30 days, where solids removal of coarse materials prior to entry has little impact on overall methane generation. As discussed above, effluent that contains residual methanogenic bacteria (e.g. recycled flushing water) will likely have greater methane generation rates than “fresh” effluent that has not had a component of it previously pass through an anaerobic system.

Hydraulic retention time - There is a wide range of reported methane production rates from piggery anaerobic digestion systems, including Australian systems. These variations are likely due to a combination of factors discussed above. For example, Skerman (2017) and Longfield (2013) showed higher methane percentages following pond desludging events. These desludging events would increase system capacity and hence increase the hydraulic retention time. Hydraulic retention time is dealt with in detail in sections 3.3 to 3.5 below.

3.3 Estimating GHG emissions from anaerobic digestion

The most relevant GHG emissions that arise from effluent ponds is methane. Additionally, ammonia (NH_3), while not a GHG, is a relevant emission as it leads to nitrous oxide (N_2O) emissions when deposited to soil and re-released. It is not generally feasible to measure GHG and related gas emissions directly under commercial conditions as they are dispersed from the surface of the manure management system and measurement equipment is very expensive, so estimation via mass flows of organic matter and nitrogen are required. The following generalised formula is used for estimating methane emissions:

$$E = VS \times B_o \times P \times MCF \times GWP$$

Where:

E = methane emissions
VS = volatile solids, in kg

B_o = biological methane potential, in m^3 CH_4 / kg VS
P = specific density of methane (0.6784 kg/m^3) and
MCF = methane conversion factor, in percentages
GWP = Global Warming Potential (currently methane = 28)

B_o is the maximum biological methane-producing capacity for manure produced by an animal expressed as m^3 CH_4 kg VS^{-1}. B_o varies with animal type and feed type (IPCC, 2006).

The methane conversion factor (MCF) reflects the portion of B_o that is converted to methane in each manure treatment system. MCF values vary with manure management and climatic conditions and can theoretically range from 0 to 100%. Both temperature and retention time play an important role in the calculation of the MCF. Table 1, taken form Table A5.5.5.7 of the National Inventory Report for Australia (Commonwealth of Australia, 2023b) provides various MCF values for different manure management systems for each state. The MCF value for short HRT tanks (< 1 month) is 0.03 or 3% and is based on IPCC (2006) values.

Table 1. Methane conversion factors by piggery manure management systems (Commonwealth of Australia, 2023b)

	NSW	**QLD/NT**	**SA**	**TAS**	**VIC**	**WA**
Outdoor (Dry lot)	0.01 (b)	0.03 (a)	0.01 (b)	0.01 (b)	0.01 (b)	0.01 (b)
Deep litter (c)	0.04	0.04	0.04	0.04	0.04	0.04
Stockpile (Solid storage) (b)	0.02	0.02	0.02	0.02	0.02	0.02
Effluent pond (Uncovered anaer. lagoon) (e)	0.75	0.77	0.75	0.70	0.74	0.77
Anaerobic digester / Covered lagoon (e)	0.10	0.10	0.10	0.10	0.10	0.10
Short HRT tank storage (< 1 month) (d)	0.03	0.03	0.03	0.03	0.03	0.03

Notes:

(a) Redding *et al.* (2015).

(b) IPCC (2006) cool region values applied as these more closely align with Australian experimental data (Redding et al., 2015) and J. Devereux and M. Redding pers. comm., QDAFF June 2014).

(c) Based on average of international literature (Cabaraux et al., 2009; Nicks et al., 2003, 2004; F. X. Philippe et al., 2010, 2012; F.-X. Philippe et al., 2007, 2011; Wiedemann et al., 2014).

(d) IPCC (2006).

(e) IPCC (1997).

GWP is a relative measure of how much heat a GHG traps in the atmosphere and is expressed as a factor of carbon dioxide CO_2-equivalent (CO_2-e).

The other GHG of interest for piggery manure management is nitrous oxide and its GWP is currently 265. The manure treatment system plays an important role in the direct emissions of nitrous oxide, with anaerobic systems (anaerobic ponds and digesters) having an emission factor of zero and short HRT systems the factor is just 0.2%. Table A5.5.5.8 and Table 5.5.5.9 of the National Inventory Report for Australia (Commonwealth of Australia, 2023a) provides various nitrous oxide emission factors and nitrogen volatilised fractions (as ammonia) for different piggery manure management systems. See Table 2 and Table 3 for these values.

Table 2. Nitrous oxide emission factors by piggery manure management systems (Commonwealth of Australia, 2023a)

Manure management system	N_2O Emission factor	Source
Outdoor(Dry lot)	0.02	IPCC (2006)
Deep litter	0.01	IPCC (2006)
Stockpile (Solid storage)	0.005	IPCC (2006)
Effluent pond (Uncovered anaerobic lagoon)	0	IPCC (2006)
Anaerobic digestor / Covered lagoon	0	IPCC (2006)
Short HRT tank storage (< 1 month)	0.002	IPCC (2006)

Table 3. Fraction on nitrogen volatilised by piggery manure management systems (Commonwealth of Australia, 2023a)

Manure management system	N_2O Emission factor	Source
Outdoor(Dry lot)	0.3	IPCC (2006)
Deep litter	0.125	Wiedemann *et al.* (2014)
Stockpile (Solid storage)	0.2	FSA Consulting (2007)
Effluent pond (Uncovered anaerobic lagoon)	0.55	Tucker *et al.* (2010), Wiedemann *et al.* (2012)
Anaerobic digestor / Covered lagoon	0	IPCC (2006)
Short HRT tank storage (< 1 month)	0.25	IPCC (2006)

3.4 Australian research on short HRT systems

The short HRT manure management system approach works on the principle of replacing traditional large anaerobic treatment pond systems (typically with retention times > 100 days), with a system where all effluent is removed from the pond system before the four-stage anaerobic digestion process is complete, thus reducing manure methane emissions. Australian research conducted by McGahan et al. (2016), reported results from an experiment that replaced a conventional effluent pond system with a short HRT system at a commercial piggery to examine emission mitigation potential. The study determined and compared GHG and ammonia emissions from each system. The short HRT system was managed in a batch scenario (all effluent was added on day 1 and emissions were measured for the duration of the experiment). Natural acidification was found to be the likely inhibitor of GHG emissions. Emissions were measured for 30 days during two seasons, winter and summer, using Open Path - Fourier Transform Infrared (OP-FTIR) spectroscopy. Measured emissions were related to volatile solids (VS) and total nitrogen (TN) loaded into the tank, and these were related to pig numbers using mass balance techniques from measured feed and animal data, verified with measured effluent properties. Preliminary emission data from the piggery shed were also measured for baseline purposes during each measurement campaign. As anticipated, this study found emissions were higher in summer (i.e. ambient temperatures over 25°C) than winter for the short HRT system, overall abatement potential was still high. Table 4 shows the calculated GHG emission factors from this study.

Table 4. Methane and ammonia-N emissions factors from a conventional effluent pond compared to a short-HRT (McGahan et al., 2016)

	Conventional Pond		Short-HRT	
	Winter	Summer	Winter	Summer
MCF	71%	126%	0.1%	18%
Ammonia-N EF	0%	10%	0.02%	0.3%

Outcomes of the research concluded that short HRT system could easily be applied to piggeries in Australia, and they were also found to be cost effective in a benefit cost analysis study done by Wiedemann et al. (2016) for a medium sized piggery.

Another Australia study that investigated the application of short HRT wastewater management on a commercial dairy farm in southern Australia was undertaken by Boersma et al., (2017). This field trial demonstrated that while the theory of short HRT may be sound, there are practical impediments to achieving short-HRT at a commercial dairy. The main issue was around the ancillary management practices, such as frequent agitation to suspend and remove settled solids. Analysis of project data suggests that intermittent mixing caused an increase in methane emissions larger than could be explained by temperature alone. They concluded that as agitation for solids removal from the storage system is a necessary requirement, further investigation is needed to ensure methane emissions do not increase during this stage.

Methane emissions during the trial's short HRT phase were 87% higher (based on methane generated per mass of VS added to the storage tank) than the emissions recorded during the baseline phase. They did, however, find that methane emissions during the baseline phase were lower than anticipated. Is it possible that the methane productivity in the baseline trial was unusually low because of the on-label monensin fed at this time, which did not occur during the short HRT treatment trial. Monensin is designed as a methane inhibitor in used in cattle feed to increase production and the microbial community in the baseline trial not being adapted to its inclusion.

Other practical challenges identified by the project included:

1. how quickly HRTs can be reduced to sufficiently low times to capture the potential abatement could be realised.
2. managing multiple pond systems where the bulk of methane emissions are from a primary pond, not the managed short HRT storage, and
3. generating data that would enable a manager to document if the potential abatement offered by short-HRT has been achieved.

3.5 International research and findings on short HRT systems

Research by Møller et al. (2004) during storage of pig and cattle manure in Danish conditions at 15°C and 20°C showed temperature in this range was not a significant influence on methane production at storage times of < 30 days. Similarly, the IPCC (Dong et al., 2006) determined that an MCF of 3% should apply for manure storage < 30 days of at temperature below 25°C, while temperatures above 25°C should apply a MCF of 30% (refer to Figure 1). This supports the findings of the McGahan et al. (2016) Australian study conducted in both summer and winter that found emissions were negligible in winter and higher in summer (i.e. ambient temperatures over 25°C), although the summer emission reduction still showed a high degree of GHG abatement.

The 2019 refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019) still include provision for short HRT systems, with the same methane producing capacities (B_o) value for the Oceania region (includes Australia) of 0.45 m^3 CH_4/kg of VS. The difference with the original 2006 guidelines is the MCF value for liquid/slurry, is that instead of < 1 month (30 days) as the only category, it now includes values for 1, 3, 4, 6 and 12 months. There are also now more climatic zones covered in the guideline. The most relevant to Australian pig production are the Warm temperate moist zone - southeastern Australia; Warm temperate dry zone - southern Australian) and Tropical dry zone - central and northern Australia. See Table 5 for these reported MCF values (IPCC, 2019).

Table 5. MCF values (%) for liquid/slurry, for climatic zones applicable to pig production areas in Australia (IPCC, 2019)

Maximum storage time	Warm temperate moist	Warm temperate dry	Tropical dry
1 month	13	15	42
3 months	24	28	62
4 months	29	32	68
6 months	37	41	74
12 months	55	64	80

It is noted also noted in the guideline (IPCC,2019) that these MCF's can be reduced by 40% if:

> *a thick, dry, crust is present. Thick dry crusts occur in systems in which organic bedding is used in the barn and is allowed to be flushed into the liquid storage tank and solids are not separated from the manure stream and further the surface is not exposed to regular heavy precipitation that may disrupt the surface.*

This guideline defines Liquid/slurry as:

> *Manure is stored as excreted or with some minimal addition of water or bedding material in tanks or ponds outside the animal housing. Manure is removed and spread on fields once or more in a calendar year. Manure is agitated before removal from the tank/ponds to ensure that most of the VS are removed from the tank.*

The guideline also allows for **five** percent of VS to be retained in the storage tank following emptying, rather than **zero** percent (i.e. completely clean) assumption implied in the original IPCC 2006 calculations. It is noted that there are several studies that show farms do not completely empty liquid/slurry storages due to the practical challenge of doing so at the farm-scale (Baldé et al., 2016). They also note that the IPCC 2000 Good Practice Guide (Zeeman & Gerbens, 2000) mention approximately 15 percent of the manure storage cannot be readily emptied.

Further international research on specific methane reduction treatments that are related to short HRT systems is covered in sections 3.6 and 3.7 below.

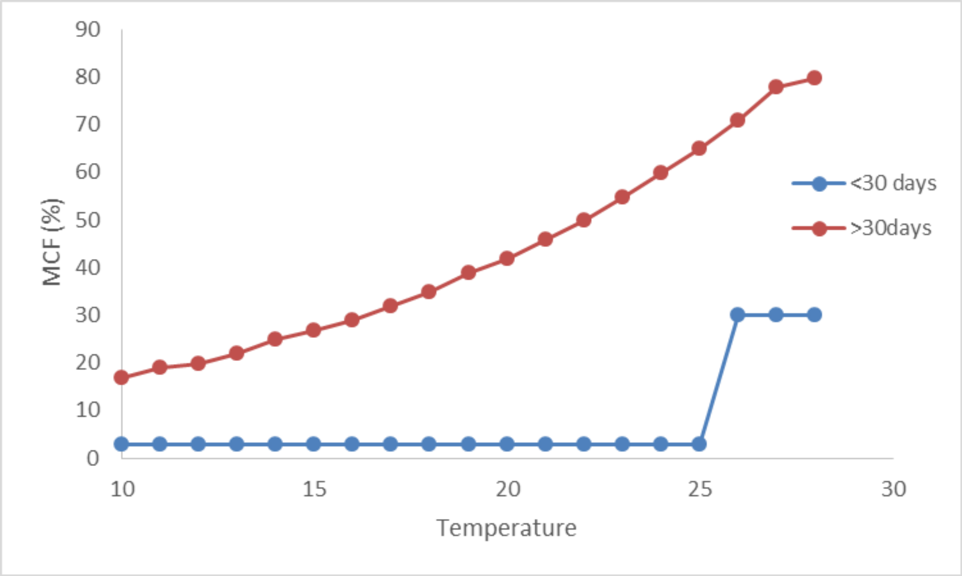

Figure 1. Emissions from pit storage below 30 days and above 30days (adapted from IPCC, 2006)

3.6 System additives to reduce methane production

Cameron and Di (2021) found that treating fresh dairy effluent with polyferric sulphate (PFS) produced substantial reductions in methane emissions (up to 99%) compared to untreated effluent. The PFS used contained approximately 20% iron and 18% sulphur. Experimental dose rates of 250 mg/L of effluent were used to achieve 98% methane production. At half this rate, methane reduction was still 85%. In field experiments conducted with 100kL effluent storage tanks dosed with 150 mg/L of effluent, they found a 99% reduction in methane emissions over 42 days.

They hypothesised that the reductions in methane emissions following treatment of dairy effluent with PFS can be attributed to three mechanisms:

1. increased microbial competition for organic matter substrate - high concentrations of sulphate and ferric ions have been reported to inhibit methanogenesis. This was caused by sulphate-reducing bacteria and ferric-reducing bacteria out-competing the methanogens for substrate.
2. direct inhibition of methanogens – although sulphate not considered toxic to microorganisms, the product of its reduction, sulphide is toxic to methanogens and has been reported to directly inhibit methanogenesis
3. anaerobic oxidation of methane – this has been shown to be the main process that prevents the emission of methane in both marine and freshwater sediments

PFS is now a recommended treatment process in guidance materials in New Zealand to reduce GHG emissions from dairy systems, however, the effect of PFS in piggery effluent is currently unknown and could be significantly different because of differing anaerobic decomposition characteristics of the two different effluents.

Holtkamp et al. (2023) conducted an experiment to look at the effect of dosing dairy and pig effluent with calcium cyanamide ($CaCN_2$) to reduce GHG emissions. Calcium-cyanamide has been used in agriculture for more than a century as a nitrogen fertilizer with nitrification inhibiting and pest-controlling characteristics.

Dairy cattle and pig slurry was treated with either 300 mg/kg or 500 mg/kg of cyanamide. The slurry was stored for 26 weeks, during which gas volume and concentration were measured. Methane suppression began within 45 min after application and persisted until the storage end in all variants, except in the pig slurry treated with 300 mg/kg, in which the effect faded after 12 weeks, indicating that the effect is reversible. Total GHG emissions decreased by 99% for dairy cattle treated with 300 and 500 mg kg^{-1} and by 81% and 99% for the pig, respectively. The underlying mechanism is related to $CaCN_2$-induced inhibition of microbial degradation of volatile fatty acids (VFA) and its conversion to methane during methanogenesis. This increases the VFA concentration in the slurry, lowering its pH and thereby reducing emissions.

3.7 pH modification

The strategy of lowering the pH of stored effluent to reduce GHG emissions has been utilised for decades (Al-Kanani et al., 1992; Hilhorst et al., 2002; Husted et al., 1991; M. Safley et al., 1983; Stevens et al., 1992) but was not widely implemented in Australia due to unresolved issues of safety (strong acid exposure) and acidic effluent post treatment requirements. The approach works on the principle of reducing the pH to inhibit the growth of microbes and the production of GHG emissions, as the emissions of methane , nitrous oxide and ammonia are a function of effluent pH. According to Boopathy (1996), Besson et al. (1985), and Conrad & Schütz (1988) the optimal pH for methane generation is 7. Research has found the methane emission halved at pH 6.5 and pH 8.3, and ammonia emissions are highest at pH > 9 and almost stop at pH < 7 (Groot Koerkamp & Klarenbeek, 1998). Hilhorst et al. (2002) observed effluent at pH 6 resulted in high emissions of nitrous oxide, but emissions of methane were eliminated. pH modification below a pH of 4.5 resulted in no emissions of any of the gases.

Several studies found that the addition of sulphuric acid to cattle and pig manure led to a reduction in ammonia emissions between 14 - 100% respectively (Molloy and Tunney, (1983), Jensen, (2002), Stevens et al., (1989), Frost et al., (1990), Al-Kanani et al., (1992), Pain et al., (1990)). In addition, Safley et al. (1983) found that the addition of phosphoric acid to cattle and pig manure led to a 50% reduction in ammonia emissions, while Al-Kanani et al. (1992) found that addition of phosphoric acid to pig manure led to a reduction of ammonia emissions by 90%.

Andersen et al. (2014) showed that the addition of sulfuric acid to pig manure led to a 50 - 85% reduction in ammonia emissions and a 20 - 85% reduction in total GHG emissions. Similarly, a study by Husted et al. (1991) showed that the addition of hydrochloric acid to cattle manure led to a 90% reduction in ammonia emissions. Oenema et al. (1993) showed maximum nitrous oxide emissions production at pH 6 and almost zero emissions at pH < 5 or > 8. Acidifying the effluent to below pH 5 could be a viable option for the reduction of GHG emissions, and it is noted that this process could occur naturally because of organic acid production if the effluent retention time was short, and the system was operated with batches.

Reports from Denmark by Petersen et al. (2012) indicated that effluent acidification to a pH around 6 by sulphuric acid is increasingly used as an ammonia mitigation strategy, with around 10% of the total effluent volume in the country being acidified by one of several technologies. This occurred in slurry channels, in storage before spreading, or during spreading. Also reported was acidification by sulphuric acid that has been found to reduce methane emissions from pig effluent by 94% to 99%, during 3-month storage periods.

It should be noted that if not carefully managed, sulphuric acid addition could exacerbate odour from effluent systems due to increased hydrogen sulphide generation. Handling and using sulphuric acid has a range of safety issues that need to be managed, as it reacts with water and organic materials, generating heat. Avoid contact with skin and inhalation of any fumes.

3.8 Solids separation

As with short HRT, solid separation systems operate as an avoided emission technique by removing VS from effluent stream before it enters an uncovered anaerobic pond. Removed solids are then managed via an aerobic process, limiting the amount of methane that can be produced. Along with methane capture and destruction (covered ponds and engineered digesters), solids separation is included in the(Carbon Credits (Carbon Farming Initiative - Animal Effluent Management) Methodology Determination 2019, 2019), under the Emissions Reduction Fund (ERF) to enable the crediting of Australian Carbon Credit Units (ACCUs).

The GHG abatement potential is dependent on the system and its' solid removal efficacy. Removing solids from the effluent stream also offers improves manure handling and reduces both sludge accumulation and undigested floating material in effluent ponds. To achieve an overall reduction in GHG emissions for farms using solids separation technology, the separated solids must be treated in an aerobic manner to avoid further methane production.

There are many different methods used for removing solids from liquids and they generally rely on either a gravitational process or a mechanical device. These methods can be grouped according to their basic removal mechanism:

- Gravitational settling,
- Perforated screens and presses,
- Centrifugal separation,
- Dissolved Air Flotation,
- Chemical flocculation,
- Combined systems, and
- Dry scraping.

The efficiency of solids separation systems is strongly influenced by the flow rate of the manure, the shape and size distribution of the particles, and their chemical nature. Pre-treatment systems partition the VS and nutrients between different manure management stages and therefore have the potential to mitigate GHG by diverting manure to systems with lower emission potential. Murphy et al. (2012) found installation of a solids separation step such as a trafficable sedimentation basin or static rundown screen with the baseline scenario could theoretically reduce piggery emissions by 58% and 22% respectively. The separated solids would require good storage management to avoid additional GHG emissions occurring from the wet solids produced by the solid separator.

A recent survey of Australian piggeries revealed that around 10% of total manure from conventional piggeries is removed from the effluent stream via solids separation (Copley et al. *in preparation*). The range of separation technologies currently available for piggery manure is included in the National

Environmental Guidelines for Indoor Piggeries (NEGIP) (Tucker, 2018) and VS removal efficiencies range from 20% (static screens) to 70% (settling basins).

Solids separation can be used in conjunction with other treatment technologies, such as CAPs or as a standalone GHG abatement system under the ERF. It also would be a beneficial pre-treatment process before short HRT systems for several reasons as it would:

- Remove coarse material that is difficult to irrigate and causes clogging.
- Reduce settled solids in storage tanks to allow easier total removal.
- Remove significant amounts of nutrients to reduce the size of required effluent irrigation areas.
- Convert a proportion of the liquid waste stream to a solids fertiliser/soil amendment that can be readily removed/sold off-farm.

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3.9 Process of how short HRT reduces emissions

The methanogenesis process will only occur when there are anaerobic conditions that are coupled with other processes that are required to breakdown the VS contained in the manure (Valentine, 2007). As described earlier, temperature and pH (section 3.2), are key components of the methanogenesis process that determine methane generation rates.

How much and how quickly methane is generated from fresh manure is likely determined by several complex chemical processes that can be different under different temperature regimes. As reported by Petersen et al. (2013) methane emissions are likely inhibited by high ammonia levels that are present in fresh manure as they are derived from the urine component of manure, and that is why the methanogenic potential in fresh manure is low. They do report, however, slow growing methanogens (Methanosarcina *spp.)* capable of adapting to as much as 7,000 mg of total ammoniacal nitrogen/l, which are known to develop in manure and anaerobic digesters.

The McGahan et al. (2016) study found natural reductions in pH that occurred over both the summer and winter trials may have also been related to ammonia levels of the fresh manure that likely led to a lowering of methane emissions. The pH in the initial days of the winter trial fell from 7.8 to 7.0 and from 8.0 to 6.8 in summer, possibly resulting from the formation of volatile fatty acids through microbial activity. They also noted that during the summer trial, the production of methane may have been inhibited by the initial formation of ammonia, with methane production increasing as the production of ammonia decreased with a decreasing pH. In contrast, during the winter trial, ammonia production was initially low, and increased over the trial, while methane production was initially higher and decreased as ammonia production increased.

To ensure methane emissions remain low, the last stage of the anaerobic process (methanogenesis) needs to either not occur or be inhibited. This is most easily determined by measuring pH to ensure it is low and has not stabilised back to the ideal range for methanogenesis. Additionally, all the effluent (and solids) requires removing to ensure and adapted methanogens do not develop and are not carried over between batches and allow reseeding to occur. This will potentially accelerate the methanogenesis process if sufficient populations remain. This is also relevant for any biofilm granulation that may form in any sludge left or attached to the walls of the short HRT tank. It has been shown by Trego et. al. (2020) that these granules can break apart, but reform into new granules that can support the ongoing methanogenesis process.

4. Research Methodology

The two overarching aims of the project are to:

1. assess the impact of short hydraulic retention time systems being applied to traditional conventional manure management systems across large and small pig production systems and
2. if feasible, develop an additional technology for managing animal effluent for inclusion in the Carbon Credits (Carbon Farming Initiative - Animal Effluent Management) Methodology Determination 2019 under the guise of methane avoidance.

To achieve this, the project will be undertaken in **seven** stages, with a planned STOP-GO after Stage four to assess whether Short HRT systems are technically feasible and likely to be adopted for Australia piggeries.

This Progress Report #1 reports on both Stages one and two of the project.

4.1 Project stages

Stage 1

The first stage of the project was a technical review of short HRT systems, including the physiochemical requirements that inhibit or reduce methane emissions from animal effluent, particularly pig effluent. This technical review investigated both the Australian research, as well as international research, particularly in Europe and North America, where these systems are common.

This first step was an important component of the project, as it will was used to inform the "How-to" guide (Stage 3), as well as the development of a submission to the Commonwealth Energy Regulator (CER) on possible amendments to the *Carbon Credits (Carbon Farming Initiative - Animal Effluent Management) Methodology Determination 2019* (Stage 7), should the project progress to that stage.

Stage 2

Stage 2 involved a desktop assessment of how short HRT systems would operate in different climatic zones of Australia where pig production is located. This included PigBal4.099 assessments of 2,000 and 10,000 SPU piggeries, using regional diet information to determine nutrient output masses and concentrations. This output was used in long-term (50+ years) daily time-step water balance modelling to determine size of application areas and the fraction of effluent that could be irrigated with short HRT based on soil water deficit/plant available water capacity.

This modelling was also being used to determine the size of ponds required in each region to treat and store effluent that is unable to be applied and meet the short HRT effluent storage requirements of < 30 days. Nutrient balance modelling to determine land application areas for conventional treatment (long HRT) versus short HRT was also being undertaken.

Stage 3

Stage 3 involves two extension outputs, the first being a how-to" guide for producers that includes:

1. Details how they would operate in a particular region
2. Advantages and disadvantages of the system
3. The likely GHG abatement potential.

The second output will be a webinar with industry to launch the guide.

Stage 4

During Stage 4, an industry survey will be undertaken. Producers will be provided with the "How-to" guide prior to the survey. The purpose of the survey is to gauge how many producers are already operating Short HRT systems and how many would be interested in operating them in the future, particularly if there is an approved methodology under the Carbon Farming Initiative (CFI) and Australian Carbon Credit Units (ACCU's) can potentially be claimed.

At this stage of the project there would be STOP-GO after consultation with APL on whether to proceed to the further stages.

Stage 5

If existing operating short HRT systems can be identified or producers are willing to install a new system, a monitoring program will be established for farms to determine:

1. Effectiveness – how much of the effluent could be utilised through the short HRT.
2. Measurements required – including volume and pH
3. Potential odour issues
4. Potential nutrient management issues
5. Potential regulatory compliance issues.

Stage 6

Provided that there is sufficient interest in adopting the technology by industry and a willing co-operator can be found, an on-farm trial/s will be established to test the technology.

Following the development of the guideline and the survey on the level of likely industry uptake, a submission would be prepared for the Commonwealth Energy Regulator (CER) for inclusion of Short HRT into the existing Animal Effluent method as a methane avoidance technology.

Stage 7

For this stage of the project, the project team would need to liaise closely with the CER to develop the process and pathway for the new methodology's acceptance and approval.

To assist with Stage 3 of the project, a desktop assessment of how short HRT systems would operate in different climatic zones of Australia where pig production was undertaken using both the PigBal - v4.099 (Skerman et al., 2015) model and the MEDLI (Department of Science, Information Technology and Innovation, 2015) model. PigBal was also used to investigate pond loading rates with and without solids separation, as well as investigate the impacts of feed wastage on effluent production. Further desk-top analysis was undertaken to assess likely GHG emission abatement, and the likely change in odour emissions between the short HRT methods and traditional (long HRT) pond management. Methodology used for these assessments is detailed in the following sections.

4.2 Modelling short HRT systems

4.2.1 PigBal modelling to generate wastestream estimations

The PigBal model uses a mass balance approach to estimate piggery waste production (solids and nutrients) based on detailed dietary data and pig production information entered by the user. It is a Microsoft® Excel spreadsheet model. PigBal 4 modelling results are typically used for:

- Designing piggery effluent treatment and reuse systems.
- Estimating the energy output and economic viability of piggery biogas collection and reuse systems.
- Estimating piggery GHG emissions for statutory reporting purposes

Assessments of 2,000 and 10,000 SPU piggeries were conducted, using regional diet information to determine nutrient output masses and concentrations. The two different sized piggeries modelled represent small to medium family businesses (2,000 SPU or ~200 sows farrow to finish) and larger family or corporate farms (10,000 SPU or ~1,000 sow farrow to finish).

For all pig classes, the sheds were assumed to be effluent based, with flushing systems. The freshwater use was based on the standard drinking water requirements, with a freshwater requirement for cleaning (hosing) and flushing of one and seven litres per SPU per day respectively.

The four standard diets provided in PigBal (A, B, C and D) were used to represent the geographic location of piggeries in Australia. The primary feed ingredients in each diet and the geographical regions they represent are detailed in Table 6. Feed consumption values for each class of pig were set to 96% of the calculated default values in PigBal and feed wastage was set at 5% for all classes of pigs. These values were based on recent survey data of Australian piggeries (Copley et al. *in preparation*).

The predicted effluent produced and concentration of total solids (TS), volatile solids (VS) nitrogen (N) and phosphorus (P) in the effluent from PigBal for the two different sized piggeries (2,000 SPU and 10,000 SPU) and four diets (A, B, C and D) are shown in Table 7.

Table 6. Primary ingredients and geographical region for each PigBal standard diet

PigBal Diet	Primary ingredients	Geographic region
A	Wheat, barley & canola meal	South Australia
B	Sorghum, wheat, barley, animal protein	Northern Australia (Qld and Northern NSW)
C	Wheat, plant protein seed and barley	Southeastern Australia (Victoria and southern NSW)
D	Barley, wheat & plant protein seed	Western Australia

Table 7. Predicted effluent production and concentrations of TS, VS, N and P for the modelled piggeries using PigBal V4.099

Piggery size (SPU)	Diet	Effluent (L/day)	TS conc. (mg/L)	VS conc. (mg/L)	N conc. (mg/L)	P conc. (mg/L)
2,000	A	23,247	25,118	20,382	2,210	558
2,000	B	23,544	26,060	21,036	1,952	549
2,000	C	23,459	25,794	20,586	1,987	570
2,000	D	23,381	25,545	20,552	2,130	577
10,000	A	116,262	25,118	20,382	2,210	558
10,000	B	117,744	26,060	21,036	1,952	549
10,000	C	117,322	25,794	20,586	1,987	570
10,000	D	116,929	25,545	20,552	2,130	577

PigBal was also used to assess the effect of varying feed wastage had on effluent production in terms of solids and nutrients.

4.2.2 Locations assessed

The locations included in the desk-top modelling assessment using MEDLI were:

- Queensland – Darling Downs, Western Downs, South Burnett;
- New South Wales – Northern Rivers, Riverina, Murray River;
- Victoria – Central North, Goulburn-Broken;
- South Australia – Murraylands, South-east, Northern cropping;
- Western Australia, Wheat belt, South west.

For each of these locations, the most appropriate diet and effluent concentration production from Table 7 was selected.

4.2.3 MEDLI Modelling

The predicted effluent produced and concentration of total solids (TS), volatile solids (VS) nitrogen (N) and phosphorus (P) in the effluent from PigBal was used in the MEDLI water and nutrient balance modelling to determine size of application areas and the fraction of effluent that could be irrigated with short HRT based on soil water deficit/plant available water capacity. Water balance modelling was also undertaken to determine the size of ponds required in each region to treat and store effluent that is unable to be applied though irrigation and meet the short HRT effluent storage requirements of < 30 days. MEDLI modelling was also used to provide a comparison of the effluent land application areas required for conventional treatment (long HRT) versus short HRT.

MEDLI is a Windows-based computer model for designing and analysing effluent disposal systems for intensive rural industries, agri-industrial processors (e.g. abattoirs) and sewage treatment plants using land irrigation. It was developed jointly by the CRC for Waste Management and Pollution Control, the Queensland Department of Natural Resources and the Queensland Department of Primary Industries (DPI&F). MEDLI is a recognised model by agricultural departments and EPA's for predicting sustainable effluent reuse systems. This section gives a summary of the MEDLI model and the various modules contained within the model. The following information is contained within the MEDLI Technical Description published by the Department of Primary Industries Queensland.

MEDLI uses daily time series climate data for estimating crop water requirements, simulating crop growth and conducting water balance computations. The data required are rainfall, temperature, Class A pan evaporation and solar radiation. The climatic data used to model the site was supplied by the Department of Science, Information Technology, Innovation and the Arts' (DSITIA) SILO database. The waste estimation component of MEDLI generates, for a given industry, the daily composition and volume of effluent before pre-treatment, storage, or irrigation. The simplest MEDLI waste estimation module uses measured waste stream details. Temporal variation in waste stream characteristics may be assigned monthly or seasonally, or for any other nominated periods, including single days. The user could enter different waste stream details for every day if the data is available. MEDLI assumes these details then apply for every year of the simulation.

The soil parameters entered into the MEDLI model are based on the soil physical and chemical characteristics observed and those identified in relevant publications or previous studies of the site. The plant growth module in MEDLI predicts the biomass accumulation and the quantities of nitrogen and phosphorus that are removed from the effluent irrigation site through crop growth and the export of harvested material. Flexibility is gained through the provision of a dynamic pasture growth model and a dynamic crop growth model.

The pasture module is selected if a plant species is grown continuously, allowing regrowth to occur following mowing (rather than resowing the crop as occurs for the dynamic crop module). In this model, plant cover increases with thermal time according to a fixed sine-curve algorithm defined by the total thermal time to reach full cover. Nitrogen stress and low biomass production modify cover development to improve the prediction of cover for stressed pastures. Growth is considered to be a function of solar radiation, plant cover and radiation use efficiency. Radiation use efficiency can be lowered by the highest of any stress due to temperature, water regime and low plant nitrogen. Prediction of daily plant growth allows estimation of the removal of N and P by nutrient uptake and storage in the shoot biomass. It is assumed that when a user-defined yield is reached, the pasture is cut and the harvested material exported off site.

MEDLI was run to for the 2,000 and 10,000 SPU scenarios for thirteen sites selected to represent the distribution of the pig industry around Australia. Details of the modelled location are shown in Table 8. For each site, a typical soil type was selected from the MEDLI database. Soil types are generally highly variable across a region and the selected soil type is a representative of only one soil profile that may occur within a region. Crop type was also selected based on a suitable combination of summer and winter crop/pasture for a particular region.

Table 8. MEDLI modelled piggery locations

State	Region	Location	Soil Type	Crop
Qld	Darling Downs	Oakey	Grey Clay	Rhodes Grass/Barley
Qld	Western Downs	Goondiwindi	Grey Clay	Rhodes Grass/Barley
Qld	South Burnett	Kingaroy	Krasnozem	Rhodes Grass/Barley
NSW	Riverina	Young	Red-brown Earth - med perm	Rye Grass 2/Barley
NSW	Northern Rivers	Casino	Black Earth	Rye Grass 2/Barley
NSW	Murray River	Corowa	Grey Clay	Rye Grass 2/Barley
Vic	North Central	Bendigo	Red-brown Earth - med perm	Rye Grass 2/Barley
Vic	Goulburn-Broken	Shepparton	Grey Clay	Rye Grass 2/Barley
SA	Murraylands	Murray Bridge	Red-brown Earth - med perm	Rye Grass 2/Barley
SA	South East	Naracoorte	Duplex 2	Rye Grass 2/Barley
SA	Northern Cropping	Roseworthy	Sand	Rye Grass 2/Barley
WA	Wheat Belt	Narrogin	Duplex 2	Rye Grass 2/Barley
WA	South Coast	Mount Barker	Sand	Rye Grass 2/Barley

For each location the model was run for three difference manure management scenario:

- **Conventional effluent treatment** – effluent from the piggery discharged to a conventional uncovered deep anaerobic treatment pond. Anerobic ponds were sized using PigBal which uses the anerobic pond activity ratio, based on the climate for a particular region to determine the required anaerobic pond volume. Following treatment in the anerobic pond, effluent was discharge to a storage pond before being considered available for irrigation. Storage pond was to ensure that the pond did not overtop with a frequency of greater than once every 10 years using MEDLI.
- **Short HRT -** effluent from the piggery discharged to a small tank (HRT of approximately 5 days) and is immediately available for irrigation. The soil type used was typical of the area with a 10 mm soil water deficit used as the irrigation trigger and then irrigated to the soil drained upper limit. Effluent that is not used through irrigation is discharged to a secondary storage pond. The secondary storage pond was sized to ensure that the pond did not overtop with a frequency of greater than once every 10 years using a water balance model.
- **Short HRT including pre-treatment using solids separation (SS) -** effluent from piggery undergoes solids separation (with solids removal rates similar to treatment with a screw press separator) and then discharged to a small tank (HRT of approximately 5 days) and immediately available for irrigation. The soil type used was typical of the area with a 10 mm soil water deficit used as the irrigation trigger and then irrigated to the soil drained upper limit. Effluent that is not used through irrigation is discharged to a secondary storage pond. The secondary storage pond was sized to ensure that the pond did not overtop with a frequency of greater than once every 10 years using a water balance model.
- See Table 9 for further explanation of modelling parameters.

The MEDLI input parameters used for each manure management scenario are summarised in Table 9. Where the input data varies dependent on the modelled location the data source has been identified.

Table 9. MEDLI input parameters used in modelling

Inputs used in modelling	Description
Modelled Period	1970 – 2022 (52 years)
Climate Data	Site specific – SILO (Department of Environment and Science, Queensland Government, 2023)
Effluent Volume	Site specific - Pigbalv4.099
Effluent Composition	Diet Specific inputs for TN, TP, VS, TS - Pigbalv4.099 TDS and EC – NEGIP (Tucker, 2018)
Pre-treatment	Conventional and Short HRT – No pre-treatment Short HRT with solids separation (Pigbalv4.099) • Effluent removal fraction 0.006 • Nitrogen removal fraction 0.37 • Phosphorus removal fraction 0.41 • Volatile solids removal fraction 0.37 • Total solids removal fraction 0.32
Primary pond size	Conventional – Site Specific PigBal v4.099
Short HRT tank size	Short HRT and Short HRT with solids separation – 5 days HRT
Secondary pond	Size adjusted to meet NEGIP overtopping frequency of less than once every 10 years.
Soil Type	Site specific
Crop Type	Site specific
Irrigation Trigger	10mm Soil Water Deficit
Irrigation Applied	Irrigated to the Drained Upper Limit (DUL) of the soil.
Irrigator Method	Lateral move
Ammonia loss during irrigation	25%

For each of the location, modelling was undertaken to determine a suitable irrigation area which met with acceptable environmental practice. The environmental criteria used to determine irrigation area size were:

- Total nitrogen loading to irrigation area less than 300 kg/ha.yr
- Total phosphorus loading to the irrigation area less than 42 kg/ha.yr
- Concentration of nitrate-N in deep drainage from soil less than 10 mg/L
- Concentration of phosphate-P in deep drainage from soil less than 0.1 mg/L

These criteria were established based on a suitably sited irrigation area with acceptable agricultural practice for nutrient application (Piggery Manure and Effluent Management Guidelines, Tucker 2015) and the trigger values detailed in the National Environmental Guidelines for Rotational Outdoor Piggeries (Tucker et al., 2013). In practice, nutrient application is likely to vary dependant on soil type, climate and crop selection, but to enable comparison of the viability of the short HRT systems, maximum nutrient loading rates were selected for the modelled scenarios.

4.3 GHG Abatement Potential

The GHG abatement potential of short HRT systems was assessed using the carbon footprint (Scope 1, 2 and 3 GHG emissions) of hypothetical piggeries with either traditional effluent treatment with large anaerobic ponds or short HRT systems. This was undertaken for four regions in Australia, using the standard diets described above. Several assumptions were required to generate the inputs to provide a representative comparison of the two systems. The assumptions used are described in Table 10.

Table 10. Inputs and assumptions used to generate carbon footprint comparison of traditional and short HRT treatment systems

Inputs used in modelling	**Description**
VS and N excretion rates and losses	PigBal V4.099
GHG emission factors	National Greenhouse Accounts Factors (2023a)
Global warming potential	IPCC AR5 global warming potentials (GWP_{100}) of 28 kg CO_2-e/kg CH_4 and 265 kg CO_2-e/kg N_2O as applied in the National Greenhouse Accounts Factors (2023a)
Land use change	GHG emissions associated with land use (LU) and direct land use change (dLUC) were included and reported separately, as recommended in ISO 14067 (2018)
Feedmill energy use	20 kWh grid electricity, 4 l diesel and 60 MJ LPG / t feed – based on in-house datasets for Australian piggeries
Feed production emissions	Major feed grains were modelled from Australian grain processes from the AusLCI database (ALCAS, 2017), where available or from Copley et al. (in preparation)
On farm energy	20.2 kWh grid electricity, 0.55 L diesel, 0.49 L petrol and 0.23 L LPG per 100 kg LWT produced/ t feed – based on in-house datasets for Australian piggeries
Scope 2 and 3 energy emission factors	National Greenhouse Accounts Factors (2023a)

4.4 Odour emissions reduction potential with short HRT

The odour emission rate reduction potential of short HRT systems was assessed using the Level 1 odour impact assessment method described in the NEGIP (Tucker, 2018). The method is currently universally applied to piggeries in Australia for development applications. The method used for determining separation distances for various manure management systems (S1 factors) at piggeries was included in the first version of the guidelines in 2004 and is derived from the work of Nicholas and McGahan (2003) and Nicholas et. al. (2003). This earlier work derived separation distance factors from odour emission rate studies at piggeries and concluded that approximately one quarter of the odour at conventional piggeries is generated from the sheds and the remaining three quarters comes from effluent treatment (pond systems). For these ponds it was also concluded that 1/6 of the emissions came from the secondary pond, with the majority (5/6 or 83%) coming from the primary pond. Thus, any system that can negate the use of or substantially reduce the size of the pond system, such as short HRT will provide a significant reduction in odour emission rates.

In Tucker (2018) there are no S1 factors supplied for short HRT systems. The systems described for conventional piggeries only differentiates depending on whether ponds are covered, and the percentage of solids removed via solids separation (see Table 11). A short HRT system that can utilise all the effluent from the sheds would not require a pond system and would most replicate an impermeable pond cover, that allows for separation distances that are half that required for a traditional uncovered anaerobic pond treatment system. Where at least 40% of the effluent could be utilised in a short HRT system, it would replicate a solids separation system with the same solids removal and a reduction factor of 0.8 would be anticipated. Table 12 provides the derived effluent treatment factors for short HRT systems that were used to assess potential odour emission rate reduction for various levels of effluent utilisation for 2,000 and 10,000 SPU piggeries.

Table 11. Summary of effluent treatment factors for use in Level 1 odour impact assessments in the NEGIP (Tucker, 2018).

Effluent treatment factor	Value
Ponds with > 40% separation of volatile solids before pond	0.80
Ponds with 25 - 40% separation of volatile solids before pond	0.90
Ponds with < 25% separation of volatile solids before pond	1.00
Permeable pond cover	0.63
Impermeable pond cover	0.50

Table 12. Effluent treatment factors applied for assessing odour reduction potential of Short HRT systems

Effluent treatment factor	Value
> 40% of effluent from sheds to short HRT and/or solids separation	0.80
> 60% of effluent from sheds to short HRT and/or solids separation	0.70
> 80% of effluent from sheds to short HRT and/or solids separation	0.60
100% of effluent from sheds to short HRT and/or solids separation	0.50

4.5 Evaluate sludge content changes with short HRT

Another component of the project was to discuss the likely changes in nutrients (N, P and K) in sludge between traditional anaerobic ponds and short HRT systems. With short HRT systems there is effectively no sludge, and all effluent is agitated and irrigated in < 30 days of storage. For traditional ponds, a larger proportion of the phosphorus (>90%) and ~25% of the nitrogen will precipitate out in the sludge, with K remaining in solution and mainly being irrigated. A large proportion of the nitrogen (~50%) will also be lost from traditional uncovered anaerobic treatment ponds via ammonia volatilisation. The effect of no sludge is that there will be approximately three times more N and as much as 10 times the amount of P to irrigate with a short HRT system that manages all the effluent from the piggery. This has been accounted for in the modelling of short HRT systems with MEDLI to determine likely required differences in effluent irrigation areas of the two systems (see Section 5.1).

5. Results

5.1 PigBal Assessments and MEDLI modelling

One important consideration in the assessment of short HRT systems is the differences in the concentration of nutrients in the effluent at the point of irrigation. Conventional anaerobic and storage ponds systems have a high HRT which results in significant loss of nitrogen from the effluent to the atmosphere and deposition of phosphorus nitrogen to the sludge that is retained in the ponds. As short HRT systems have a low HRT and no sludge generation prior to irrigation, the nutrient levels remain high. Nutrient concentrations applied through irrigation must be balanced against the nutrient demand of the crop, to ensure any loss of nitrogen and phosphorus from a site is minimised. Nutrient loss from the agricultural system contribute to elevated nutrients in ground and surface waters which may increase the risk of eutrophication. Regulatory approval of new short HRT systems is likely to be dependent on an operator's ability to demonstrate sustainable irrigation practices for a particular location.

The following sections summarise the key outcomes of the PigBal and MEDLI modelling with full results for both the 2,000 SPU and 10,000 SPU scenarios provided in Attachment A.

5.1.1 2,000 SPU Operation

MEDLI was used to determine the nutrient concentrations in the effluent at the point of irrigation, with the concentrations for the 2,000 SPU scenario for all modelled locations shown in Table 13. The concentrations are also impacted, in conventional operations by the dilution/concentration of nutrients through rainfall and evaporation to the ponds.

Table 13. Nutrient concentrations in irrigation water for 2,000 SPU operation.

Location	Conventional		Short HRT		Short HRT with SS	
	N mg/L	P mg/L	N mg/L	P mg/L	N mg/L	P mg/L
Oakey	473.4	69.7	1,905	549	1,200	323.9
Goondiwindi	612.0	126.6	1,905	549	1,200	323.9
Kingaroy	534.1	91.1	1,905	549	1,200	323.9
Young	465.6	95.4	1,939	570	1221	336.3
Casino	511.9	69	1,905	549	1,200	323.9
Corowa	504.0	110.4	1,939	570	1,221	336.3
Bendigo	488.2	102.8	1,939	570	1,221	336.3
Shepparton	522.0	111.8	1,939	570	1,221	336.3
Murray Bridge	625.0	132	2,156	558	1,358	329.2
Naracoorte	502.6	104.2	2,156	558	1,358	329.2
Roseworthy	598	133.5	2,156	558	1,358	329.2
Narrogin	590.7	141.34	2,078	577	1,309	310.4
Mount Barker	405.6	99	2,078	577	1,309	310.4
Average	**526**	**107**	**2,000**	**562**	**1,260**	**327**

The concentration of nitrogen and phosphorus in the effluent irrigation water are significantly higher than the conventional treatment system concentrations, with the short HRT system having a nitrogen concentration 3.8 times higher, and phosphorus 5.3 times higher. The short HRT with solids separation results in effluent irrigation water with total nitrogen 2.4 time higher than the conventional and 3.1 times higher for phosphorus. The ratio of nitrogen to phosphorus in conventional treatment is around 4.9 while for a short HRT system it is 3.6 and with solids separation it is 3.8. This shows the change in proportions of nutrients with short HRT systems having a higher proportion of phosphorus in the effluent. The result of this change is that when short HRT effluent is used for irrigation, the application rate is likely to be limited by the maximum phosphorus loading.

Irrigation areas for each scenario were determined through successive MEDLI runs to ensure the nutrient loadings were not excessive and the concentrations of nutrients did not exceed the criteria noted in Section 4.2.3. Irrigation areas and nutrient loadings for the 2,000 SPU scenario are provided in Table 14.

Note that for conventional systems, if all the sludge is applied on the same site, the required application areas would be the same as the short HRT scenario without solids separation.

Table 14. Required irrigation areas and nutrient loadings for 2,000 SPU operation.

	Conventional			**Short HRT**			**Short HRT with SS**		
	Area ha	N Loading kg/ha.yr	P Loading kg/ha.yr	Area ha	N Loading kg/ha.yr	P Loading kg/ha.yr	Area ha	N Loading kg/ha.yr	P Loading kg/ha.yr
Oakey	12	199.9	31.4	110	136.4	41.9	65	144.3	41.6
Goondiwindi	10	172.1	38	110	136.0	41.8	65	144.2	41.5
Kingaroy	10	209.1	38.1	110	130.7	40.1	65	138.3	39.8
Young	10	178.8	39.1	100	131.1	41.1	60	136.5	40.1
Casino	10	260.7	37.5	95	132.5	40.8	55	143.6	41.4
Corowa	10	169.3	39.6	110	133.5	41.9	65	141.4	41.5
Bendigo	10	174.3	39.2	100	132.1	41.4	65	131.9	37.4
Shepparton	10	172.4	39.4	110	132.8	41.6	65	140.7	41.3
Murray Bridge	15	112.3	25.3	110	148.8	41.1	65	157.7	40.8
Naracoorte	10	172.4	38.1	90	142.0	39.2	50	160.0	41.4
Roseworthy	10	159.3	37.9	95	145.5	40.2	65	132.9	34.4
Narrogin	10	155.2	39.6	105	138.7	41.1	65	140.3	38.9
Mount Barker	10	148.2	38.6	80	127.4	37.7	45	141.8	39.3

As expected, the required effluent application area for short HRT systems is significantly greater than that required for effluent from conventional treatment systems. Short HRT with solids removal require a smaller irrigation area due to the reduced concentration of nutrients in the irrigation water. Generally, the limiting factors determining the irrigation area for short HRT systems was the phosphorus loading and the nitrate leaching rate through the soil.

MEDLI models the proportion of effluent that can be irrigated based on the user defined irrigation trigger. The irrigation trigger used for the modelling was for irrigation to occur when the soil reached a soil water deficit of 10mm, and then irrigation is applied until the drained upper limit of the soil is reached (or there is no more water available for irrigation). Based on the irrigation areas defined in Table 14, different proportions of the effluent could be used for irrigation (see Table 15).

Table 15. Proportion of effluent usage and pond sizes for 2,000 SPU.

	Conventional			Short HRT			Short HRT with SS		
	% Use	Pond 1	Pond 2	% Use	Tank	Pond 2	% Use	Tank	Pond 2
Oakey	100%	7,500	3,000	97%	125	510	98%	125	510
Goondiwindi	100%	6,500	3,000	97%	125	780	98%	125	780
Kingaroy	100%	7,300	3,000	94%	125	2600	94%	125	2,600
Young	100%	8,600	3,200	84%	125	5,700	84%	125	5,700
Casino	99%	6,500	3,000	82%	125	11,000	82%	125	11,000
Corowa	100%	8,600	3,000	94%	125	1,400	94%	125	1,400
Bendigo	99%	8,600	3,000	85%	125	4,900	85%	125	4,900
Shepparton	100%	8,200	3,000	94%	125	1,800	94%	125	1,800
Murray Bridge	100%	7,700	3,000	95%	125	850	95%	125	850
Naracoorte	100%	7,700	4,000	74%	125	8,000	74%	125	8,000
Roseworthy	100%	7,700	3,000	81%	125	3,400	80%	125	3,400
Narrogin	100%	7,800	3,000	87%	125	1,900	87%	125	1,900
Mount Barker	98%	8,800	4,400	61%	125	11,000	61%	125	11,000

For conventional systems, between 98 and 100% of effluent could be reused through irrigation. For short HRT systems, the proportion of effluent used ranged between 61% in the colder wetter areas of southern Australia to 97% in the drier hotter regions in Queensland.

MEDLI was used to determine the required storage pond sizes for conventional systems, with a minimum 3,000m^3 pond used, with the capacity increased if required to ensure that overtopping did not occur with a frequency greater than one in ten years.

For the short HRT system, a time series of the daily overtopping from the 125m^3 short HRT tank was obtained as output from the MEDLI model. This was used in a water balance model to determine the required pond size for loss through evaporation. A minimum depth of 3m was used for the short HRT storage pond and a maximum overtopping frequency of one in ten years, or five times over the 52-year modelled period.

5.1.2 10,000 SPU Operation

Outcomes of the MEDLI and water balance modelling found that results for irrigation area required, and pond sizes for the 10,000 SPU scenario for the short HRT system and the short HRT with solids separation were directly scalable from the 2,000 SPU scenario, with five times the effluent application area ranging between 400 and 550 ha depending on the climate, soil type and crop type. With the introduction of solids separation, this area was reduced to between 225 and 325 ha. The consistency with the 2,000 SPU scenario is due to the short retention time in the tank prior and no sludge generation occurring resulting in the concentrations of nutrients in the irrigation water the same in both scenarios.

For the conventional operations, some changes in the concentrations of nutrients in the irrigation water were noted when compared to the 2,000 SPU scenarios. This is due to the changes in the water balance of the large conventional pond resulting from rainfall and evaporation. Generally, the concentration of nitrogen in the irrigation water increased between 12% and 25% compared a conventional small-scale operation. Changes in the phosphorus concentrations were generally less than 5% compared with the 2,000 SPU irrigation water concentrations. The changes in the relative proportions of nutrients applied, generally resulted in an increase in crop yield for the larger conventional operations.

Full results of the modelling are provided in Attachment A.

5.1.3 Pond loading and HRT

The MEDLI modelling results were based on concentrations of VS and nutrients in effluent derived from some typical operations modelled in PigBal. A range of factors have the potential to impact on the effluent volume and composition including:

- Feed wastage percentage
- Hosing/flushing volumes
- Drinking water wastage

Changes in these factors can have a significant impact on the required ponds sizes and associated effluent irrigation areas for both conventional and short HRT systems due to the changes in HRT and VS loading rates.

5.2 GHG abatement potential

The results of the GHG abatement potential of short HRT systems compared to traditional long retention time treatment of effluent in anaerobic ponds is shown in Table 16 for four geographical regions. Table 17 shows the disaggregation of emissions by Scope and process, as well as the percentage relative contribution of each for the south-west Western Australia region as an example. The short HRT assessment was performed by assuming all the effluent was managed in the system. The highlighting of the cells is a “heat-map” to show relative contributions of each process.

Table 16. Comparison of the Carbon footprint of traditional and short HRT treatment systems

	GHG emissions (kg CO_2-e/kg LW sold)		GHG Reduction (%)
Diet	**Traditional Pond**	**Short HRT**	
South Australia	3.7	1.2	66
Southern Qld	4.1	1.5	64
Northern Victoria	3.9	1.4	64
South-west WA	3.9	1.4	65

Table 17. Comparison of the Carbon footprint of traditional and short HRT treatment systems by Scope for southwest WA region

Emission Source	**GHG emissions (kg CO_2-e/kg LW sold)**	**Contribution (%)**	**GHG emissions (kg CO_2-e/kg LW sold)**	**Contribution (%)**
	Traditional Pond		**Short HRT**	
Scope 1				
Piggery enteric methane	0.15	3.8%	0.15	10.8%
Piggery manure methane	2.66	68.0%	0.10	7.5%
Piggery manure direct nitrous oxide	0.00	0.0%	0.03	2.5%
Piggery services	0.03	0.8%	0.03	2.1%
Feedmilling & Feed production	0.04	1.0%	0.04	2.8%
Scope 2				
Piggery services	0.14	3.5%	0.14	9.9%
Feedmilling & Feed production	0.04	0.9%	0.04	2.6%
Business GHG emissions - Scope 1 & 2	**3.06**	**78.0%**	**0.53**	**38.4%**
Scope 3				
Manure indirect nitrous oxide	0.02	0.6%	0.01	0.9%
Piggery services	0.01	0.1%	0.01	0.4%
Feedmilling & Feed production	0.76	19.4%	0.76	55.0%
Transport	0.02	0.6%	0.02	1.7%
Off-farm Emissions - Scope 3	**0.81**	**20.7%**	**0.80**	**58.0%**
Land Use Change emissions - (kg CO2-e/kg LW sold)	***0.05***	***1.3%***	***0.05***	***3.6%***
Carbon footprint GHG emissions	**3.92**	**100%**	**1.38**	**100%**

5.3 Odour abatement potential

Assessment of the effect that a range of short HRT systems may have on required separation distances using the NEGIP approach was undertaken for 2,000 and 10,000 SPU piggeries (see Table 18). Developed effluent treatment factors from Table 12 were used in the assessment, along with effluent removal, surface roughness and terrain weighting factors all set to one, and the receptor type factor set to 11.5 (legal house) in the separation distance formula. Table 19 shows the likely maximum number of SPU that a 2,000 and a 10,000 SPU piggery with traditional uncovered ponds could expand to if they adopted short HRT systems. These calculations are based on the adopted effluent treatment factors from Table 12, noting that these factors are not based on any measurements and before they are adopted would need to be further validated.

Table 18. Calculated separation distances for a range of short HRT systems compared to traditional pond

Effluent treatment factor	Separation distance (m) for 2,000 SPU	Separation distance (m) for 10,000 SPU
Effluent to traditional uncovered anaerobic pond	***1,381***	***3,808***
> 40% of effluent generated from sheds to short HRT	1105	3,046
> 60% of effluent generated from sheds to short HRT	967	2,666
> 80% of effluent generated from sheds to short HRT	829	2,285
100% of effluent generated from sheds to short HRT	691	1,904

Table 19. Calculated separation distances for a range of short HRT systems compared to traditional pond

Effluent treatment factor	Maximum number of SPU	Maximum number of SPU
Effluent to traditional uncovered anaerobic pond	***2,000***	***10,000***
> 40% of effluent generated from sheds to short HRT	2,850	14,250
> 60% of effluent generated from sheds to short HRT	3,523	17,615
> 80% of effluent generated from sheds to short HRT	4,500	22,498
100% of effluent generated from sheds to short HRT	6,010	30,049

5.4 Effect of feed wastage on GHG and odour emissions

An assessment was carried to understand the effect of increased feed wastage on both nutrient excretion rates and likely GHG increases. Standard scenarios were undertaken with a feed wastage value of 5%, with these increased to 10% to show likely changes. This analysis was undertaken for the 2,000 SPU scenario for all diets in PigBal. Identical percentage changes were observed for the 10,000 SPU scenario and are not presented here. Table 20 shows the predicted TS, VS, N, P and K excretion rates in t/yr for a 2,000 SPU piggery with 5% and 10% feed wastage an input in PigBal. Also shown is the range in increase, with the two GHG important components, VS and N increasing by around 30% and 9% respectively. Table 21 shows the effect that this increase in feed wastage would likely have on GHG emissions for a short HRT system that manages 100% of the effluent, with the range of increase being only 5.8 to 6.5% for all four diets assessed.

Table 20. Effect of increased feed wastage on waste excreted for four diets for 2.000 SPU piggery scenario

Excretion (t/yr)	Diet A		Diet B		Diet C		Diet D		Range of increase	
Feed wastage	5%	10%	5%	10%	5%	10%	5%	10%	Min.	Max.
TS	213.1	270.9	223.9	281.7	220.9	278.7	218.0	275.9	25.8%	27.1%
VS	173.0	227.3	180.8	234.9	176.3	230.4	175.4	229.7	30.0%	31.4%
N	18.8	20.4	16.8	18.3	17.0	18.6	18.2	19.8	8.7%	9.1%
P	4.7	5.1	4.7	5.1	4.9	5.3	4.9	5.3	7.9%	8.0%
K	4.7	5.0	4.6	4.9	4.8	5.1	4.3	4.6	6.8%	7.0%

Table 21. Effect of increased feed wastage on likely GHG emissions for four diets for 2.000 SPU piggery scenario

Diet	GHG emissions for 5% feed wastage	GHG emissions for 10% feed wastage	Increase
	kg CO2-e/kg LW sold Short HRT	kg CO2-e/kg LW sold Short HRT	%
A	1.24	1.3	6.5
B	1.50	1.6	6.0
C	1.39	1.5	5.8
D	1.38	1.5	6.5

Changes in feed wastage and the associated impact on effluent quality shown in Table 20 will impact the loading rates to the treatment ponds and consequently, the concentration of nutrient in the effluent for both conventional and short HRT systems. The impact will be most notable in short HRT systems as the reduced time in pond <30 days limits the opportunity for loss of nitrogen to the atmosphere and phosphorus to sludge. Increases in the concentration of nutrients will increase the required irrigation areas for effluent disposal in ensure sustainable irrigation practices.

6. Discussion

This study assessed the technical feasibility, likely required increased effluent irrigation areas, storage volumes, as well as the GHG and odour potential abatement of converting the treatment of piggery effluent from traditional large uncovered anaerobic ponds to short HRT systems. It considered a small piggery (2,000 SPU) and large piggery (10,000 SPU). The assessment was desk-top and covered a technical review of the literature on short HRT (and other related GHG mitigation technologies), and modelling of various scenarios to gain an insight of the likely requirements for adoption of the technology on farm.

6.1 Technical review

There is limited Australian research on short HRT systems for piggeries, other than the study by McGahan et al. (2016) that reported methane conversion factors of 0.1% in winter and 18% in summer. Ammonia-N emissions factors were also low at 0.02 and 0.3% for winter and summer respectively. This study found natural reductions in pH over both the summer and winter trials after fresh effluent entered the storage tank. This was likely related to the ammonia levels of the fresh manure that led to a lowering of methane emissions. In another study on short HRT systems with dairy effluent in Tasmania, Boersma et. al. (2017) found practical impediments to achieving short HRT at a commercial dairy. The main issue was around the ancillary management practices, such as frequent agitation to recover settled solids that could potentially have a significant influence on methane emissions. These practical impediments would need to be overcome for the short HRT system to be adopted widely at commercial piggeries in Australia.

Emission factors for short HRT systems (< 1 month storage) are included in the latest NIR (Commonwealth of Australia, 2023b) as a 3% methane conversion factor (MCF) for all states. This provides a pathway for the adoption of short HRT systems into the Carbon Credits (Carbon Farming Initiative - Animal Effluent Management) Methodology Determination 2019 under the ERF. The values in the NIR were adopted from IPCC (2006) values and represent a significant methane emission abatement over traditional uncovered anaerobic ponds that have MCF ranging between 70 and 77%, depending on the state or territory. The updated IPCC Guidelines (2019), from the 2006 version also include provision for short HRT systems as liquid/slurry systems. Interestingly, these updated IPCC guidelines include additional retention times of 1, 3, 4, 6 and 12 months, instead of the current more or less than 1 month storage. Also, it proposes that 5 percent of VS is retained in storage after emptying, rather than 0 percent (i.e. completely clean) assumption implied in the original IPCC 2006 calculations.

In other European research, Møller et al. (2004) found methane production during storage of pig and cattle manure at 15°C and 20°C showed that temperature in this range was not a significant influence at storage times of < 30 days. This supports the findings of the McGahan et al. (2016) study that found emissions in winter were low (i.e. ambient temperatures below 20°C). At higher temperatures, methane production increases, as the optimum temperature range for satisfactory gas production takes place in the mesophilic range between 25 to 35°C. The IPCC (2019) guideline now have higher reported MCF values for pig production regions in Australia, ranging from 13 to 42%, depending on the climatic zone. These would represent significantly higher methane emissions than are currently adopted 3% in Australia for all climatic zones, even with a 40% reduction allowed for in the IPCC crusting of storages.

pH modification is a potential method that could be utilised along with short HRT, as the theory of short HRT is that fresh effluent will undergo pH reduction naturally when left in a storage tank for less than 30 days. pH has a significant effect on the performance of the anaerobic digestion process, as methanogenic bacteria are very sensitive to pH and do not thrive at pH levels < 6 and methane generation is almost zero at pH < 5 or > 8. If pH begins to rise to a point where methane could be generated, the effluent could be acidified to inhibit methane emissions.

Some additives have also proven to have a significant reduction in GHG emissions. These include polyferric sulphate, with a 99% reduction in methane emissions from dairy effluent over 42 days and calcium-cyanamide that had methane reductions of 81% and 99% for pig effluent when added at rates of 300 and 500 ppm of effluent.

Short HRT storage may offer the potential to be used as a systems approach in reducing overall GHG emissions from effluent treated in uncovered anaerobic ponds. Solids separation prior to short HRT storage would allow greater practical management of the stored effluent. Provided the separated solids are stored/treated in a manner that anaerobic activity is minimised, minimal emissions would occur from the separated component. An assessment of overall GHG emissions for a 2,000 SPU piggery showed that emissions would be similar if 100% of the effluent was treated in a short HRT, compared to the effluent first being pre-treated with solids separation before being managed in a short HRT system.

pH modification or additives could be an add-on technology to ensure methane generation remains inhibited in the storage tank prior to reuse. Reasons for this may be climatic conditions preventing regular effluent reuse (< 30 days) is prevented and/or difficulties in removing all residual material between batches.

6.2 Modelling of short HRT systems

Short HRT systems rely on frequent application of relatively small volumes of effluent. Results of the modelling determined that short HRT systems could be used to manage a high proportion of effluent in most regions of Australia, with only two of the thirteen sites modelled utilising less than 80% of the effluent generated from both small and medium sized operations. Regions with higher rainfall and cooler temperatures were found to be less suited to the implementation of short HRT systems due to the lower requirement for frequent effluent application.

For a small scale (2,000 SPU) short HRT system for an operation based in Queensland, it would be expected that in the order of 95% of the effluent could be used through an annual application of 7.5mm to a 110 ha irrigation area, assuming the farm had no solids separation. If the farm installed a solids separation system, then the irrigation area could be reduced to 65ha with the effluent application rate increasing to 12.5mm. From an operational perspective, the application of effluent over a smaller area may be more practical and allow for multiple applications over an annual period, rather than just one single 7.5mm application. Removal of solids through a solids separation system may also improve the management of effluent due to reduced solid material (both floating and settling) in the short HRT tank, and reduced blockages through application.

For a larger scale (10,000 SPU) operation located in the southern region Western Australia (Mount Barker), the proportion of effluent that could be applied though short HRT is 61%. The is largely due to the higher rainfall and lower evapotranspiration in this area, resulting in a reduced applicability for short HRT systems, as soil conditions are often too wet to sustainably apply effluent.

To minimise environmental risk resulting from the application of relatively high strength effluent, it must be ensured that spreading occurs evenly over a dedicated area. Due to the relatively high areas, and low irrigation rates spreading for short HRT systems is typically undertaken using a tractor and spreader such as shown in Figure 2. Buffer distances from sensitive receptors such as waterways, native vegetations, groundwater bores and residences should also be considered when selecting spreading areas. GPS tracked spreading can be used to assist in managing the even application of nutrients.

Figure 2. Effluent spreading

6.3 GHG and odour abatement potential

The GHG abatement of short HRT systems is shown to be very high when compared to traditional uncovered anaerobic ponds. The four pig production regions that were assessed were southern Qld, south-western WA, SA and northern Victoria (Table 16). When the GHG intensity was assessed on total GHG emissions (Scope 1, 2 and 3), the GHG abatement ranged between regions between 64 and 66%. This was based on modelling that assumed 100% of the effluent was managed via a short HRT system. Abatement, however, would still be high (around 50%) if at least 80% of the effluent was managed via a short HRT system.

A detailed analysis of the disaggregated emissions for south-western WA (Table 17) showed that Scope 1 manure emissions (methane and nitrous oxide) reduced from 2.66 to 0.13 kg of CO2-e/kg LW sold, representing a 95% reduction in Scope 1 GHG emissions.

The odour abatement of short HRT systems was shown to be potentially high when adopted as an alternative to traditional uncovered anaerobic ponds. Assessments were undertaken with different scenarios of the amount of effluent treated in short HRT systems. With 100% of the effluent treated in short HRT, required separation distances using the NEGIP formula were 50% less than for traditional uncovered anaerobic ponds. This means that if a piggery was to adopt short HRT with at least 80% of the effluent produced, it could have approximately 2.5 times more SPU, with the same required separation distance. The proposed treatment factors used in this study are based on any measurements and before they are adopted, would need to be further validated.

7. Implications & Recommendations

The short HRT system would likely best function via a systems approach to maximise GHG mitigation, with solids separation as a pre-treatment. The system is also most suited to areas of Australia with lower rainfall and high mean temperatures allowing for frequent application of effluent.

The separation of solids, prior to effluent entering a short HRT storage would reduce the amount of organic matter, as well as reduce nutrients they would need to be irrigated following short HRT storage. This would subsequently reduce the land area required for effluent irrigation. The separated solids could be managed on site via stockpiling and composting before removal off-farm as an organic fertiliser, reducing the nutrient loads on the piggery farm operation.

Another advantage of solid separation prior to short HRT, is that irrigation would be easier to undertake, with the larger particles removed. This would both reduce the effort required to agitate the storage tank at removal and enable a wider range of irrigation equipment to be used. Cleaning of the short HRT storage after each batch would also be simpler as the solids removed would cause less settling in the tank. Removal of all organic material would be important between each batch of effluent to ensuring new effluent added would not be reseeded with beneficial anaerobic bacteria.

This approach could work with piggeries that currently manage their effluent streams with uncovered anaerobic digestion ponds. The infrastructure requirements to direct effluent from an anaerobic treatment system to short retention system is reasonably simple and has been found to be cost effective when the scale is sufficient at Australian piggeries (Wiedemann et al., 2016b), thus it could be applied at piggeries. The system could also be an addition to existing anaerobic treatment where some of the effluent could be directed to a short HRT system daily or seasonally,

The application of a pH modification could also be used as an alternative treatment process that could be used with effluent in situations where climatic conditions inhibit regular irrigation to meet the short HRT criteria of <30 days or residual effluent in storage tanks promoting methanogenesis. There are, however, some limiting factors that can impact on the abatement potential of pH modification systems. One issue with pH modified effluent to an acidic level can be hazard issues caused on other farming activities, as well as during its use. It will be more corrosive, and the higher salinity content may limit land applications and reuse options. Applying low pH effluent could cause some issues in some soil types, however, this is only likely to be short-term due to very low application rates of <15mm/yr in most cases. Research has shown that pH modification can be applied to piggeries, however it has not been adopted widely outside of Europe.

It is recommended that the next stage of the project be undertaken (Stage 3) that will include the development of a "how-to" guide and webinar for producers on the operation of short HRT systems in various pig production regions; the advantages and disadvantages of them over traditional uncovered ponds and likely GHG abatement potential. In conjunction with this will be an industry survey (Stage 4) to gauge the level of producer interest in short HRT systems.

8. Intellectual Property

There is no intellectual property arising from this project.

9. Technical Summary

This will be included in the final report for the project.

10. Literature cited

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11. Publications Arising

Nil to date.

ATTACHMENT A: EFFLUENT APPLICATION MODELLING FULL RESULTS (MEDLI)

2000 SPU

INPUTS											OUTPUTS											
Location	**Mean Rainfall**	**Mean Evap.**	**Diet**	**Pond 1**	**Pond 2**	**Soil Type**	**Crop**	**Irr Area**	**Irr. Trigger**	**Irr. Applied**	**% Irrigated**	**Vol Overtopping**	**Overtopping Fr**	**Crop Yield**	**Irr. Depth**	**Irr. Water Concs**		**Irr. Area Loading**		**Deep Drainage**		**Deep Drainage**	
	mm	mm		m3	m3			ha	SW Defecit (mm	Depth Above DUL (mm)		m3/yr	no/year	t/ha.yr	mm	Average N	Average P mg	kg N/ha	kg P/ha	Average N	Max N mg/L	Average P	Max P mg/
Oakey	607	1814	B	7500	3000	Grey Clay	Rhodes Grass/Barley	12	10	0	100%	0	0	12.9	45.1	473.4	69.7	199.9	31.44	7.13	9.3	0.01	0.01
Goondiwindi	587	1940	B	6500	3000	Grey Clay	Rhodes Grass/Barley	10	10	0	100%	0	0	12.3	30	612	126.6	172.1	38	5.24	6.07	0.01	0.01
Kinaroy	754	1636	B	7300	3000	Kransnozem	Rhodes Grass/Barley	10	10	0	100%	0	0	19.4	41.7	534.1	91.1	209.14	38.1	3.89	21.2	0.01	0.01
Young	649	1440	C	8600	3200	Red-brown Earth - med perm	Rye Grass 2/Barley	10	10	0	100%	48.9	0.09	12.8	40.1	465.6	95.4	178.8	39.1	5.8	18.5	0.06	0.1
Casino	1043	1582	B	6500	3000	Black Earth	Rye Grass 2/Barley	10	10	0	99%	101.5	0.08	18.2	54.3	511.9	69	260.7	37.5	5.8	28.1	0.05	0.1
Corowa	546	1543	C	8600	3000	Grey Clay	Rye Grass 2/Barley	10	10	0	100%	0	0	14.5	35.8	504	110.4	169.3	39.6	5	10.3	0.01	0.01
Bendigo	537	1421	C	8600	3000	Red-brown Earth - med perm	Rye Grass 2/Barley	10	10	0	99%	37.2	0.06	12.3	38.1	488.2	102.8	174.3	39.2	7.6	25.6	0.06	0.09
Shepparton	480	1479	C	8200	3000	Grey Clay	Rye Grass 2/Barley	10	10	0	100%	1.57	0.02	13.8	35.22	522	111.8	172.4	39.4	7	13	0.01	0.01
Murray Bridge	350	1584	A	7700	3000	Red-brown Earth - med perm	Rye Grass 2/Barley	15	10	0	100%	0	0	7.1	19.2	625	132	112.3	25.3	13.2	19.5	0.09	0.1
Naracoorte	516	1475	A	7700	4000	Duplex 2	Rye Grass 2/Barley	10	10	0	100%	18.2	0.08	15	36.6	502.6	104.2	172.4	38.1	5.84	18.1	0.05	0.08
Roseworthy	447	1748	A	8700	3000	Sand	Rye Grass 2/Barley	10	10	0	100%	20.5	0.02	12.2	28.4	598	133.5	159.3	37.9	9.2	100.7	0.06	0.1
Narrogin	445	1754	D	7800	3000	Duplex 2	Rye Grass 2/Barley	10	10	0	100%	0	0	12.6	28	590.7	141.34	155.2	39.6	3.07	6.52	0.05	0.06
Mount Barker	637	1390	D	8800	4400	Sand	Rye Grass 2/Barley	10	10	0	98%	69.25	0.09	14.4	38.9	405.6	99	148.2	38.6	3.3	26.3	0.04	0.07
Oakey	607	1814	B	125	510	Grey Clay	Rhodes Grass/Barley	110	10	0	97%	201.1	4.4	11	7.6	1904.7	549	136.4	41.9	1.75	7.92	0.01	0.01
Goondiwindi	587	1940	B	125	780	Grey Clay	Rhodes Grass/Barley	110	10	0	97%	223.2	5.2	10.6	7.6	1904.7	549	136	41.8	3.99	5.16	0.01	0.01
Kinaroy	754	1636	B	125	2600	Kransnozem	Rhodes Grass/Barley	110	10	0	94%	552.5	8.8	15.2	7.3	1904.7	549	130.7	40.1	4.48	19.66	0.01	0.01
Young	649	1440	C	125	5700	Red-brown Earth - med perm	Rye Grass 2/Barley	100	10	0	84%	1357	9.2	10.7	7.2	1938.7	570	131.1	41.1	5.84	27.8	0.08	0.1
Casino	1043	1582	C	125	11000	Black Earth	Rye Grass 2/Barley	95	10	0	82%	1547	12.9	11.7	7.4	1904.7	549	132.5	40.8	1.7	28.4	0.07	0.1
Corowa	546	1543	C	125	1400	Grey Clay	Rye Grass 2/Barley	110	10	0	94%	489.7	7.8	12.6	7.3	1938.7	570	133.5	41.9	4.7	8.9	0.01	0.01
Bendigo	537	1421	C	125	4900	Red-brown Earth - med perm	Rye Grass 2/Barley	100	10	0	85%	1302.3	8.8	10.4	7.3	1938.7	570	132.1	41.4	9.72	33.5	0.08	0.1
Shepparton	480	1479	C	125	1800	Grey Clay	Rye Grass 2/Barley	110	10	0	94%	1032	9.3	11.7	7.3	1938.7	570	132.8	41.6	5.7	9.6	0.01	0.01
Murray Bridge	350	1584	A	125	850	Red-brown Earth - med perm	Rye Grass 2/Barley	110	10	0	95%	389.9	8.7	6.4	7.4	2155.8	558	148.8	41.1	19.5	19.5	0.1	0.1
Naracoorte	516	1475	A	125	8000	Duplex 2	Rye Grass 2/Barley	90	10	0	74%	2170	11.6	13.8	7	2155.8	558	142	39.2	6.34	24.8	0.05	0.08
Roseworthy	447	1748	A	125	3400	Sand	Rye Grass 2/Barley	95	10	0	81%	1651.4	8.8	11.5	7.2	2155.8	558	145.5	40.2	9.9	100.7	0.06	0.1
Narrogin	445	1754	D	125	1900	Duplex 2	Rye Grass 2/Barley	105	10	0	87%	1068.8	9.9	11.7	7.1	2078.1	577	138.7	41.1	7.3	23.1	0.08	0.1
Mount Barker	637	1390	D	125	11000	Sand	Rye Grass 2/Barley	80	10	0	61%	3311	11.3	12.8	6.5	2078.1	577	127.4	37.7	3.51	28.3	0.05	0.08
Oakey	607	1814	B	125	510	Grey Clay	Rhodes Grass/Barley	65	10	0	98%	211.7	4.4	11.6	12.8	1199.8	323.9	144.3	41.6	2.9	7.9	0.01	0.01
Goondiwindi	587	1940	B	125	780	Grey Clay	Rhodes Grass/Barley	65	10	0	98%	218.6	5.2	11.1	13	1199.8	323.9	144.2	41.5	3.61	5.26	0.01	0.01
Kinaroy	754	1636	B	125	2600	Kransnozem	Rhodes Grass/Barley	65	10	0	94%	555.1	8.9	15.6	12.3	1199.8	323.9	138.3	39.8	4.19	19.5	0.01	0.01
Young	649	1440	C	125	5700	Red-brown Earth - med perm	Rye Grass 2/Barley	60	10	0	84%	1362.8	9.2	10.9	11.9	1221.2	336.3	136.5	40.1	6.4	30.8	0.07	0.1
Casino	1043	1582	C	125	11000	Black Earth	Rye Grass 2/Barley	55	10	0	82%	1525.4	12.9	12.6	12.8	1199.8	323.9	143.6	41.4	1.9	28.4	0.07	0.1
Corowa	546	1543	C	125	1400	Grey Clay	Rye Grass 2/Barley	65	10	0	94%	488.6	7.8	12.9	12.4	1221.2	336.3	141.4	41.5	5.4	9.4	0.01	0.01
Bendigo	537	1421	C	125	4900	Red-brown Earth - med perm	Rye Grass 2/Barley	65	10	0	85%	1292.3	8.7	10.3	11.2	1221.2	336.3	131.9	37.4	8.1	30.9	0.07	0.1
Shepparton	480	1479	C	125	1800	Grey Clay	Rye Grass 2/Barley	65	10	0	94%	531.3	9.3	12	12.3	1221.2	336.3	140.7	41.3	7.4	15.4	0.01	0.01
Murray Bridge	350	1584	A	125	850	Red-brown Earth - med perm	Rye Grass 2/Barley	65	10	0	95%	389.9	8.7	6.6	12.4	1358	329.2	157.7	40.8	22.3	55.5	0.1	0.1
Naracoorte	516	1475	A	125	8000	Duplex 2	Rye Grass 2/Barley	50	10	0	74%	2156.2	11.7	14	12.6	1358	329.2	160	41.4	8.6	31.8	0.05	0.08
Roseworthy	447	1748	A	125	3400	Sand	Rye Grass 2/Barley	65	10	0	80%	1658.4	8.7	11	10.4	1358	329.2	132.9	34.4	8.7	100.7	0.06	0.1
Narrogin	445	1754	D	125	1900	Duplex 2	Rye Grass 2/Barley	65	10	0	87%	1061.3	9.8	11.7	11.4	1309	310.4	140.3	38.9	9.6	23	0.07	0.1
Mount Barker	637	1390	D	125	11000	Sand	Rye Grass 2/Barley	45	10	0	61%	3291	11.4	13.4	11.5	1309	310.4	141.8	39.3	4.9	29.2	0.05	0.07

* Ovetopping events for conventional are from Pond 2 and for Short HRT are from the small short HRT tank.

Note: Nitrate leaching from the short HRT system for Murray Bridge exceeded the 10mg/L limit but the volume of leaching was so small that the applicaion was considered acceptable