Australian Government
Department of Agriculture and Water Resources

AUSTRALIAN Pork

Development of New Emission Reduction Fund (ERF) Methods for the Pork Industry

Final Report

APL Project 2016/098

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Executive Summary

The Emission Reduction Fund (ERF) is a voluntary incentive scheme that enables participants to generate revenue by reducing greenhouse gases (GHG) or sequestering carbon. For participants to claim abatement and generate Australian Carbon Credit Units (ACCUs), abatement must be generated using a specified ERF methodology determination (method).

There are two methods that can currently be used to generate ACCUs from piggeries: The *Destruction of Methane Generated from Manure in Piggeries 1.1 Methodology Determination 2013* and the *Destruction of Methane from Piggeries Using Engineered Biodigesters Methodology Determination 2013*. Both methods are designed for application at piggeries with either covered ponds or engineered digesters. The *Destruction of methane generated from manure* (i.e. the covered pond method) has been utilised by a number of registered projects and has provided a substantial new revenue stream (in excess of $10M) to the pig industry since 2012. However, these methods are generally only applicable to larger piggeries (typically >1000 sows farrow-finish, i.e. 10,000 standard pig units) and require substantial capital expenditure. The method is also not applicable for pigs housed on deep litter, without effluent ponds.

Other options exist to mitigate GHG emissions from pork production. Research commissioned by Australian Pork Limited (APL) and the National Agricultural Manure Management Program (NAMMP) quantified the mitigation potential for short hydraulic retention time (short HRT) effluent systems and deep litter housing, when used in preference to conventional housing with long HRT effluent treatment. In response to this, the industry commissioned the present project to investigate the opportunity for developing these into ERF methods, and to provide technical material to support method development.

Concurrently, the Federal Department of the Environment and Energy (DEE) has commissioned the development of a new method titled the *Animal Effluent Management Methodology Determination* which was approaching completion when the present report was completed.

The following report has three major sections;

- (I) literature review,
- (II) stakeholder engagement, and
- (III) development of technical materials for integration into the proposed *Animal Effluent Management Methodology Determination*.

The following section summarises the conclusions of each section.

Literature Review
The literature review (Chapter 2 to 5) provides an overview of the ERF, the existing methods and potential new technologies that could be incorporated into an ERF method relevant to pigs. It outlines key considerations that would need to be considered to include new mitigation techniques and provides a framework and overview of the new method. The discussion paper focusses on new mitigation techniques that are robust, well supported by literature and understood to be technically feasible. Of the *emission avoidance* techniques, the short HRT, solids separation and alternative housing (deep litter) techniques were found to be technically feasible and were presented to industry and Government stakeholders for review, as described in the following section.

Stakeholder Engagement
The project included a stakeholder engagement process that included engagement with industry and the DEE. A series of meetings were held to provide an overview of potential mitigation techniques and to outline the technical requirements for applying these techniques. Industry members were asked to provide feedback regarding the likely adoption rate of the techniques proposed, and to provide feedback on options to improve the functionality of the existing methods for covered ponds. This engagement process concluded that alternative housing (deep litter) was unsuitable for integration into a method, principally because this mitigation required either i) that a pig farm was converted from

conventional housing with effluent ponds to deep litter, or ii) that a deep litter shed was preferentially built in place of a conventional piggery. The first case was deemed to be unlikely, because conventional piggeries are a substantial capital investment and generally allow better pig management than deep litter. The second was considered feasible, but questions were raised about how a proponent would demonstrate that the construction of a deep litter shed was additional rather than being *business as usual*. Because the financial incentives from ACCU sales is low compared to pig sales, it was considered too difficult to substantiate. Consequently, the deep litter housing option was not pursued. The short HRT option was considered feasible, though concerns were raised about the potential for other environmental concerns relating to nutrient management. These were not considered insurmountable, because farms are required to demonstrate sound nutrient management practices to meet the requirements of their environmental licence, which could be done with the correct system design (for example, only operating the short HRT system during favourable seasons and maintaining wet weather ponds). Solids separation was considered a feasible option for integration into a potential method.

Development of Technical Material for the Animal Effluent Method

Technical specifications were provided for including solids separation and short HRT systems in the method. Additionally, the authors provided technical support regarding development of the new *Animal Effluent Method*, supporting simplification by proposing removal of the current baseline approach (Pigbal). These specifications are detailed in the report and enable inclusion of these techniques in the proposed new method.

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Glossary of Terms

ACCU	Australian Carbon Credit Unit
AD	Anaerobic digestion
APL	Australian Pork Limited
B_o	biological methane potential
C:N ratio	Carbon/nitrogen ratio
CAPEX	Capital Expenditure
CFI	Carbon Farming Initiative
CH_4	Methane
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
COD	Chemical Oxygen Demand
DEE	Federal Department of the Environment and Energy -
EF	Emission factor
ERAC	Emissions Reduction Assurance Committee
ERF	Emissions Reduction Fund
FCR	Feed conversion ratio
FDS	Fixed dissolved solids
FS	(Total) fixed solids
FSS	Fixed suspended solids
GHG	Greenhouse gas
GWP	Global warming potential
HRT	Hydraulic retention time
IPCC	Intergovernmental Panel on Climate Change
MCF	Methane conversion factor
MMS	Manure Management System
N	Nitrogen
N_2O	Nitrous oxide
NAMMP	National Agricultural Manure Management Program
NGER	National Greenhouse and Energy Reporting
NH_3	Ammonia
NH_3-N	Ammoniacal nitrogen
NIR	National Inventory Report
NO_2	Nitrogen dioxide
OP-FTIR	Open Path - Fourier Transform Infrared
PigBal / PIGBAL	Piggery Waste Management Model
SPU	Standard Pig Units
SS	(Total) suspended solids
TDS	Total dissolved solids
TS	Total solids
VDS	Volatile dissolved solids
VS	(Total) volatile solids
VSS	Volatile suspended solids

1 Introduction

The ERF and predecessor, the Carbon Farming Initiative (CFI) have provided a substantial new revenue stream (> $10M) to the pig industry since 2012. Two methods exist that can be used by the pig industry: i) the *Carbon Credits (CFI) (Destruction of Methane Generated from Manure in Piggeries-1.1) Methodology Determination 2013,* and ii) the *Carbon Credits (CFI) (Destruction of Methane from Piggeries using Engineered Biodigesters) Methodology Determination 2013*. Both methods can be applied at piggeries with conventional effluent management systems (flushing systems) and require substantial investment to apply because of the requirement to install a methane capture and destruction/use system. The pathway to realising these approved methods was supported by industry research and a proactive industry assistance plan to develop the methods with the Federal Department of Climate Change (now the Department of the Environment and Energy - DEE). Since the introduction of these methods, further Australian Pork Limited (APL) and National Agricultural Manure Management Program (NAMMP) research has confirmed baseline and mitigation emissions for two manure management systems, revealing new opportunities to reduce emissions with either short hydraulic retention time (HRT) or Deep Litter systems. This provided the context for further development of ERF methods for the pig industry.

While substantial financial returns have been realised by the pig industry via application of the covered pond and engineered digester method determinations, these methods do not allow participation by large segments of the industry. In particular, producers that require fast paybacks on investment, smaller piggeries, or deep litter piggeries have not adopted the current methods. Research by the author and colleagues demonstrated that emissions could be mitigated using low cost, short HRT effluent treatment systems (McGahan et al. 2016) or deep litter housing (Phillips et al. 2016) in preference to long HRT effluent ponds. Considering this, investigation was warranted into the potential for new ERF methods that could allow a larger proportion of the industry to participate in the ERF, with a broader range of mitigation options.

1.1 Objectives

The project aimed to enable development of new ERF methods suitable for the pig industry by providing technical material to the Federal DEE. The project was conducted in consultation with the Federal DEE and industry, and the specific objectives were developed and reframed during the course of the project based on this consultation. These objectives (including revised and additional objectives) are outlined below:

1. Develop a discussion paper and engage government stakeholders (**original objective**),
2. Collate the technical requirements for each method, providing the technical basis for method development (**original objective**),
3. Collate and review material to support development of draft methods, in consultation with the DEE (**original objective**),
4. Develop briefing report covering the technical, practical and economic feasibility and likely uptake of solids separation and short HRT as mitigation techniques. (**revised objective**),
5. Support inclusion of additional approaches, specifically focussing on solids separation in the revised method by:
    a. Providing technical specifications for including solids separation in the method,
    b. Providing technical specifications for including short HRT systems in future iterations of the method, via updates to a technical document that is separate to the method,
    c. Providing ongoing technical assistance to develop the method for including these techniques (**revised objective**), and
    d. In addition to these mitigation techniques, outdoor housing was investigated, however it was excluded during the consultation process.

6. Technical support regarding development of the revised covered pond/digester method, supporting simplification by proposing removal of the current baseline approach using PIGBAL. This will be advanced by developing a briefing paper to outline the technical basis for a revised approach and may include review of audit reports submitted by pig industry ERF project holders. This has the potential to substantially reduce complexity (and therefore compliance costs) for industry members that have covered ponds or digesters and can therefore deliver value to industry from the project (**revised objective**).

Original objectives that were discontinued following the consultation process were provision of technical specifications for inclusion of deep litter housing as an alternative to conventional housing/effluent treatment, and herd management mitigation methods.

1.2 Overview of Report

The following table details how each objective of project was achieved and how this is summarised in the report, noting that separate deliverables were provided throughout the course of the project and are summarised here.

Table 1. Objectives and associated report sections

Objective	Description	Chapter / Section	Notes
1	Discussion paper	Chapter 2 to 5	Delivered to APL 27/02/17
	Engage government stakeholders	Chapter 6	Summary of stakeholder engagement
2 and 3	Collate the technical requirements for each method	Chapter 2 to 5	
4	Briefing report on technical, practical and economic feasibility and likely uptake of solids separation and short HRT as mitigation techniques	n/a	Delivered to APL 06/07/17
5	Support inclusion of additional approaches	Chapter 5 and 7	
6	Method simplification	Chapter 7, Section 7.3 and7.4	

2 Animal Effluent Management Method

2.1 Manure Management Greenhouse Gas Emissions

Emissions from the Australian agricultural sector account for approximately 15% of Australia's annual greenhouse gas (GHG) emissions, while emissions from Australian livestock industries account for over 10% of the annual emissions (Commonwealth of Australia, 2016). Most of these emissions originate from enteric fermentation by ruminants; although with increases in intensive farming, manure management contributes an increasing proportion of GHG emissions, as shown in Figure 1. This is particularly the case for intensive livestock production, such as poultry, pig, dairy and feedlot beef, which collectively account for 84% of manure management emissions in Australia's National Greenhouse Accounts, published in the National Inventory Report (NIR) (Commonwealth of Australia, 2016). Methane (CH_4) and nitrous oxide (N_2O) are the two main GHGs produced by livestock industries and have a much greater global warming potential (GWP) than carbon dioxide (GWPs of 25 and 298 respectively) (Commonwealth of Australia, 2016).

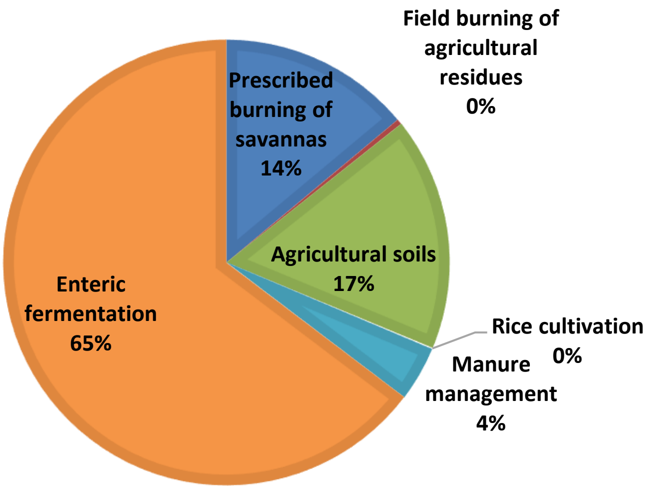

Figure 1. Contributions to Agricultural Emissions (Commonwealth of Australia, 2015)

2.2 Manure Characteristics

The chemical composition of manure is dependent on many factors, including the type, breed and age of the animals, feed availability and farming methods (Sánchez and González, 2005). Manure is a mixture of urine, faeces, waste feed and water. Depending on the manure management system used, this may be handled in a liquid or a solid form. Liquid (effluent) manure management systems use water as a means of transporting and treating manure. Because of the high organic loading associated with manure systems, these systems operate anaerobically. Systems that handle manure as a solid do not utilise water as a transport mechanism and may use bedding material to absorb excess moisture in urine and manure to maintain a predominantly aerobic environment.

The compounds in effluent and solid manure fractions can be partitioned into different physical components, as described by the following matrix adapted from Taiganides (1977, cited in Birchall, 2010):

TS	=	VS	+	FS
॥		॥		॥
SS	=	VSS	+	FSS
+		+		+
TDS	=	VDS	+	FDS

Where;

TS = total solids
VS = (total) volatile solids
FS = (total) fixed solids
SS = (total) suspended solids
VSS = volatile suspended solids
FSS = fixed suspended solids
TDS = total dissolved solids
VDS = volatile dissolved solids
FDS = fixed dissolved solids

The characteristics of effluent and manure fractions can be characterised by these components, as explained briefly below.

Total solids (TS): The Total Solids (TS) content of manure is the mass of solids remaining after a sample has been dried in a 103 C oven for 24 hours ("dry weight") and is comprised of both suspended solids (SS), and total dissolved solids (TDS).

Volatile solids (VS): The volatile solids component is the biodegradable organic matter or degradable component. It is determined by the quantity of TS burnt or driven off when a material is heated to 550 C for at least 1 hour.

Fixed solids (FS): The fixed solids constitute the residual inorganic compounds (N, P, K, Ca, Cu, Zn, Fe etc.) in a suspended or dissolved state.

Suspended solids (SS): Particles that are retained on filters with pore size of 1 μm.

Total dissolved solids (TDS): All dissolved solids (TDS) are ions. There is a strong correlation between TDS and the electrical conductivity of effluents.

2.3 Manure Management - Manure Management System (MMS)

Manure storage and treatment encourages the growth of microorganisms to consume organic material, either in the presence of oxygen (aerobic) or in the absence of oxygen (anaerobic). Both aerobic digestion and anaerobic digestion (AD) reduce pathogens, odour and the TS content. Anaerobic digestion is slower but much less energy intensive compared to an aerobic digestion, which requires constant aeration to replace spent oxygen, and is therefore the preferred means of handling liquid streams.

2.3.1 Anaerobic Digestion

Anaerobic digestion (AD) is a series of biological process by which biodegradable organic matter is decomposed by a consortium of microorganisms in the absence of oxygen, producing CH_4, CO_2 and other contaminate gases. This process occurs naturally in many anoxic environments, such as mammalian guts and waste sediments. Anaerobic decomposition is a four-stage process, with different groups of microorganisms involved at each stage:

1. Hydrolysis,
2. Acidogenesis,
3. Acetogenesis, and
4. Methanogenesis.

Long retention times in anaerobic systems are needed to ensure all four stages are completed.

During the hydrolysis stage, solid material is broken down by enzymes into soluble molecules. During acidogenesis stage, the soluble molecules are degraded by acid forming bacteria into acetate, hydrogen and CO_2. In the acetogenesis stage, volatile fatty acids are converted into acetic acid, CO_2, and hydrogen. Finally, during the methanogenesis stage, the two groups of methanogens produce methane from either acetate or hydrogen plus CO_2. Anaerobic digestion (AD) will occur naturally in effluent treatment ponds, in which case the gases are released directly to the environment. These uncontrolled anaerobic treatment systems are common in the pig industry and represent the major target for mitigation of manure emissions.

2.3.2 Anaerobic Digestion and Biogas Capture

The use of AD systems to produce and capture biogas is a common practice in most parts of the world and has been the subject of several reviews (Wu, 2007, Abbasi et al., 2012). Systems can range from very simple covered pond designs, to advanced, in-ground digester systems or above ground, tank based systems. After capture, biogas can be burnt to generate electricity and heat (refer to Figure 2). An additional benefit from AD and biogas capture is odour reduction.

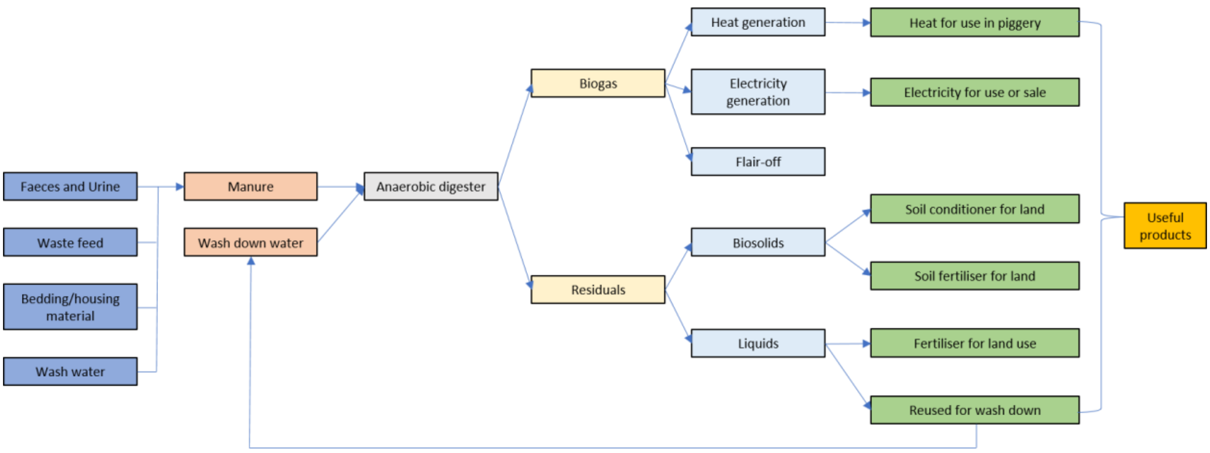

Figure 2. Generalised anaerobic digestion process of agriculture manure

The yield of biogas and the resulting methane composition produced from an anaerobic digester is highly dependent on various factors such as the biogas potential of feedstock, design of digester, inoculum, nature of substrate, pH, temperature, loading rate, hydraulic retention time, C:N ratio, volatile fatty acids content, and other trace gases, which all influence the biogas production (Dhevagi et al., 1992). Table 2 shows the significant variation in biogas methane concentrations produced by anaerobic digestion of different livestock manures. The methane percent concentration of biogas produced from anaerobic digesters in the Oceania regions (warmer regions) is notably higher than most international studies.

Temperature significantly affects methane production due to the sensitivity of methanogenic bacteria to low temperatures (Molloy and Tunney, 1983). The optimum temperature range for satisfactory gas production takes place in the mesophilic range, which is between 25 to 35 ◦ C (Uzodinma et al., 2007, Chae et al., 2008). Temperatures below this range severely limit the production of methane. This can be seen in Kavuma's (2013) study, which only obtained a methane yield of 47.1% and 45.3% for piggery and dairy manure respectively, due to digester temperature below 24 ◦ C. This temperature effect may explain the difference in methane percent concentrations between Oceania regions and other international studies.

Table 2. Methane percent concentration of bio gas produced from anaerobic digesters – divided into Oceania and international studies

Biogas source	Digestion type	Methane concentration of biogas	Location	Reference
	Oceania studies			
Piggery	Covered anaerobic pond	Average: 80% Range: 67-88%	NSW, Australia	(Longfield, 2013)
Piggery	Floating cover on anaerobic pond	62% to 73%	Queensland, Australia	(Skerman, 2017)
Piggery	Floating cover on anaerobic pond	Average: 68.9% Range: 67.3-71.6%	Queensland, Australia	(Skerman and Collman, 2012)
Piggery	Covered anaerobic pond	Average: 63.2% Range: 54.0 to 70.4 %	Victoria, Australia	(Birchall, 2010)
Piggery	Covered anaerobic pond	74%	New Zealand	(Craggs et al., 2008)
Piggery	Lab scale	63-66%	Fiji	(Prasad, 2012)
Dairy	Covered anaerobic pond	82%	New Zealand	(Craggs et al., 2008)
Diary	Lab scale	61-64%	Fiji	(Prasad, 2012)
Poultry	Lab scale	60-65%	Fiji	(Prasad, 2012)
	International studies			
Piggery	Lab scale	55% to 70%	Vietnam	(Cu et al., 2015)
Piggery		65%	USA	(White and Plaskett, 1981)
Dairy	Lab scale	57-69%	Egypt	(El-Mashad and Zhang, 2010)
Diary	Covered anaerobic pond	60%	USA	(Bothi, 2007)
Diary	Lab scale	70%	Nigeria	(Ukpai and Nnabuchi, 2012)
Diary		60%	USA	(Kirk and Bickert, 2004)
Poultry	Lab scale	60% to 70%	Vietnam	(Cu et al., 2015)

Methanogenic bacteria are also very sensitive to pH and do not thrive at pH < 6.5. The optimum methane production is achieved when the pH value of the anaerobic digester is between 6 and 7. The pH in an anaerobic digester is also a function of the retention time. During the start-up period of digestion, large quantities of organic acids are formed by acid producing bacteria, and the pH drops to below 5, temporarily inhibiting methanogenic bacteria digestion activity. As the digestion process continues, the concentration of ammonia increases due to digestion of nitrogen, which then increases the pH values to an optimal methane producing level. When the pH stabilises between pH 6 and 8, the digester will produce higher levels of methane.

The 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 AD (Stevens et al., 1989). At very low C:N ratios, elevated ammonia levels can inhibit digestion and this can be a concern with very concentrated manure sources.

The diverse range of methane production from full-scale covered anaerobic ponds from the above-mentioned Australian studies reflect the wide variation of performance that such systems may achieve. This variation may be due to the differences between the climate, chemical characteristics of treated effluent, operating efficiency, temperature and hydraulic retention time of systems. The studies of Skerman (2017) and Longfield (2013) showed higher methane percentages following pond desludging events that would increase the hydraulic retention time and hence improve the operating efficiency.

2.3.3 Greenhouse Gas Estimation

The two relevant GHG emissions that arise from effluent ponds are CH_4 and N_2O. Additionally, NH_3, while not a GHG, is a relevant emission as it leads to N_2O emissions when deposited to soil and re-released. It is not generally feasible to measure gaseous emissions directly under commercial conditions, as they are dispersed from the surface of the MMS, 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 (0.45 for piggery effluent)
P = specific density of methane (0.6784 kg/m^3) and
MCF = methane conversion factor, in percentages
GWP = Global Warming Potential (methane = 25)

The methane conversion factor (MCF) reflects the portion of B_o that is converted to methane in a given manure treatment system (IPCC, 2006). 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.

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).

2.4 Requirements of the ERF

The *Australian Carbon Credits (Carbon Farming Initiative - CFI) Act 2011* allows the crediting of GHG abatement from emissions reduction activities throughout all sectors of the Australian economy. Greenhouse gas abatement is achieved by either avoiding or reducing emissions, or by removing carbon from the atmosphere.

Initially, the CFI was designed to complement the carbon pricing mechanism by focusing on sectors not encompassed by the carbon price, specifically: agriculture, waste, land use, land use change and forestry. Due to the repeal of the carbon price, the CFI has been expanded by the *Carbon Farming Initiative Amendment Bill 2014* to establish the Emissions Reduction Fund (ERF). The ERF expands on the CFI by extending the scope of eligible emissions reduction activities and now covers all sectors of the economy. There a several key components of the legislation that determine the admissibility of a technology to be included in the ERF, as detailed below.

2.4.1 Eligibility

A method determination must set out the requirements to be met for a project to be an eligible offsets project. The Regulator must not declare that a project is an eligible offsets project unless the Regulator is satisfied that the project meets these requirements.

2.4.2 Additionality

A key requirement under the ERF is that credits are issued for emissions reductions that are **additional**, that is, a project's emissions reductions must go beyond what is common practice or would have occurred in the absence of the offset program for the relevant industry and must not be required by another government program or scheme (either Commonwealth, State or Territory). This aspect is an important part of the offset approval process, as offsets must represent real, measurable and surplus emission reductions.

The three-part additionality requirements for an eligible offsets project are as follows:

1. ***Newness*** requirement: project must be a new project. That is, the project must not have begun to be implemented when an application for registration is made.
2. ***Regulatory additionality*** requirement. The project must not be required to be carried out by or under a Commonwealth, State or Territory law.
3. ***Government program*** requirement. The project must not be likely to be carried out under another government program or scheme if it were not declared an eligible offsets project under the ERF.

The amended "newness" requirement requires projects to be declared eligible offsets projects by the Clean Energy Regulator before they commence project activity, unless the method covering the project specifies otherwise. This is because the ERF is not intended to support projects that are already underway without support from the ERF. The verification of newness from an auditing perspective could be evidenced by photographs of the previous MMS, and appropriate evidence of construction of a new emission abatement project (construction invoices, date stamped photographs and/or a site inspection). The newness requirement requires the assessment of whether a project has begun or not and *the Act* defines examples of this.

2.4.3 Offsets Integrity Standards

The 'offsets integrity standards' ensure that abatement of GHG emissions credited under the ERF conform to internationally recognised offsets integrity criteria. These criteria are designed to ensure that abatement is real, additional, verifiable and conservative. The offsets integrity standards require that an eligible project should result in GHG abatement that is unlikely to occur in common practice for the relevant industry and is an eligible carbon abatement under *the Act*.

In summary, the offsets integrity standards also include whether:

- amounts are measurable and capable of being verified,
- the methods used are supported by clear and convincing evidence,
- material emissions which are a direct consequence of the project are deducted, and
- estimates, assumptions or projections used in the determination should be conservative.

Thus, emissions offsets must be **real, additional, permanent, independently verifiable, enforceable, measurable, transparent and conservative**. These are defined as:

- ***Real***: Offsets represent actual reductions in GHG emissions,

- ***Additional***: Emissions reductions are "additional" if they occurred because of the presence of financial incentives associated with the existence of GHG markets, and emissions reductions being used as offsets are not "business as usual",

- ***Permanent***: Reductions should be non-reversible and not cause an increase in GHG emissions in other sectors,

- ***Independently verifiable***: Independent monitoring and verification requirements must be in place to ensure that GHG emissions reductions are delivered,

- ***Enforceable***: An emission reductions project should be undertaken using a method determination referred to in *the Act*, and official registration requirements that define their creation, provide for transparency, and ensure exclusive ownership,

- ***Measurable***: Emission reductions should be quantifiable,

- ***Transparent***: Information regarding the process of generating, certifying, verifying, and selling offsets should be available and easy to understand, and

- ***Conservative***: a conservative baseline for comparison should be identifiable and measurable.

3 Greenhouse Gas Emissions from Pig Effluent

3.1 Production Systems

The Australian pork industry comprises of production systems that could be classified as being either conventional, deep litter or outdoor. Each of these systems utilise different manure management processes and produce different GHG emissions, as shown in Figure 3.

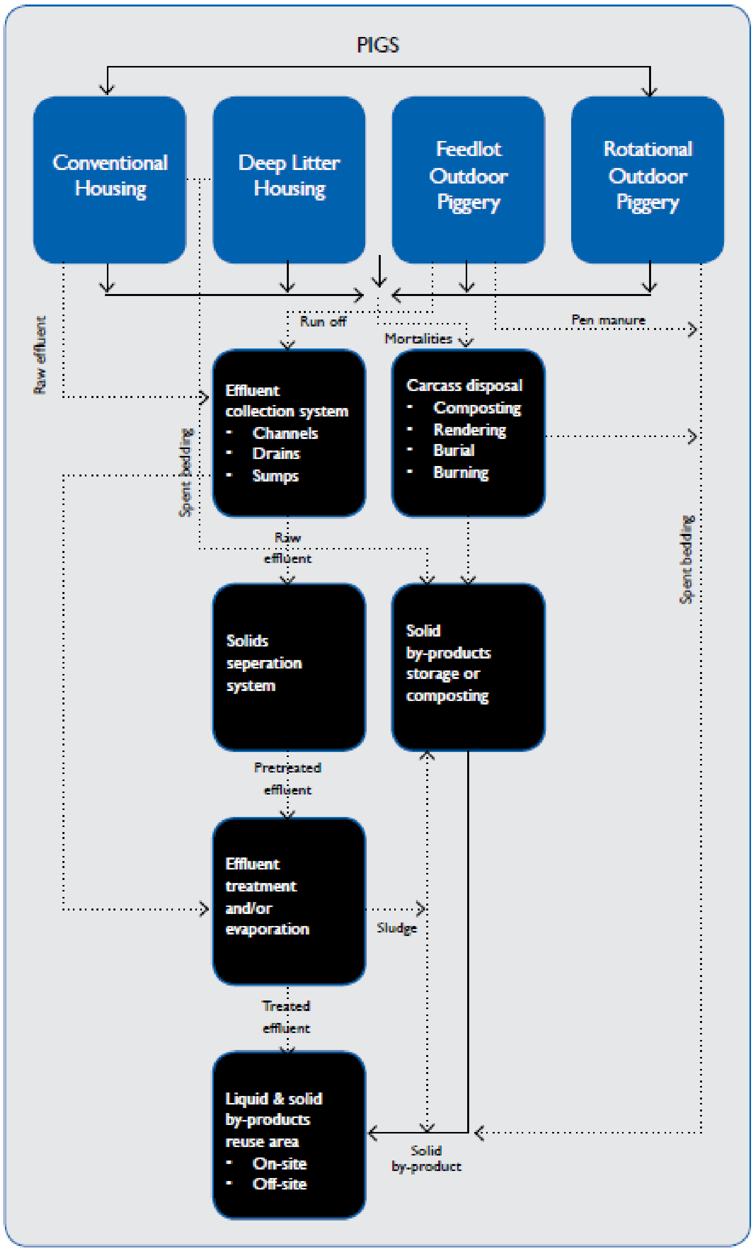

Figure 3. Piggery manure and effluent flow diagram (Tucker, 2015)

3.2 Conventional Piggeries

Conventional piggeries accommodate pigs within sheds with partly or fully slatted flooring, to allow for the collection of by-products in channels or pits under the flooring. Large amounts of water are required to regularly flush effluent from the under-floor channels or pits, making the primary by-product from conventional piggeries a liquid effluent stream.

Most Australian piggeries use ponds to treat the liquid component before the effluent is irrigated or evaporated. Some piggeries also use separation systems to remove a portion of the solids before treatment in anaerobic ponds. These separation systems can generally be classified as either mechanical (e.g. screens, screw presses etc.) or solids settling (e.g. sedimentation basins, evaporation pond systems - SEPS). Some smaller piggery operations capture the effluent in a sump and then irrigate it directly (Tucker, 2015). An APL production system survey found that 83% of Australian pork producers used anaerobic ponds to treat piggery effluent (Wiedemann et al., 2014a). As Figure 4 shows, the by-products from conventional piggeries include separated solids, sludge and effluent.

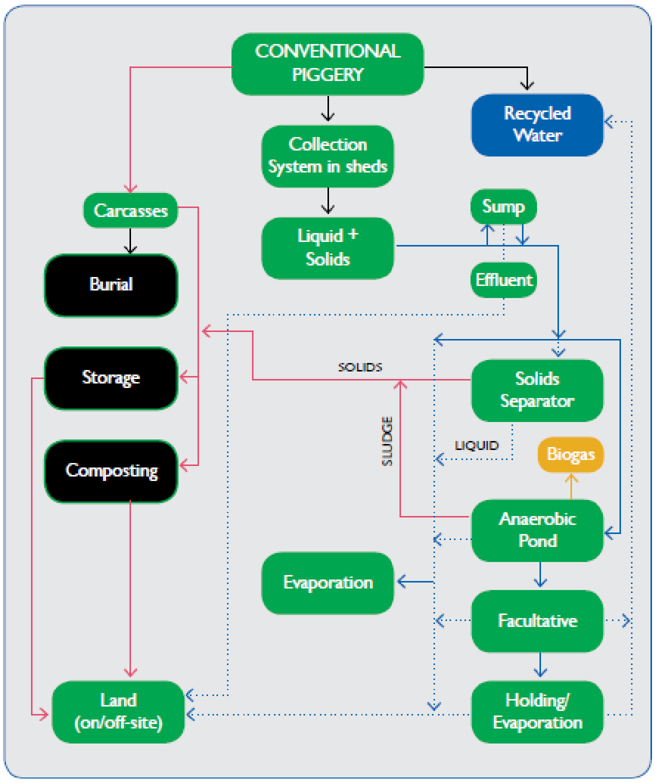

Figure 4. By-product management options- conventional piggeries (Tucker, 2015)

Wiedemann et al. (2016a) showed that GHG emissions from conventional Australian pork production are dominated by methane production from anaerobic ponds (62-64% of total emissions). Case studies of an Australian conventional piggery of approximately 6000 pig grow-out units with anaerobic ponds showed total GHG of 5,706 tons of CO_2 per year (5.32 kg CO_{2-e}/kg HSCW) (Kruger, 2015).

3.3 Deep Litter Piggeries

Deep litter piggeries house pigs in enclosed structures with pens bedded with straw, sawdust, rice hulls or similar absorbent bedding material. The bedding material absorbs the faeces and urine, with the resulting by-product being present in a solid form, eliminating the need to use water for cleaning. Bedding is topped up as needed to ensure the system remains relatively dry, without the generation of an effluent stream. Used bedding is usually replaced when the batch of pigs is removed, or on a regular basis. As Figure 5 shows, the major by-product of this system is spent bedding.

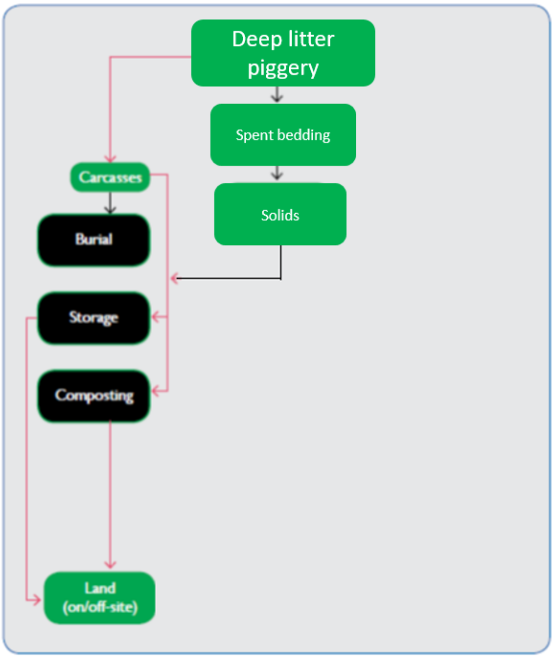

Figure 5. By-product management options- deep litter piggeries (adapted from Tucker, 2015)

The deep litter housing system reduces GHG emissions by handling manure in a solid aerobic environment (Wiedemann et al., 2016a, Phillips et al., 2016), which acts as a mitigation strategy when this replaces a conventional effluent management system. Wiedemann et al. (2016a) found that deep litter piggeries generated 33-40% lower GHG emissions than conventional piggery systems utilising long HRT effluent treatment. Figure 6 shows the flow of manure management emissions for deep litter piggeries.

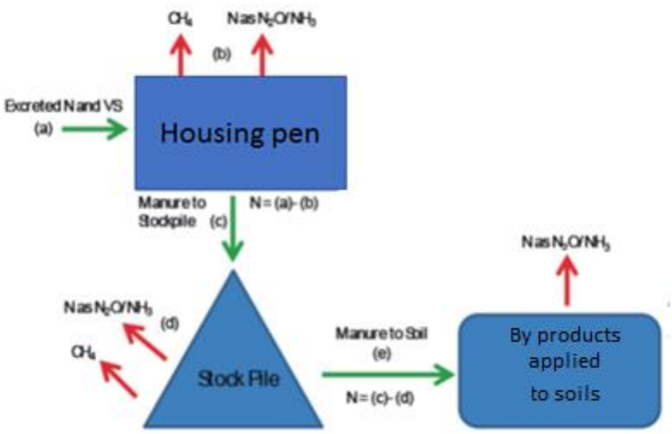

Figure 6. Mass flow method of estimating manure management emissions – deep litter piggeries (adapted from NIR Vol 1 report Commonwealth of Australia, 2016)

3.4 GHG Mitigation Options

Effluent treatment in uncovered anaerobic ponds is the largest emission source from Australian piggeries and offers the best target for GHG mitigation. The use of covered anaerobic ponds or anaerobic biodigesters to capture biogas and methane has been widely adopted to reduce emissions in the pig industry (Murphy et al., 2012) and mitigation was estimated to be 55% of piggery emissions by Wiedemann et al. (2016a).

Alternative GHG mitigation options for effluent generated at conventional piggeries could include solids separation or short hydraulic retention time (HRT) systems and pH modification. These systems could treat some or all or the VS in the effluent stream. Further GHG mitigations options could include the conversion of conventional piggeries to alternative housing systems (e.g. deep litter), that have lower GHG manure emissions. These alternative GHG mitigation options are classed as "avoided" techniques and are covered in more detail in Section 5.1. Additionally, there is the potential for individual farms to use multiple abatement technologies to increase the GHG mitigation efficiency and thus ACCU's.

4 Current Approved Methods

To understand the context for developing new ERF methods or introducing new mitigation techniques into existing methods, this section reviews the existing methods relevant to the pig industry specifically, and to manure or waste water treatment more generally.

Under Part 3 of the *Carbon Credits (Carbon Farming Initiative - CFI) Act 2011* eligible emissions reduction activities are undertaken as offsets projects and must be covered by, and undertaken in accordance with, a method determination. The purpose of a method determination is to establish standard industry-wide procedures for estimating emission abatement from eligible projects to ensure validity of emission reductions. Additionally, a method determination stipulates rules for monitoring, record keeping and reporting to ensure compliance with governmental regulations.

A method determination contains:

- a description of the activity,
- requirements for operation of eligible projects,
- rules for carrying out the activity,
- instructions for determining project baselines (abatement must be measured relative to a baseline that reflects what would occur in the absence of the CFI project),
- procedures for estimating abatement because of the project, and
- data collection, monitoring, reporting and record-keeping requirements.

The two methods developed and approved for use under the ERF cover the capture and combustion of methane generated from piggery by-products are:

1. *Carbon Farming (Destruction of Methane Generated from Manure in Piggeries 1.1) Methodology Determination 2013, and*
2. *Carbon Credits (Carbon Farming Initiative) (Destruction of Methane from Piggeries Using Engineered Biodigesters) Methodology Determination 2013; including the new Variation.*

Another approved method that specifically covers the capture and combustion of methane generated from conventional wastewater treatment is titled "*Carbon Credits (Carbon Farming Initiative - Domestic, Commercial and Industrial Wastewater) Methodology Determination 2015*".

A brief description of the two-approved animal wastewater treatment methods and the approved wastewater treatment method are provided below.

4.1 Carbon Farming (Destruction of Methane Generated from Manure in Piggeries 1.1) Methodology Determination 2013

For a project to participate under this method it must be carried out at a piggery and involve the installation of covered pond to capture biogas containing methane. This collected methane must then be combusted to convert it to carbon dioxide. To calculate the amount of methane destructed, the amount of biogas sent to the combustion device must be measured and multiplied by a methane destruction efficiency and a methane content of the biogas.

The net abatement amount of CO_2-e for a project is the quantity of methane emissions avoided as a consequence of the project (collected and combusted methane), minus GHG emissions from the use of purchased (grid) electricity and fuel used to operate the gas capture and combustion equipment. The net abatement claimable must not only subtract the fuel and electricity used to operate the gas capture system, but also subtract N_2O emissions emitted from the combustion device (e.g. flare, internal combustion engine, boiler).

The abatement is capped at a baseline that is required to be calculated. The baseline for a project is the methane that would have been generated and released in the absence of the covered pond. The project baseline must be calculated based on the amount of VS in the piggery project effluent stream which is deposited into each pond included in the project. The PIGBAL model is required to calculate the VS quantity in the piggery by-product stream.

Any flaring system used in the project must use a type of flare that is designed to maintain continuous destruction of methane; and include a system that detects and records when operation of the flare fails for periods exceeding 20 minutes.

Some important calculations and default values in the method include:

- Destruction of methane calculated from the measured biogas and multiplied by a destruction efficiency of 0.98, and
- Measured methane calculated from measured methane content of biogas or a default methane concentration of 0.7.

A covered pond system used as part of an approved project must have a minimum depth of 2 m and comply with the best practice principles for the design of effluent treatment ponds as set out in the *National Environmental Guidelines for Piggeries 2010 (Tucker, 2015)*. Only effluent from the operation of the project piggery can be used in the covered pond and no additional wastes are allowed.

Table 3 summarises the gases accounted for in the abatement calculations for in the *Destruction of Methane Generated from Manure in Piggeries 1.1) Methodology Determination 2013.*

This approved method must be incorporated into the new *Animal Effluent Management Method*.

Table 3. Gases accounted for in the abatement calculations - Destruction of Methane Generated from Manure in Piggeries 1.1) Methodology Determination 2013

	Source	**Greenhouse gas/carbon pools**
Baseline	Anaerobically treated by-products in project pond	Methane (CH_4)
Project Activity	Electricity from the grid and fuel used for gas capture and combustion	Carbon dioxide (CO_2)
		Methane (CH_4)
		Nitrous oxide (N_2O)
	Gas capture and combustion via internal combustion engine	Methane (CH_4)
		Nitrous oxide (N_2O)
	Gas capture and combustion via gas boiler used to heat water or generate steam	Methane (CH_4)
		Nitrous oxide (N_2O)
	Gas capture and combustion via flaring	Methane (CH_4)
		Nitrous oxide (N_2O)

4.2 Carbon Credits (Carbon Farming Initiative) (Destruction of Methane from Piggeries Using Engineered Biodigesters) Methodology Determination 2013; Including the New Variation

As with the *Destruction of Methane Generated from Manure in Piggeries Method*, projects carried out under this method must be at a piggery and involve the installation of equipment to prevent the emission of biogas, collect biogas and combust the methane component of the biogas to convert it to CO_2. The difference being that it must use one or more engineered biodigesters to capture the biogas.

The definition of an **engineered biodigester** under the method is: *a closed unit in which the biological treatment of biomass or other organic matter occurs through anaerobic digestion. This includes, but is not limited to, high rate anaerobic ponds, plug-flow reactors, continuously stirred tank reactors, fixed film digesters, and up-flow anaerobic sludge blanket digesters*.

Unlike the approved method for covered ponds, the piggery biodigester method allows for piggery manure generated at other sites, as well as additional wastes, to be included in the anaerobic digestion process. These additional wastes are classified as either eligible or ineligible. The method provides a list of eligible and ineligible wastes. For an additional waste to be classified as ERF eligible additional waste it would need to have been treated in an anaerobic pond if it was not accepted by the project proponent; and the volume of methane released from that waste:

(i) will not exceed 50% of the total CH_4 released from the engineered biodigester,

(ii) will not contain more than 20% CH_4 from highly variable B_o substrates, and

(iii) will not contain more than 20% CH_4 from a single substrate that is a highly variable B_o substrate.

The measured CH_4 sent to the combustion devices and amount of abatement is capped at the theoretical volume of CH_4 from piggery and ERF eligible waste streams, and Australian Carbon Credit Units will not be issued for the destruction of methane from ERF ineligible waste.

As with the covered pond method, the baseline emissions must also be calculated from the VS entering the system. For piggery by-products, VS is estimated using the PIGBAL model. For ERF eligible and ineligible additional waste, VS must be measured according to a described protocol. The volume of CH_4 from standard project (piggery by-products) and ERF eligible additional waste must be added together to determine the total amount of CH_4 generated that can be claimed as abatement. The volume of CH_4 from ERF ineligible additional waste must be subtracted from the total volume of CH_4 combusted from all waste in the project to determine the abatement.

Project proponents that add additional wastes to the digester need to account for not only the project emissions from the use of fuel and grid electricity to operate the biogas capture system and the NO_2 emissions from the combustion device, but other project GHG emissions that occur from the addition of the any additional piggery by-products, ERF eligible waste and ERF ineligible wastes. These include:

- emissions caused by the transport of waste to the project site,
- fugitive emissions of ERF ineligible waste from venting events and incomplete combustion,
- emissions of CH_4 from the uncontrolled anaerobic treatment of ERF ineligible additional waste, and
- emissions from the post-engineered biodigester treatment and/or disposal of ERF ineligible additional waste, including landfill, anaerobic ponds or aerobic treatment.

Table 4 summarises the gases accounted for in the abatement calculations for in the *Destruction of Methane from Piggeries Using Engineered Biodigesters) Methodology Determination 2013*.

This approved method must be incorporated into the new *Animal Effluent Management Method*.

Table 4. Gases accounted for in the abatement calculations - Destruction of Methane from Piggeries Using Engineered Biodigesters

	Source	GHG/carbon pools
Baseline	Greenhouse gas emissions from piggery manure and ERF eligible additional waste treated in an anaerobic pond	Methane (CH_4)
Project Activity	Electricity generation —gas capture and combustion via internal combustion engine	Methane (CH4)
		Nitrous oxide (N2O)
	Electricity from the grid and fuel used for pre-treatment, gas capture and combustion and post-treatment	Carbon dioxide (CO_2)
		Methane (CH4)
		Nitrous oxide (N2O)
	Gas capture and combustion via gas boiler used to heat water or generate steam	Methane (CH4)
		Nitrous oxide (N2O)
	Gas capture and combustion via flaring	Methane (CH4)
		Nitrous oxide (N2O)
	Engineered biodigester fugitive emissions	Methane (CH4)
	Effluent from the engineered biodigester; open storage of liquid effluent component during post treatment	Methane (CH4)
	Aerobic post treatment of digestate	Methane (CH4)
		Nitrous oxide (N2O)

Note: This should also include transport emissions and emissions from the uncontrolled anaerobic breakdown of ineligible waste (CH_4). The post-treatment emissions should also include anaerobic emissions from post-treatment ponds (CH_4 only) and landfill emissions (CH_4 only).

4.3 Carbon Credits (Carbon Farming Initiative) (Domestic, Commercial and Industrial Wastewater) Methodology Determination 2015

It has been proposed by DEE that this approved method be used as the basis for the new Animal Effluent Method, hence a brief summary of the method used to calculate GHG abatement is included here.

For a project to participate under this method it must be replacing deep open anaerobic pond (is a pond with a depth of more than 2 metres, in which biological treatment occurs through anaerobic digestion and resulting methane emissions are not captured) that has been treating domestic or commercial wastewater or industrial wastewater and involve the installation of equipment to replace deep open anaerobic ponds to capture the gas using an anaerobic digester and combust the CH_4 component in the gas to convert it to CO_2. Under this method an anaerobic digester means: *a system that either a covered lagoon [pond] or an engineered biodigester and includes one or more closed units designed to promote anaerobic digestion and a biogas collection system*. It also includes the equipment associated with the transfer of biogas to a combustion device.

Under this method the definition of a covered pond means: *a lagoon [pond] that is an existing anaerobic lagoon (the uncovered lagoon) that is covered to create a closed unit; and does not contain any heating or stirring features that were not present in the uncovered lagoon*. The definition of an engineered biodigester means: *a purpose built closed vessel that is for the biological treatment of organic matter through anaerobic digestion, and that has heating and stirring features and is not a covered lagoon [pond]*.

This method is similar to the piggery biodigester method in that it allows for the additional wastes to enter the project system, and these are classified as eligible and ineligible. The net abatement amount for the project is the quantity of methane emissions avoided because of the project, minus project emissions that result from operating the project, including emissions from the ineligible waste.

The baseline for an eligible wastewater project is the emissions that would have been generated and released from each deep open anaerobic pond included in the project in the absence of the abatement activity. A key difference with this method compared to the two piggery effluent methods is the calculation of baseline emissions. The project proponent may choose to work out baseline emissions using two methods. Method 1 calculates baseline emissions using sampling (Chemical Oxygen Demand measurements - COD) from the operation of a deep open anaerobic pond. Method 2 calculates the baseline emissions using the amount of CH_4 sent to a combustion device. This key difference means that a waste estimation model is not used to calculate the baseline and emissions are not capped based on a theoretical estimation but are calculated from the amount of CH_4 captured and destroyed from eligible waste.

Whichever method is used for working out baseline emissions for the first reporting period must then be used for working out baseline emissions for subsequent reporting periods. The amount of CH_4 generated from additional waste (eligible and ineligible) is calculated from sampling and measuring VS content in the waste and the relevant CH_4 producing capacity. When calculating the baseline emissions, a factor of 0.75 is used if the anaerobic digester is an engineered digester and 1.0 if the anaerobic digester is a covered pond. This accounts for the increased methane generation from an engineered digester, compared to the deep open anaerobic pond that the project digester is replacing.

Another key difference with this method is that that the CH_4 sent to the combustion device can be back-calculated from the amount of electricity generated if the combustion device is an internal combustion engine and biogas volumes do not need to be measured. Due to the high uncertainty of historical measurements, a conservative uncertainty factor of 0.89 is applied before converting to baseline emissions.

Table 5. Gases accounted for in the abatement calculations - Carbon Farming Initiative - Domestic, Commercial and Industrial Wastewater

	Source	**Greenhouse gas/carbon pools**
Baseline	Treatment of eligible wastewater for the project in a deep open anaerobic pond	Methane (CH_4)
Project Activity	Fuel consumption	Carbon dioxide (CO_2)
		Methane (CH_4)
		Nitrous oxide (N_2O)
	Electricity consumption	Carbon dioxide (CO_2)
		Methane (CH_4)
		Nitrous oxide (N_2O)
	Emissions from anaerobic digester leakage or venting events	Methane (CH_4)
	Emissions from the combustion of biogas	Methane (CH_4)
		Nitrous oxide (N_2O)
	Emissions from the end management of digestate	Methane (CH_4)
		Nitrous oxide (N_2O)

4.4 Comparison of Methods

All three methods define the net GHG abatement amount as the quantity of CH_4 emissions abatement generated as a consequence of the project, minus emissions from project activities. These are classed as CH_4 destruction methodologies. The two piggery method determinations (*The Piggeries Using Engineered Biodigesters and Destruction of Methane Generated from Manure in Piggeries 1.1*) are quite similar and use model predictions of VS to determine baseline methane mitigation potential. On the other hand, *The Domestic, Commercial and Industrial Wastewater Methodology Determination* uses COD measurements or back-calculation from energy generation to estimate emission abatements, without comparison to a modelled baseline. The back-calculation from energy generation to estimate emission abatements provides a far simpler approach to determining baseline emissions.

The use of direct measurement is likely to be more accurate than model predictions, provided the measurement method provides a high level of certainty. Emission predictions using modelling have been shown to underestimate emissions (Baldé et al., 2016, McGahan et al., 2010).

The *Domestic, Commercial and Industrial Wastewater Methodology Determination* and the *Piggeries Using Engineered Biodigesters Methodology Determination* allow the incorporation of additional waste into the project. These methods rely on measurement to determine the VS input from additional waste, with CH_4 production calculated from either measured or tabulated biological CH_4 potential rates. Table 6 provides a comparison of the emission sources and project boundaries accounted for in the four currently approved methods relevant to the capture and destruction of CH_4. Table 7 shows the comparison of baseline, organic matter production estimates (VS or COD), B_o and MCF techniques between the four methods.

Of these methods, the *Domestic, Commercial and Industrial Wastewater Methodology Determination* has the greater scope to be easily adapted to multiple waste streams. It also has a simpler method to determine baseline emissions and abatement.

Table 6. Comparison of emission sources project boundaries accounted for in abatement calculations for all four Methods

	Source and GHG	Methodology Determination		
		1	2	3
Baseline	GHG emissions from effluent in project ponds	+	+	+
Project activity	Fuel consumption	+	+	+
	Electricity consumption	+	+	+
	Emissions from leakage or venting events	+	-	+
	Emissions from the combustion	+	+	+
	Emissions from the end management of digestate	+	-	+
Project scope	Additional wastes	+	-	+
	Emission destruction	+	+	+
	Emission avoidance	-	-	-

1- Carbon Credits (Carbon Farming Initiative) (Destruction of Methane from Piggeries Using Engineered Biodigesters) Methodology Determination 2013; including the new Variation.
2- Carbon Farming (Destruction of Methane Generated from Manure in Piggeries 1.1) Methodology Determination 2013
3- Carbon Credits (Carbon Farming Initiative - Domestic, Commercial and Industrial Wastewater) Methodology Determination 2015

Table 7. Comparison of Baseline, organic matter (VS or COD), B_o and MCF between Methodology Determinations

	Baseline	VS	Bo	MCF
Carbon Credits (Carbon Farming Initiative) (Destruction of Methane from Piggeries Using Engineered Biodigesters) Methodology Determination 2013; Including the new Variation.	Standard	PigBal	0.45	Refer to NIR (Commonwealth of Australia, 2016) Ranges from 0.7 – 0.77 (State specific)
	Eligible additional waste	PigBal + Method 1	From Schedule 1 or measured in accordance section 5.5.	Refer to NIR (Commonwealth of Australia, 2016) Ranges from 0.7 – 0.77 (State specific)
	Ineligible additional waste	PigBal +Method 2	From Schedule 2 or measured in accordance with section 5.5.	Refer to NIR (Commonwealth of Australia, 2016) Ranges from 0.7 – 0.77 (State specific)
Carbon Farming (Destruction of Methane Generated from Manure in Piggeries 1.1) Methodology Determination 2013.	PigBal	PigBal	0.45	0.9
Carbon Credits (Carbon Farming Initiative - Domestic, Commercial and Industrial Wastewater) Methodology Determination 2015.	COD	n/a	n/a	0.8 For deep anaerobic pond set out in Part 5.3 of the NGER (Measurement) Determination)
	Energy production back calculation	n/a	n/a	0.8 For deep anaerobic pond set out in Part 5.3 of the NGER (Measurement) Determination)

5 Potential Technologies

This chapter covers the potential for new methane avoidance techniques that could be included in a new method.

5.1 Avoided Emission Techniques

Avoided emission techniques were assessed by reviewing the recently updated National Inventory Report (NIR) (Commonwealth of Australia, 2016) to identify feasible alternative manure management systems that produce less emissions than anaerobic ponds. Additionally, the IPCC (Dong et al., 2006) and recent Australian reviews by Murphy et al. (2012), Wiedemann et al. (2014a) and Wiedemann et al. (2016b) were considered, together with research from the National Agricultural Manure Management Program (NAMMP). These extensive reviews provide the basis for the following section. From this previous work, the short HRT technique is a known and advanced option. Additionally, solid separation, pH modification and alternative housing were considered for other avoided emission techniques to be considered. It should be noted that these techniques would require emissions abatement to be estimated from models. Models could be developed by modifying the existing manure estimation models such as PigBal. In contrast, the destruction methods can calculate abatement from the back-calculation of energy generated or measured biogas production.

5.1.1 Short-HRT

Background

The Short-Hydraulic Retention Time (HRT) system operates as an avoided emission technique, by minimising 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 short periods (< 30 days) before utilisation to avoid CH_4 generation.

Short-HRT systems can be defined as: *a manure collection and storage system below a slatted floor in an enclosed animal confinement facility OR a tank/sump, 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 with effluent storage of < 30 days are common practice in European and North American piggery and dairy industries, where manure is often stored in pits beneath the shed flooring before land application (Petersen et al., 2016). In Australia, short-HRT systems are not common practice in the pig industry.

Generalised Abatement Approach and Feasibility

This approach works on the principle of replacing the anaerobic treatment system with a predominantly aerobic environment, thus reducing manure CH_4 emissions.

Australian research conducted and published by McGahan et al. (2016), reported results from an experiment that replaced the conventional effluent pond system with a short HRT system at a piggery, to examine emission mitigation potential. The study determined and compared GHG and NH_3 emissions from each system. The short-HRT system was conducted 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 inhibit the production of GHG. Emissions were measured for 30 days during two seasons, winter and summer, using OP-FTIR spectroscopy. Measured emissions were related to volatile solids (VS) and nitrogen (N) 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.

Short-HRT system could easily be applied to piggeries and was found to be cost effective in a benefit cost analysis study done by Wiedemann et al. (2014a) for a medium sized piggery.

Abatement Potential and Supporting Evidence

On the basis of a conservative analysis of CH_4 emissions relative to the inflow of VS and NH_3 and N_2O emissions as a fraction of the excreted N, GHG emissions were found to be 79% lower from the short-HRT system (refer to Table 8 and Table 9).

Table 8. GHG emissions from a conventional effluent pond compared to a short-HRT system (McGahan et al., 2016) (g/AU.day)

	Conventional Pond		Short-HRT	
	Winter	Summer	Winter	Summer
CH4	452	789	0.0107	4.108
NH3	73	313	negligible	0.0298

Table 9. GHG 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%
NH3-N EF		10%	0.02%	0.3%

Both the Short-HRT implemented by McGahan et al. (2016) and European/ North American pit/slurry systems can avoid GHG emission via short retention time storage. In addition to the McGahan study, the following studies have shown a reduction in GHG emissions due to short retention time manure storage and the resulting avoidance of anaerobic digestion: Dong (2006), Massé et al. (2008) and Møller et al., (2004).

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, and abatement provided relative to the volume of effluent diverted to this low emission technique.

Requirements

There are several requirements for the implementation of a short-HRT system for emission abatement, including storage/retention time, type of processing, application of treated effluent and effluent climatic conditions. The maximum storage requirement is < 30 days and is based on the IPCC (Dong et al., 2006) guideline that is referred to in the National Greenhouse Gas Inventory (NGGI) (Commonwealth of Australia, 2016). The GHG emissions from pit storage below animal confinements from storage < 30 days ranged from 3-30% MCF, while storage over than 30 days ranged from 17-80% (refer to Figure 7) (Zeeman, 1994, IPCC, 2006, Møller et al., 2004).

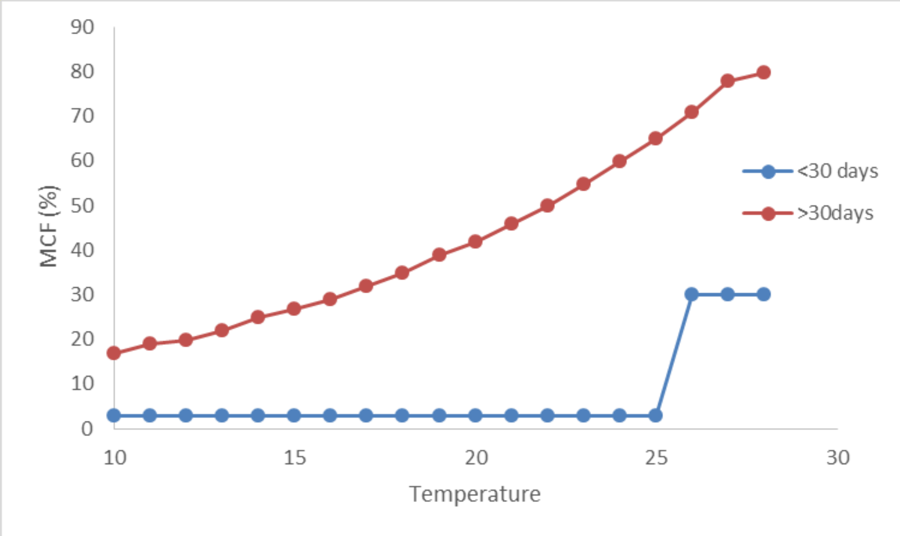

Figure 7. Emissions from pit storage below animal confinements from storage below 30 days and above 30days (adapted from IPCC, 2006)

Research by Møller et al. (2004) on CH_4 production 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 at storage times of < 30 days. Similarly, the IPCC determine that GHG emissions from manure storage < 30 days of pit storage below animal confinements at temperature below 25◦ C should apply a MCF of 3%, while temperatures above 25 ◦ C should apply a MCF of 30% (refer to Figure 7). This supports the findings of the McGahan et al. (2016) Australian study, conducted in both summer and winter, that found emissions were higher in summer (i.e. ambient temperatures over 25 ◦ C). Although, in the Australian study emissions were higher in summer, abatement potential was still high. The impact of temperature would therefore need to be considered if this technology was to be integrated into an ERF method, i.e. southern states.

GHG Emission Sources

Figure shows the possible GHG emissions sources from a short-HRT system.

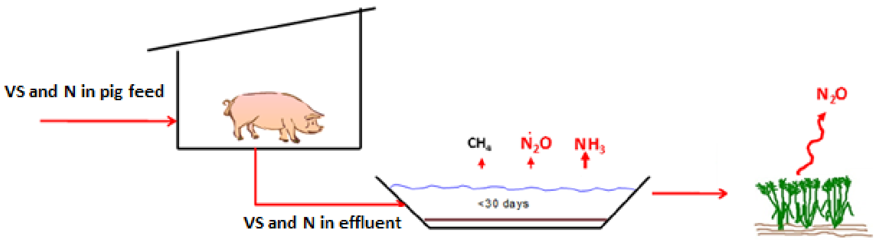

Figure 8. CH_4, N_2O and NH_3 emissions sources from a short-HRT system

Leakage

Leakage is the shifting of activities that generate emissions to areas not included in the measured area of an offsets project, thus resulting in smaller net GHG reductions. The CFI Act has offset integrity standards that require all methods to calculate and deduct leakage emissions from the calculated project abatement. Possible leakage from a short-HRT system would include residual emissions from the short HRT vessel and emissions from application of digestate to land. If solids are separated prior to land application, emissions from the storage and handling of solids will also need to be considered.

Boundaries

GHG emissions from the short-HRT system and end-use applications of digestate must be included in short-HRT project boundary (refer to Table 10). If this technique is applied in conjunction with other GHG avoidance technologies, such as solids separation, additional emissions from that process will also need to be taken into account.

Table 10. Generalised GHG assessment boundary for baseline and project activities (Short HRT)

	Source	Greenhouse gas/carbon pools
Baseline (Conventional anaerobic treatment)	Anaerobically treated waste in project ponds	Methane (CH_4), Ammonia (NH_3)
	Effluent (and solids if relevant) applied to land	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils	Ammonia (NH_3), Nitrous oxide (N_2O)
Project activity – Short HRT	Anaerobically treated waste in alternative manure management system	Methane (CH_4) Nitrous oxide (N_2O)
	Effluent (and solids if relevant) applied to land	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils	Ammonia (NH_3), Nitrous oxide (N_2O)

Considerations

There are several limiting factors that can impact on the abatement potential of a short-HRT system. The most significant of these is retention time. A retention time of more than 30 days increases the possibility of pH stabilisation, possibly resulting in the system becoming anaerobic and consequently generating CH_4. There is also the possibility of the residuals from treated batches seeding subsequent batches of effluent, encouraging more rapid development of anaerobic conditions conducive to methane production.

There are several operational information gaps about short-HRT systems that will need consideration. They are as follows:

- *Storage time of system:* <30-day storage time is based on general IPCC guidelines and aligns with the Australian research. However, it is unknown whether slightly longer storage times could be used without generating additional emissions,
- *Batch processing:* McGahan et al. (2016) conducted the experimental short-HRT in batches. It is unknown if this system could be run in longer batches or continuous processing without generating additional emissions under certain conditions,
- *Natural acidification of effluent:* This is one of the main mechanisms preventing GHG emissions. It is unknown how long acidification will occur in system and whether it will be affected by other management practices. If the natural effluent acidification (from the

acidogenesis stage) could be ensured and monitored, it may be possible to create a more flexible technique via monitoring of this indicator,

- *Use of recycled water for flushing*: This is common practice and the impact on emissions is unknown. It is possible recycled water may seed the system, resulting in a more rapid rise in anaerobic conditions and emissions,
- *Continuous flow systems:* These may act to seed the system allowing it to stabilise and begin generating emissions,
- *GHG emissions is correlated with ambient temperature*: According to the IPCC guidelines, a short-HRT system at temperatures over 26° C will have an MCF of 30%, or 10 times the emission rate of lower temperatures. McGahan et al. (2016) showed that the MCF for short-HRT system at temperatures over 26° C was 18% (Refer to Table 9). Further research into the mechanisms and supporting literature is required to determine how robust this relationship is, and what requirements must be put in place to ensure conservative estimates are used in a method, and
- *Emissions from irrigation associated with nitrogen (N_2O)*: These will need to be considered, as they may be higher than the baseline. Mass flow calculations combined with factors from the NIR (Commonwealth of Australia, 2016) should allow quantification of these emissions but further work is required to ensure these emission estimates are conservative.

5.1.2 Solid Separation

Background

The solid separation system operates as an avoided emission approach by removing VS from effluent system and managing it via an aerobic process, thus limiting the amount of CH_4 that can be produced. The GHG abatement potential is dependent on the system applied and its' solid removal efficacy for a specific waste stream. Removing solids from the effluent stream also offers improved MMS reliability and reduces sludge accumulation in effluent ponds. However, 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 CH_4 production. It could be used in conjunction with other treatment technologies, or as a standalone GHG abatement system.

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 solids separator.

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 each system depends on the flow rate of the manure, the shape and size distribution of the particles, and their chemical nature.

Generalised Abatement Approach and Feasibility
Although only a small percent of conventional piggeries use solid separation (~10%). The range of separation technologies currently available for piggery manure has been reviewed, and solids removal efficiency for screens and separators ranges from 10% to 30% (Tucker, 2015). Dissolved air flotation systems and tangential flow separators can achieve 50% to 70% efficiencies but have a high capital cost. A combined gravity settling basin and fan screw press system has been tested and achieved a solids removal efficiency of 24% for VS (Poad et al., 2010). 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 emissions by 58% and 22% respectively.

A solid separator system is quite feasible to apply to the piggeries as the technology is already well-researched and proven and could therefore be readily adopted if the incentives were sufficient. Furthermore, this approach could be used in conjunction with other GHG abatement systems to further increase the GHG abatement efficacy of projects.

Requirements
There are several requirements for using a solid separation system for emission abatement, including solids removal efficiency of the specific system and effluent and solid management after treatment. Post treatment effluent and solid must be managed to ensure the GHG emissions of the total system are reduced.

GHG Emission Sources

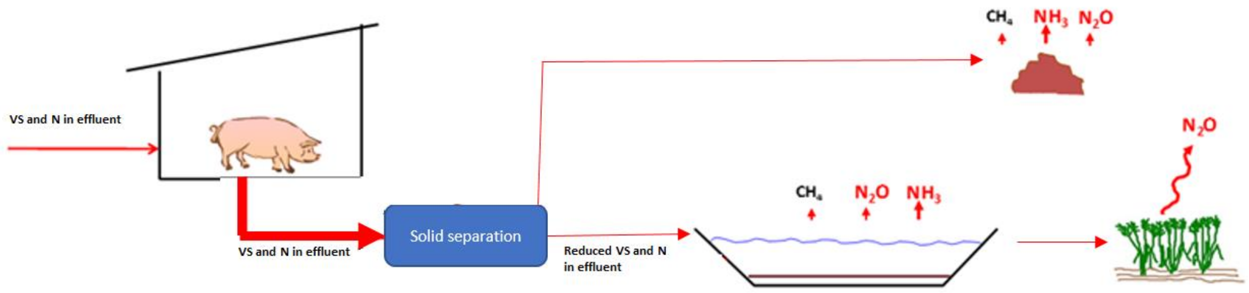

Figure 9. Possible project emissions from a solid separation system.

Leakage
Possible leakage from a solid separation system would include residual emissions from the storage and handling of solids and emissions from application of solids to land.

Boundaries
GHG emissions from the solid separation system and end-use applications of digestate must be included in the project boundary. If this solids separation technique is applied in conjunction with another technique, additional emissions from that process will also need to be considered.

Table 11. Generalised GHG assessment boundary for the baseline and project activities (solid separator)

	Source	Greenhouse gas / carbon pools
Baseline	Anaerobically treated by-product in project ponds.	Methane (CH_4), Ammonia (NH_3)
	Effluent and solids applied to land.	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils.	Ammonia (NH_3), Nitrous oxide (N_2O)
Project activity – solid separation	Solid manure stockpiles.	Methane (CH_4), Ammonia (NH_3), Nitrous oxide (N_2O)
	Effluent and solids applied to land.	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils.	Ammonia (NH_3), Nitrous oxide (N_2O)

Considerations

There are several operational information gaps about solid separation systems that will need consideration. They are as follows:

- The GHG emission abatement efficiency of different types of solid separation systems.
- Feasibility of implementation of a solid separator system (whether the GHG emission reduction justify the cost of implementation of system),
- Reactivity of effluent and solids removed: i.e. a solid separator may remove larger molecules that are not as reactive as smaller molecules left in effluent, thus leaving a higher proportion of reactive molecules in effluent. The effect of solid separation on the reactivity and resulting GHG production needs to be researched,
- There could be possible odour releases which could impact on other legislative/licencing requirements of industry producers,
- Hybrid systems: it is unknown the effect on GHG emission abatement when a solid separation system is used in conjunction with another GHG abatement system (e.g. short HRT), and
- Emissions from solids management will need to be considered as these may be higher than the baseline. Mass flow calculations combined with factors from the NIR (Commonwealth of Australia, 2015) should allow quantification of these emissions but further work is required to ensure these emission estimates are conservative.

5.1.3 pH Modification of Effluent

Background

Lowering the pH of stored effluent will reduce GHG emissions. This strategy has been utilised for decades (Stevens et al., 1992, Hilhorst et al., 2002, Husted et al., 1991, Safley et al., 1983, Al-Kanani et al., 1992) but was not widely implemented due to unresolved issues of safety (strong acid exposure) and acidic effluent post treatment requirements.

Generalised Abatement Approach and Feasibility
This 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 CH_4, N_2O and NH_3 are a function of effluent pH. According to Boopathy (1996), Besson et al. (1985), and Conrad & Schütz (1988) the optimal pH for CH_4 is 7. Research has found the CH_4 emission halved at pH 6.5 and pH 8.3, and NH_3 emissions are highest at pH > 9 and almost stop at pH < 7 (Groot Koerkamp and Klarenbeek, 1998).

The application of a pH modification system to piggeries is technically feasible. While gas abatement potential is high, the acidic pH of treated effluent severely limits the potential land application and reuse options. Additionally, this system could be used as a minor secondary treatment option with additional systems, such as the Short-HRT or solid separation being the primary treatment option. This would reduce the amount of effluent that is acidified and thus reduce the amount of treated acidic effluent applied to land.

Abatement Potential and Supporting Evidence
Hilhorst et al. (2002) observed effluent at pH 6 resulted in high emissions of N_2O, but emissions of CH_4 were eliminated. pH modification below a pH of 4.5 resulted in no emissions of any of the gases.

A number of 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%.

More recently, Andersen et al. (2014) showed that the addition of sulfuric acid 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 optimal N_2O emissions production at pH 6 and are almost zero emissions at pH < 5 or > 8. Acidifying the effluent to below pH 4.5 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.

Requirements
There are several requirements for the implementation of a pH modification system for emission abatement, including storage, pH range, type of processing and application of treated effluent. Acidifying the effluent to < pH 4.5 will achieve the maximum GHG emissions abatements. This may be possible using natural acidification processes that occur in short/batch effluent handling systems but would be more difficult and costly to apply if acid or base needed to be added to the system.

GHG Emission Sources

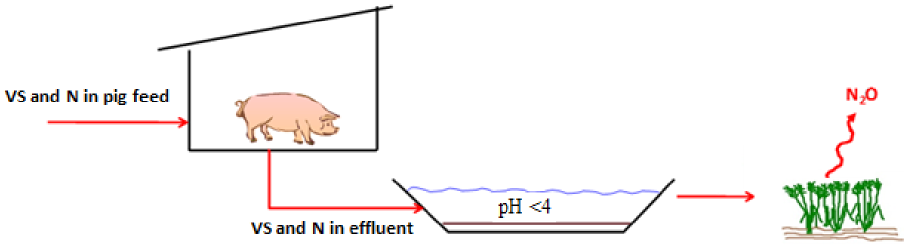

Figure 10. Possible project emissions from a pH modification system.

Leakage
Possible GHG leakage from a pH modification system would include the pH stabilisation and vessel becoming anaerobic and emissions from application of digestate to land. Leakage from anaerobic digestion can be controlled by: pH monitoring and artificial pH control.

Boundaries
GHG emissions from a pH modification system and end use of digestate must be included in the project boundary (refer to Table 12).

Table 12. Generalised GHG assessment boundary for the baseline and project activities (pH modification)

	Source	Greenhouse gas/carbon pools
Baseline Conventional piggery	Anaerobically treated by-product in project ponds	Methane (CH_4), Ammonia (NH_3)
	Effluent and solids applied to land	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils	Ammonia (NH_3), Nitrous oxide (N_2O)
Project activity – acidification	Anaerobically treated by-product in alternative manure management system	
	Solid manure stockpiles	Methane (CH_4), Ammonia (NH_3), Nitrous oxide (N_2O)
	Effluent and solids applied to land	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils	Ammonia (NH_3), Nitrous oxide (N_2O)

Considerations
There are several limiting factors that can impact on the abatement potential of pH modification systems. The most significant confounding factor is pH. Stabilisation of pH > 6 can cause the system to become anaerobic, producing significant GHG emissions. Additionally, because the slurry is not homogeneous the added acids or bases can cause unexpected emissions of gases (Sharpe et al., 2002). Another problem is the acidic pH of treated digestates can be hazardous to other farming activities, is corrosive and the high mineral content limits potential land applications and reuse options. Research has shown that pH modification can be applied to piggeries, however it has not been widely implemented due to confounding factors associated with treatment.

There are several operational information gaps about pH modification systems that will need consideration. They are as follows:

- *Artificial acid or base doses:* Dose required (and costs) for specific animal effluents in an Australian setting is unknown,
- *pH of system:* Effluent pH modification would need to be ensured and monitored.
- *Contact time:* The storage time of pH modification system for maximum GHG abatement is unknown,
- *Management of treated acidic effluent:* acidic pH of treated digestates severely limits the potential land application and reuse options. Also, the effects of pH modification on other management practices and equipment are unknown. This could be managed by allowing the natural process of pH modification to occur or by modifying pH before land application,
- *Hybrid systems:* It is unknown the effect on GHG emission abatement when a pH modification system is used in conjunction with another GHG abatement system,
- *Legal considerations:* There may be additional work place health and safety and management/licencing requirements if it is required to handle strong acids or bases, and
- *Emissions from irrigation associated with nitrogen (N_2O)*: These will need to be considered as these may be higher than the baseline. Mass flow calculations combined with factors from the NIR (Commonwealth of Australia, 2016) should allow quantification of these emissions but further work is required to ensure these emission estimates are conservative.

Alternative Housing to Avoid Effluent Treatment

Conversion of conventional piggeries with an anaerobic pond system to alternative housing systems may also mitigate emissions considerably. The conversion of system results in changes to the treatment of by-product from anaerobic to aerobic, thus avoiding the production of GHG from the use of anaerobic ponds.

5.1.4 Deep Litter Housing

Background

Deep litter systems house animals on litter (straw, sawdust, rice hulls or similar) in a shed with either a concrete base or a compacted clay floor. Sheds may be covered by a fabric roofed structure, a skillion-roofed shed or a converted conventional housing structure. Deep litter systems are best suited to stages where the animals move through in batches. The bedding is topped up as needed, and then replaced at the end of each batch. Bedding can be difficult to source during drought years and these systems require more management than conventional systems. Deep litter has been used widely in Europe for housing of cattle and pigs over winter. Research has shown that deep litter can be applied to piggeries for GHG emission reduction (Phillips et al., 2016).

Generalised Abatement Approach and Feasibility

The use of bedding eliminates the need to use water for removing manure, because it is both absorbed in and evaporated from the litter material and is then removed and replaced when the batch of animals is removed. Consequently, deep litter sheds do not require effluent ponds. Manure is thus contained in a solid, predominantly aerobic form that is not conducive to production of CH_4. Recent research has shown deep litter sheds resulted in about 66-80% lower emissions compared with housing in conventional flushed sheds (Phillips et al., 2016). Once deep litter is removed from the shed it is typically stockpiled or composted and then used as a replacement fertiliser by being spread on the paddock. Stockpiling and composting are predominantly aerobic manure treatment systems, limiting GHG emissions.

The application of a deep litter system is technically feasible in the pig industry, being a frequently used management practice in some regions.

Abatement Potential* and *Supporting Evidence

Deep litter results in predominantly aerobic manure treatment resulting in lower emission factors (EFs) for CH_4, but not nitrous oxide (N_2O), in comparison to uncovered anaerobic ponds (Dong et al., 2006). International research has reported modest decreases for emissions of N_2O, NH_3 and CH_4 from pigs housed on litter compared with conventional housing with anaerobic effluent treatment (Nicks et al., 2004, Philippe et al., 2010, Sharpe et al., 2002). However, Phillips et al. (2016) in an Australian study observed a 66% and 80% decrease in emissions from the manure excreted in litter-based housing with litter or without litter stockpiling respectively, compared with conventional housing with an uncovered anaerobic effluent-treatment pond (Refer to Table 13). This provides a sound basis for mitigation strategies that utilise litter-based housing as an alternative to conventional housing with uncovered anaerobic effluent-treatment ponds in Australia.

Table 13. GHG emissions from pigs housed on deep litter compared to conventional long HRT anaerobic pond (Phillips et al., 2016)

	Conventional long HRT Pond	Deep Litter	Deep Litter + Stockpile
Total GHG emissions (t CO_2-e/10,000 SPU/yr)	5,254	768	2,320
% Mitigation compared to Long HRT Pond		85%	56%

Requirements

The conversion of conventional piggeries with anaerobic pond systems to deep litter system would be required for emission abatement. Post treatment of solid must be managed to ensure GHG emission of total system are reduced.

GHG Emission Sources

To summarise, deep litter pig production systems have the following emission sources:

- Emissions from the litter surface within the shed,
- Emissions from stockpiles, and
- Emissions from land application areas.

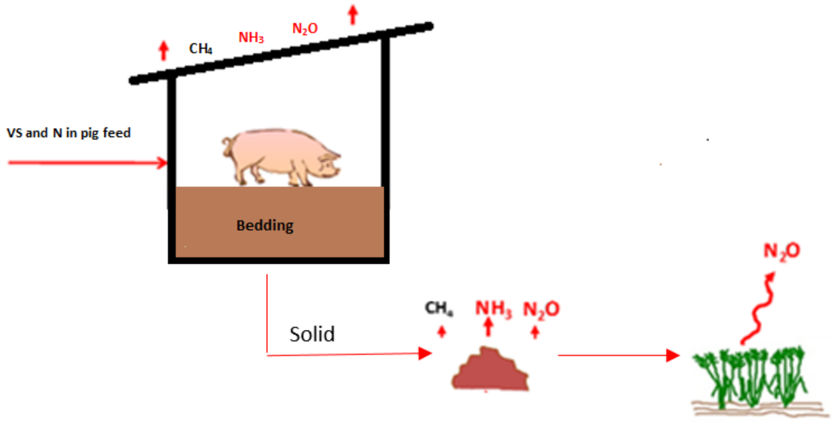

Figure 11. Possible project emissions from a deep litter system.

Leakage
Possible leakage from a deep litter system would include potential N emissions from the storage and handling of solids and emissions and from the application of solids to land.

Boundaries
GHG emissions from the deep litter system and end-use applications of solids must be included in project boundary.

Table 14. Generalised GHG assessment boundary for the baseline and project activities (deep Litter)

	Source	Greenhouse gas / carbon pools
Baseline	Emissions from the animal house	Ammonia (NH_3)
	Anaerobically treated by-product in project ponds	Methane (CH_4), Ammonia (NH_3)
	Effluent and solids applied to land	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils	Ammonia (NH_3), Nitrous oxide (N_2O)
Project activity – Deep Litter	Emissions from the animal house	Methane (CH_4), Ammonia (NH_3), Nitrous oxide (N_2O)
	Solid manure stockpiles	Methane (CH_4), Ammonia (NH_3), Nitrous oxide (N_2O)
	Effluent and solids applied to land	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils	Ammonia (NH_3), Nitrous oxide (N_2O)

Considerations

There are several considerations about deep litter systems that will need consideration. They are as follows:

- *N_2O production:* the balance between CH_4 and N_2O production. The production of N_2O would have to be quantified to ensure the benefits from CH_4 reduction are not outweighed by emissions from N_2O,
- *Litter supply*: a sustainable source of bedding is required. Drought can cause bedding material scarcity, increasing costs, and
- *Loss of production*: Deep litter systems can be difficult to manage, and lower production rates compared to conventional housing systems are typical under Australian conditions.

5.2 Summary

The potential new methane mitigation options are summarised in Table 15, with a qualitative assessment of the feasibility of using these practices and including them in an ERF method.

Table 15. Qualitative feasibility assessment of techniques and practices for avoidance of GHG

	Capital Cost	Mitigation Potential	Ease of meeting ERF requirements	Ease of applying commercially	Potential leakage	Commonly used in Australia #
Emission avoidance						
Short HRT	M	H	M	M	M	No
Solid separation	M	L - H	M	H	M	Yes
pH modification	M	H	M	L/M	L	No
Deep litter	H	H	L	L	M	Yes

* 1 High = ≥ 30 percent mitigating effect; Medium = 10 to 30 percent mitigating effect; Low = ≤ 10 percent mitigating effect.
# commonly = over 50%

Including these methods in an ERF method would require a different mode of operation; i.e. inclusion of emission avoidance technologies (Figure 12) in addition to emission destruction technologies, such as the existing methane destruction methods. This modification would require different baseline and emission calculations to encompass emissions abatement from both emission destruction and avoidance technologies. Abatement could be readily determined from modelling and measurement or a combination of these. This would require the measurement of organic matter flows (measured via VS or COD) or the use of current industry model (PigBal) and is similar to the current baseline checking method in the existing piggery methods.

The new method could function with the same general principle of:

Net abatement = Project abatement (Methane destroyed or avoided) – Project emissions

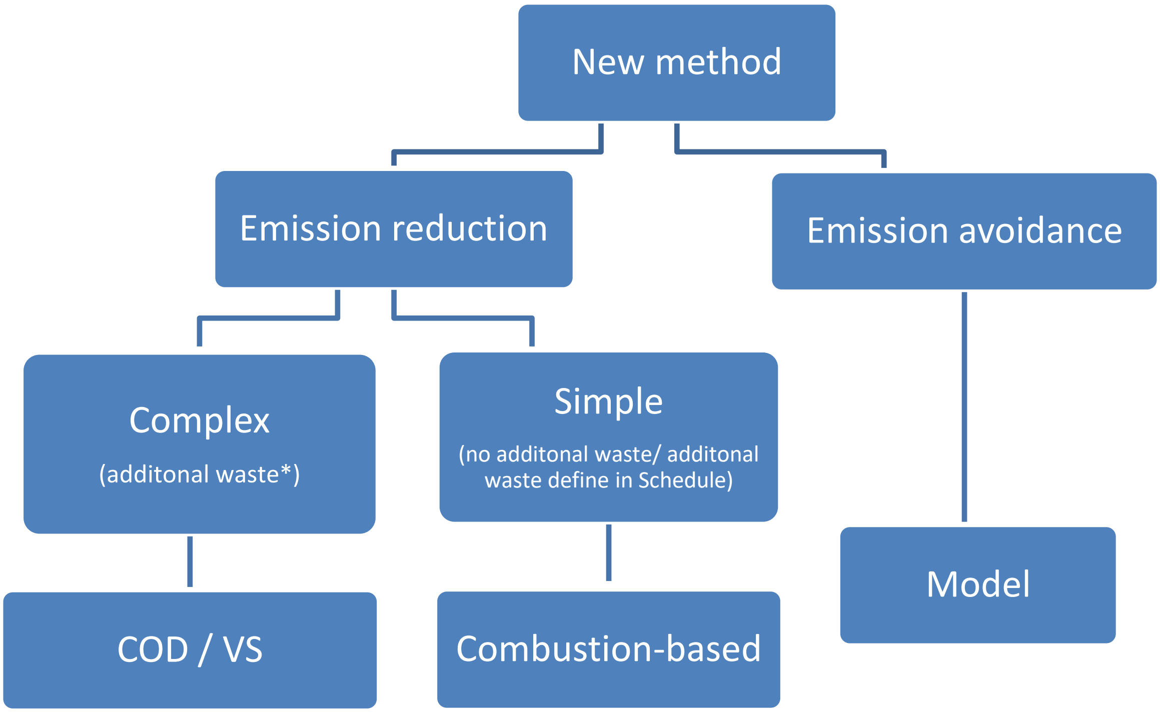

Figure 12. Proposed scope of method to include incorporation of emission avoidance technologies

** additional wastes not defined in the Schedules.*

5.3 Determining Project Abatement

For methane avoidance technologies, a variety of measurement and modelling would be required, depending on which technologies were included:

1. *Short HRT:*
   a. Prediction of VS and N production from modelling, combined with volume measurements of the quantity of effluent diverted to the approved technology, and
   b. Measurement of VS and N or COD concentrations and volume measurements of the quantity of effluent diverted to the approved technology.
2. *Solids separation:*
   a. Measurements of VS and N or COD concentrations of separated solids and mass of solids, and
   b. Conservative standard values of the removal efficiency of the solids separation system combined with measurements of VS concentrations.
3. *Alternate housing (deep litter):*
   a. Prediction of VS and N production from modelling.

The major challenges with determining methane avoidance from methods that don't capture and destroy methane are:

1. Being able to get accurate measurements of VS or COD concentrations of effluent due to its variability from day to day, variations in particle size and loss of VFA's during the testing process,
2. Measurements of the VS in solids (solids separation techniques) may not be representative of the VS in the whole by-product stream, because the more available (volatile) and easily digestible solids may remain in the liquid component of the waste stream following solids separation, and
3. Health and safety issues around the use of acidifying substances.

Some of the issues associated with measurement and estimation using modelling maybe overcome using conservative values.

5.4 Project Emissions

Project emissions could be determined by covering the same inclusive list that exists in the current wastewater method and the piggery digester methods. These include:

- emissions from fuel used in operation of the emission mitigation project,
- emissions from grid electricity used in operation of the emission mitigation project,
- emissions from storage, transport, handling or pre-treatment of effluent,
- emissions of nitrous oxide from the combustion of biogas,
- emissions from incomplete combustion of methane,
- methane emissions from minor venting are assumed to be two percent of the methane flow sent to combustion devices other than electrical generators, and
- post treatment management and application of (effluent and solid) digestate (including N_2O emissions from irrigation).

The numbers of factors would need to increase dependent on the number of additional waste avoidance technologies added.

6 Stakeholder Engagement / Industry Consultation

The following section outlines the consultation process undertaken as part of the project. Consultation was conducted in a series of meetings with DEE, industry members and other experts.

6.1 Consultation Process

As noted in the project objectives, the project aimed to assist in the development of an ERF method, including new technologies and techniques applicable for pig production. In addition to providing detailed review and technical information, a consultation process was initiated with the Federal DEE early in the project (meeting 1) to scope a potential ERF project and provide briefing materials. Following this meeting, the Federal DEE initiated an ERF method development project which also included consultation with industry and industry experts. Participation in these meetings, and relevant outcomes are summarised in the following sections.

Table 16. Summary of consultation process for implementation of new technologies in an ERF method

	Meeting 1	Meeting 2	Meeting 3	Meeting 4
Location	Federal DEE	Federal DEE	Federal DEE	University of Queensland, Brisbane
Date	18/10/2016	18/01/2017	15/06/2017	28/07/2017
Attendees	Ben Docker Richard Chisolm Stephen Wiedemann Janine Price	Ben Docker Ben Holt Stephen Wiedemann	Stephen Wiedemann Eugene McGahan others (see full list in Appendix 1).	Stephan Tait, Eugene McGahan, James Graham, Ben Holt, Stephen Wiedemann

6.2 Meeting 1

At this meeting, DEE Staff identified the potential to develop new or integrated methods for the pig industry. Specifically, it was noted that there would be advantages to revising existing methods, with the potential to integrate new aspects into these methods or a future simplified method.

It was emphasised by DEE that demonstrating the potential for total abatement (abatement potential x update potential across industry) was a key requirement for any new method.

One possibility raised by DEE staff was that two methods may be developed, namely: i) one method targeting avoided manure emissions using multiple methods (covered ponds, digesters, short HRT, alternative housing and incorporating different managements such as avoided solids storage or covered storage), and ii) one method targeting herd management options.

It was noted that the both methods could utilise the modelling tool "PigBal", developed by Skerman.

The Department noted that a review was currently underway of the 'Engineered digester' method and that findings from this review would be relevant to future work, particularly if a revised method was proposed that covered the scope of the current 'Engineered digester' method.

The Department noted that one approach could be for industry to provide technical expertise to develop the requirements of the method, while the drafting, operational rules and legal aspects were led by the Department. The Department was keen to ensure that there is a mechanism to enable wide range of views and input into the development of any new method (e.g. through a technical working group and/or user reference group). To advance the assessment of the proposed mitigations, DEE noted that it would be beneficial if the main technical requirements were outlined in a discussion paper.

It was resolved at the meeting that:

1. The Department would provide further feedback to APL and Integrity Ag Services following consideration of the proposed mitigations and feedback from the Engineered Digesters review,
2. Integrity Ag Services would provide a draft discussion paper outlining the mitigation options, proposed methods, and a brief overview of the technical requirements to model abatement (Discussion paper: Development of Emission Reduction Fund Methods for the Pig Industry, previously submitted to the APL on February 27th, 2017), and
3. Both parties agreed to work towards a definite proposal for new methods by late February 2017. This timing coincides with the APL environmental technical committee meeting for 2017, at which a proposal could be presented and endorsed by industry.

6.3 Meeting 2

Following Meeting 1 a draft discussion paper was circulated to APL for review. On the 29th of November 2016, it was sent to DEE for review (this material is largely summarised in the preceding chapters of this final report). Meeting 2 was conducted on the 18th of January 2017.

It was resolved at the meeting:

1. *To confirm the outcomes regarding piggery mitigations:*
    a. The Department intends to incorporate short HRT mitigation into the proposed effluent method. Assistance is requested in providing factors, calculation methods, design and operation (e.g. measurement) requirements, to cover this sufficiently in the revised method over the next few months, so that the method can be made within about 6 months,
    b. Inclusion of the deep litter mitigation would require further assurances regarding the cost-benefit, likely uptake and the complexity that might be introduced by this aspect if included in the animal slurry method. The Department will provide a timeline for when such complexities would need to be resolved for this mitigation to be considered in the current revision. Alternatively, it may be possible to include deep litter in either future revisions or in a separate alternative by-product management method, and
    c. The herd management method will be considered at a later date, after the current method revisions have been completed, pending findings of the Government review of climate change policies and the operation of the ERF.

2. *Comments* were provided on the draft method, supplied by DEE, and are summarised as follows:
    a. Allowance for inclusion of non-eligible wastes is a strength,
    b. Inclusion of the short HRT and potentially deep litter is a strength,
    c. The method requires that the baseline system to include a deep anaerobic pond for manure treatment and this excludes some sectors, for example the poultry sector, and this should be considered when reviewing the scope of the method,
    d. There is some confusion regarding the use of COD or VS as the measure of by-product stream GHG potential. VS may be a better measure (as it is actual rather than theoretical), but at a minimum it needs to be clarified which method is to be used throughout the document,

e. It needs to be clarified whether a historical baseline is used with respect to total emissions, or emission intensity? Could a relative baseline be established to allow for expansion/contraction?,
f. An alternative requires exploration, for a way to address the requirements for a pond in a specified year (2014), as this may be problematic for new piggeries,
g. Review is needed of some specific factors that don't appear to be referenced and may vary between initial by-product sources and digester efficiency rates, and
h. Further consideration is also warranted regarding the requirements for measurement and where these can be removed to reduce sampling costs and uncertainty. Sampling uncertainty is high and therefore sampling is not preferred.

6.4 Meeting 3

The technical requirements of each of the techniques identified as a potential technology in the above review were presented in this consultation. The practical and economic feasibility of the techniques to be applied to Australian pig industry was discussed with workshop attendees. This workshop was held as part of the requirements of Stage 2 of the project: "Technical requirements complete - Progress report submitted to APL.". The outcome of this workshop has already been presented to APL in the Milestone 3 Report, however outcomes are repeated here for clarity.

6.5 Workshop Outcome

The following tables summarise the key outcomes of the workshop on the practical and economic feasibility of short HRT, solid separation, effluent pH modification and deep litter housing in an Australian piggery context. Additionally, the consultation covered outdoor housing, but it was subsequently excluded during the consultation process. A summary of the technical evaluation and workshop summary of the outdoor housing system is presented in Appendix 2.

Table 17. Review and workshop outcomes: assessment of technical, practical and economic feasibility for the Short HRT system

Item	Decision	Notes and considerations
Review summary		
Technical feasibility (scientific evidence, compliance with method requirements)	Yes	A number of requirements have been identified that need to be specified in the method to ensure abatement. With these requirements met, the technique is considered technically feasible taking into account the ERF abatement integrity requirements. Specific points are outlined below.
Additional	Yes	Traditional uncovered anaerobic pond to a Short HRT
Real and Permanent	Yes	Offsets represent actual reductions in GHG emissions and are non-reversible and will not cause an increase in GHG emissions in other sectors.
Measurable, Verifiable	Yes	Emission reductions are quantifiable. Abatement would be calculated by the volume of and VS concentration of effluent diverted to the short HRT system. Emission abatement would be predictive, and conditions inhibiting emissions could be monitored via a pH meter.
Transparent and Conservative	Yes	Transparency ensured by using NIR compliant published calculation techniques based on Australian research. Conservativeness ensured by using emission factors based on Australian research together with project requirements that ensure conditions will not be suitable for emission generation. This can also be monitored using pH.
Workshop Summary		
Practical Feasibility (could this technique be taken up?)	Further research/consultation required.	A number of considerations were raised. Specifically, could nutrient / pathogen / weed seed problems be adequately addressed? Could the volumes of effluent be managed and may only suit small operations. Increased odour generation was also raised. Need to consider state government regulations. Would farmers manage this day to day?
Economic Feasibility (is it worthwhile taking this technique up?)	Further research/consultation required	Questions were asked regarding the economics for smaller producers when costs, particularly management of the system were taken into account.
Expected uptake of the method	Further research/consultation required	Questions were raised about the likely uptake, particularly with smaller operations.

Table 18. Review and workshop outcomes: assessment of technical, practical and economic feasibility for the Solid separation system

Item	Decision	Notes and considerations
Review summary		
Technical feasibility (scientific evidence, compliance with method requirements)	Yes	A number of requirements have been identified that need to be specified in the method to ensure abatement. With these requirements met, the technique is considered technically feasible considering the ERF abatement integrity requirements. Specific points are outlined below.
Additional	Yes	Providing it is a newly installed solid separator
Real and Permanent	Yes	Offsets represent actual reductions in GHG emissions and are non-reversible and will not cause an increase in GHG emissions other sectors.
Measurable, Verifiable	Yes	Emission reductions are quantifiable. Solid separation technique could be monitored via VS and/or solid reductions. Abatement would be calculated by the reduction of VS from effluent. Emission abatement would be predictive.
Transparent and Conservative	Yes	Transparency ensured by using NIR compliant published calculation techniques. Conservativeness ensured by using emission factors based on the NIR and international research together with project requirements that ensure conditions will not be suitable for emission generation. This can also be monitored using Total Solids (TS).
Workshop Summary		
Practical Feasibility (could this technique be taken up?)	Yes	Technology is available to do this, and there are co-benefits such as being able to transport the material off-site.
Economic Feasibility (is it worthwhile taking this technique up?)	Yes	It is a reasonably low-cost and manageable process and is therefore expected to be cost effective
Expected uptake of the method	Yes	Uptake is expected to be reasonable considering the above. If it was taken up it could drive further innovation.

Table 19. Review and workshop outcomes: assessment of technical, practical and economic feasibility for the pH modification system

Item	Decision	Notes and considerations
Review summary		
Technical feasibility (scientific evidence, compliance with method requirements)	Yes	A number of requirements have been identified that need to be specified in the method to ensure abatement. With these requirements met, the technique is considered technically feasible taking into account the ERF abatement integrity requirements, though practical feasibility needs to be considered. Specific points are outlined below.
Additional	Yes	Traditional uncovered anaerobic pond to an acidified storage system
Real and Permanent	Yes	Offsets represent actual reductions in GHG emissions. Once effluent is irrigated, the abatement is non-reversible and will not cause an increase in GHG emissions other sectors.
Measurable, Verifiable	Yes	Emission reductions are quantifiable. pH modification technique could be monitored via pH metre. Abatement would be calculated by the volume of effluent diverted VS flow. Emission abatement would be predictive.
Transparent and Conservative	Yes	Transparency ensured by using published calculation techniques based on International research. Conservativeness ensured by using emission factors based on international research together with project requirements that ensure conditions will not be suitable for emission generation. This can be monitored using pH.
Workshop Summary		
Practical Feasibility (could this technique be taken up?)	Provisional No	While GHG abatement potential is high, the acidic pH of treated effluent limits the potential land application and reuse options. There may also be issues with licencing if additives are used with the effluent treatment system
Economic Feasibility (is it worthwhile taking this technique up?)	More research to determine dose rates and economics	Unknown.
Expected uptake of the method	Provisional No	Unknown, but expected to be limited by the practical feasibility.

The discussion regarding pH modification noted that the alternative approach (raising pH) could also be used to mitigate GHG from effluent. This may be done relatively easily with lime and could offer benefits for areas where the soil is acidic, and lime is routinely applied. This would include many parts of southern Australia. Considering this, pH modification may be a viable means of storing effluent without GHG emissions.

Table 20. Review and workshop outcomes: assessment of technical, practical and economic feasibility for the Deep litter housing

Item	Decision	Notes and considerations
Review summary		
Technical feasibility (scientific evidence, compliance with method requirements)	Yes	A number of requirements have been identified that need to be specified in the method to ensure abatement. With these requirements met, the technique is considered technically feasible to the pig industry considering the ERF abatement integrity requirements. Specific points are outlined below.
Additional	Yes	Traditional anaerobic pond to a deep litter system
Real and Permanent	Yes	Offsets represent actual reductions in GHG emissions and are non-reversible and will not cause an increase in GHG emissions other sectors.
Measurable, Verifiable	Yes	Emission reductions are quantifiable. Emission abatement would be predictive.
Transparent and Conservative	Yes	Transparency ensured by using NIR compliant published calculation techniques based on Australian research. Conservativeness ensured by using emission factors based on Australian research together with project requirements that ensure conditions will not be suitable for emission generation.
Workshop Summary		
Practical Feasibility (could this technique be taken up?)	Provisional No	In most cases, this is a major infrastructure change that isn't easily/frequently done.
Economic Feasibility (is it worthwhile taking this technique up?)	Provisional No	There are many factors that influence this decision. Usually deep litter sheds are built to reduce capital costs, but pig performance tends to be inferior and labour can be higher. It is unlikely that the sale of ACCUs would be sufficient to change the decision.
Expected uptake of the method	Unknown	Uptake would be difficult to determine because decisions regarding housing are made infrequently and for a variety of reasons. It may be hard to establish additionality.

6.6 Meeting 4

Meeting 4 was conducted with DEE staff and a group of experts to determine key aspects of the proposed *Animal Effluent Management* method. A summary of key technical outcomes of relevance to the additional technologies is provided here:

1. Avoided methane emissions technique (Solids Separation): Avoided emission technique is to be included in the method. Key requirements include measurement of:
    a. Tonnes of TS (auditable),
    b. Concentrations of VS and N determined by approved laboratory analysis with approved sampling strategy,
    c. Bo to be determined from scientific literature or sampling and approved laboratory analysis, and
    d. Project emissions
2. Short HRT to be included with some modification as "pH mediated emission avoidance". Key requirements include:
    a. Either via measurement of flow (ML) x VS and N concentration, OR
    b. Estimated via an approved method, and
    c. Project emissions
3. Avoidance technique proposed to use 'generic' equations which utilise factors referenced in a supporting document (table). This aims to enable inclusion of additional factors (for new technologies) at a later stage without revision of the legislative document.

7 Development of Animal Effluent Management Method

The following sections outlines both the key technical aspects required for including emission avoidance technologies in a proposed Animal Effluent Management method, as well as key modifications made to the method to improve and simplify the destruction technologies. These technical aspects, modifications and input variables, along with detailed justification were developed and provided to DEE to assist in method development.

7.1 pH Modification

The pH modification system operates as an avoided emission technique, by minimising 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 short periods (< 30 days) before utilisation to avoid CH_4 generation.

The DEE has been supplied with specific pH modification system emission factors and formulas (in spreadsheet form) for the inclusion of pH modification into the new method. Integrated emission factors were developed (pre-calculated and aggregated emission factors) to make integration into the method and actual use of formulas easier for users.

7.2 Solid Separation

The solid separation system operates as an avoided emission approach by removing VS from effluent system and managing it via an aerobic process, thus limiting the amount of CH_4 that can be produced. The GHG abatement potential is dependent on the system applied and its' solid removal efficacy for a specific by-product stream.

The DEE has been supplied with specific solid separation emission factors and formulas (in spreadsheet form) for the inclusion of solid separation into the new method. Integrated emission factors were developed (pre-calculated and aggregated emission factors) to make integration into the method and actual use of formulas easier for users.

7.3 Revision of PigBal Baseline Method

Two methods have been developed and approved for use under the Emission Reduction Fund (ERF), covering the capture and combustion of methane generated from piggeries, these are:

1. *Carbon Farming (Destruction of Methane Generated from Manure in Piggeries 1.1) Methodology Determination 2013, and*
2. *Carbon Credits (Carbon Farming Initiative) (Destruction of Methane from Piggeries Using Engineered Biodigesters) Methodology Determination 2013.*

For the existing methods, abatement is capped at a baseline that must be calculated and reported in the project offsets report. The baseline for a project registered under one of the existing methods ***is the methane that would have been generated and released in the absence of the project activity***. The project baseline must be calculated based on the amount of volatile solids (VS) in the piggery project effluent stream. The PIGBAL model is required to calculate the VS quantity in the piggery by-product stream. However, it was noted on review that the *Industrial Wastewater method* has a simplified approach.

The Wastewater project proponent may choose to work out baseline emissions using two options: Option 1 calculates baseline emissions using sampling (Chemical Oxygen Demand measurements -

COD) from the operation of a deep open anaerobic pond; Option 2 calculates the baseline emissions using the amount of CH_4 sent to a combustion device. This key difference in baseline calculation means that a waste estimation model (e.g., PIGBAL) is not used to calculate the baseline and emissions are not capped based on a theoretical estimation but are either calculated from the amount of CH_4 captured and destroyed or COD measurements of baseline pond.

A rationale for modifying the method to adopt the *Industrial wastewater method* approach was developed and presented to the DEE as a means of simplifying the ERF method and auditing process. This rationale is summarised in the following sections, i) the reasoning for applying a new/different baseline approach, ii) the scientific basis for the approach suggested, and iii) supporting information.

7.3.1 Reasoning for a New Approach

It is proposed that the baseline calculation of emissions via modelling in the existing methods adds unnecessary complexity, record keeping and auditing costs, and is redundant. The use of a baseline calculation approach can be removed from the new proposed method without affecting the accuracy and integrity of the method. The reason for including a baseline in the anaerobic digestion methods was based on the understanding that biogas capture and destruction systems (anaerobic digesters) could generate more methane than was theoretically possible in an uncovered anaerobic pond (pond). The baseline was added as a check to confirm that the claimable abatement (the capture and destruction of methane) was less than the theoretical methane production from the estimation of VS flow in the animal waste. Consultation with piggery anaerobic digester operators and ERF auditors has shown that, in all but one instance of approved projects that include covered ponds, as well as mechanically stirred and heated systems, the claimable methane abatement was below modelled baseline estimates. One operation is understood to have exceeded modelled baseline estimates, but the baseline estimate was not used to limit abatement. In effect, the baseline has not been applied as a limiting threshold on abatement to date. Additionally, this baseline modelling approach is costly to apply because of the onerous data requirements and high auditing costs for a complex modelling process. To understand why this is the case it is useful to understand the anaerobic treatment process and the factors that influence methane generation, as well as the operation of traditional uncovered anaerobic treatment ponds that replaced by approved projects under the ERF.

7.3.2 Technical Basis - Anaerobic Digestion in Digesters and Uncovered Ponds

Process

As described in section 2.3 , anaerobic digestion (AD) is a series of biological processes by which biodegradable organic matter is decomposed by a consortium of microorganisms in the absence of oxygen, producing CH_4, CO_2 and other contaminate gases (Gunaseelan, 1997). There are many variables that affect methane production during anaerobic digestion, including pond characteristics, temperature/inter-seasonal variations, manure chemical characteristics, pH and hydraulic retention time (HRT) (Gunaseelan, 1997).

Temperature and Seasonal Effects

Temperature is one of the major parameters that affects the methane production process (methanogenesis). The acid forming, and methanogenic bacteria have an optimum range of 30 to 45 °C and the digestion process will slow at temperatures outside this range. Anaerobic digestion can still however occur at temperatures as low as 3–9°C, with the minimum temperature decreasing as the pond ages, probably due to the establishment of temperature adapted anaerobic bacteria (Craggs et al., 2008). Both covered and uncovered animal effluent ponds will have a decreased capacity to breakdown organic material in the cooler months (Kruger et al., 1995). However, when temperatures increase in summer the digestion process rapidly accelerates and methane production increases. Skerman and Collman, 2012 found that the methane production increased two-fold in summer compared to winter at a partially covered anaerobic pond at Gatton in south-east Queensland. Craggs et al. (2008) found greater differences than this for covered anaerobic ponds for both piggeries and dairies in the cooler climates of New Zealand (Figure 13). Sharpe and Harper (1999) reported a seven to eight-fold difference between winter and summer emissions from an anaerobic piggery pond in Georgia, USA, where the winter temperatures are much colder. This highly seasonal effect is likely due to organic matter that was deposited / retained in the pond during the cooler months and remained undigested. The emissions in the warmer months in Australia have been shown to exceed the theoretical maximum emissions of methane by 150% in an uncovered anaerobic piggery pond (McGahan et al., 2016). Warmer temperatures in summer increase biological activity and natural mixing in uncovered anaerobic ponds (see Figure 14) and methane production can exceed the theoretical maximum in the short-term (DeSutter and Ham, 2005). In warmer, more tropical regions, this seasonal methane production is less pronounced.

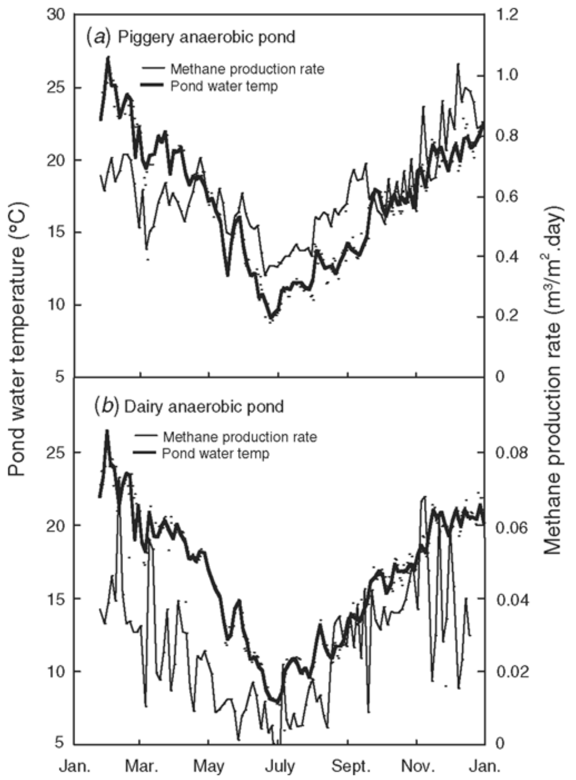

Figure 13. Aerial methane production and average daily pond surface water temperature of (a) a piggery and (b) a dairy farm anaerobic pond measured between January 2006 and January 2007 (Craggs et al., 2008).

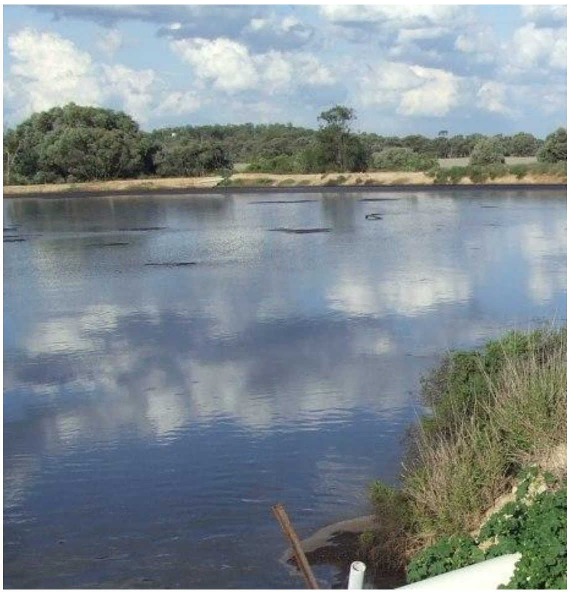

Figure 14. Natural mixing from an uncovered anaerobic pond at a piggery.

Anaerobic digesters with heating and stirring are not significantly influenced by ambient seasonal temperature changes (Pham et al., 2014). Anaerobic digesters that are heated and/or stirred change the emission profile by stabilising methane production and thus producing a consistent daily biogas (methane) production. This is generally done for economic reasons, where a consistent supply of methane (energy) is required to operate electrical or heating equipment. The effect of heating and stirring to produce a consistent biogas (methane) production can be seen in Figure 15.

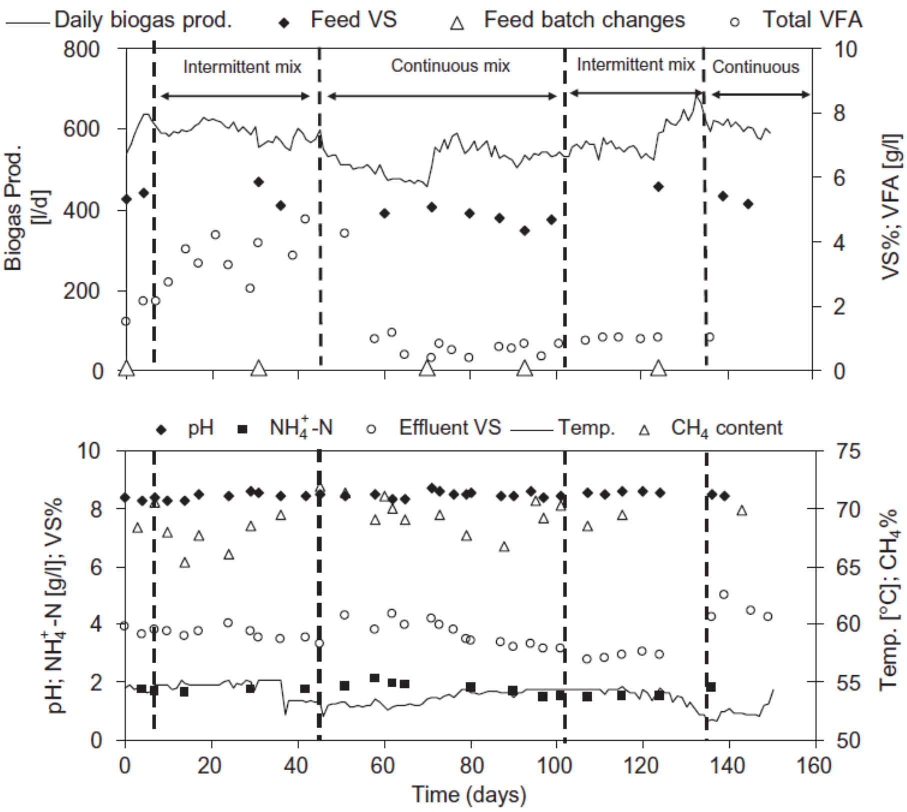

Figure 15. Methane production from a heated and mixed digester (Kaparaju et al., 2008).

The Influence of Hydraulic Retention Time

Hydraulic retention time or the amount of time effluent spends in the digestion process has a significant effect on the breakdown or organic matter. The longer the HRT, the more time the anaerobic bacteria have to digest the incoming organic matter and ultimately produce methane. Traditional uncovered anaerobic ponds in animal industries may have very long HRT (>100 days and up to 300 days) due to the design, VS loading rates and the high organic matter content of animal manures. Covered anaerobic ponds and engineered digesters used in the animal industries have much shorter HRT (<30 days) due to the high capital costs of construction. Industry observations suggest that methane is also produced in secondary holding ponds after the effluent is released from covered ponds/digesters, suggesting that HRT in covered ponds/digesters does not allow maximum digestion of all VS. This reflects a balance between minimising HRT (and construction costs) and maximising methane potential.

Efficiency of Volatile Solids Destruction in Uncovered Ponds, Covered Ponds and Digesters

Comparing the VS:TS ratio of raw animal effluent to digested sludge can be used as a measure of the ability of an anaerobic system at digesting organic matter. Low VS:TS ratios in the sludge signify a pond with a good ability at reducing (digesting) VS, conversely high VS:TS ratios would be seen where the pond is less able to digest the incoming VS. Raw piggery effluent has a VS:TS ratio of ~0.8 (Kruger et al 1995). Sludge samples were collected and analysed for VS and TS from uncovered anaerobic ponds at 10 piggeries in southern Queensland and the results reported in Tucker et al (2010). The VS contents of the sludge ranged from 5.3% to 9.5% (wet basis). The TS content of the sludge ranged from 6.9 – 17.1% (wet basis), with the average VS:TS ratios of all sludge samples being 0.52. One sludge sample from a heavily overloaded pond that had a very short HRT due to an excessive solids accumulation had a VS:TS ratio of 0.78 (raw manure), all other sludge samples had VS:TS ratios less than 0.60, with the lowest being 0.38. This average VS:TS ratio of 0.52 represents an average VS reduction of fresh manure to sludge digestate of over 70%. Skerman and Collman (2012) measured the VS:TS ratio of both incoming effluent and sludge at a partially covered pond in southern Queensland. The inflow and sludge samples had average VS:TS ratios of 0.72 and 0.52 respectively, representing a VS reduction of around 60% from influent to sludge digestate. Similarly, Birchall (2010) measured VS removal rates for a covered anaerobic pond in Victoria of 64%. A Korean study found anaerobic digestion of piggery manure using a stirred and heated anaerobic digester achieved a VS reduction of 55%. However no further VS reduction occurred due to its inherent non-readily biodegradable materials (Chae et al., 2002).

Comparison of Methane Generation from Australian Uncovered and Covered Ponds, and Digesters

Methane generation from Australian uncovered ponds are very high, with the NIR reporting high to very high methane conversion factors (Commonwealth of Australia 2015) and experimental data showing that these ponds can approach theoretical maximum levels of methane production (McGahan et al. 2016). Research into VS destruction rates confirms the high efficiency of these systems. The key factors contributing to the high VS destruction and methane generation rates are the long HRT design and high temperatures experienced in Australia over summer, resulting in the destruction of residual that has been stored during the colder months.

Reported VS to TS ratios in covered ponds and digesters in Australia show similar or lesser destruction rates than uncovered ponds, and this can be explained by the shorter retention time for these systems, resulting in slightly lower breakdown rates and lower methane generation.

To further support this, project proponents and auditors were consulted to investigate whether existing projects registered under the ERF generated gross abatement that was equivalent or higher than the baseline estimates modelled to satisfy audit requirements.

This consultation revealed that the baseline cap is not being triggered via the auditing process in the existing methane destruction projects. In short, no projects have exceeded the baseline to the extent that abatement was limited. The majority of projects have produced significantly less methane than predicted using the baseline method, providing further evidence that these systems are not exceeding the methane generation rate of uncovered ponds.

These results support a revised approach in the method, where a calculated baseline is not required.

7.3.3 Conclusions

It can be concluded that under Australian conditions, covered ponds and engineered digesters are unlikely to exceed the emission potential from traditional uncovered anaerobic ponds used for the treatment of animal manure. This is due to the long HRT used for these uncovered ponds compared to covered ponds and digesters and the high summer temperatures that assist in the degradation of undigested VS. This is supported by measurements of high methane emissions from uncovered anaerobic ponds in Australia. Additionally, VS:TS ratio measurements in the sludge from uncovered ponds shows similar or greater VS degradation than covered ponds and digesters indicating similar or higher methane generation.

These conclusions support the approach being proposed under the new animal effluent management method where a baseline calculation check of emissions is not included as it would be redundant. This is further supported by a high-level review of existing methane destruction projects approved under the ERF for animal effluent that identified baseline methane emissions modelling has never been applied as a cap of emissions abatement. Under the new proposed method, net abatement can be simply calculated from determining gross abatement and subtracting any project emissions. For methane destruction projects, gross abatement can be calculated accurately from records of energy production, methane destruction and/or measurements of biogas flow, as per the current approved wastewater method. For projects that avoid VS being digested anaerobically and producing methane, gross abatement can be determined from actual measurements of VS.

An ERF method based on this theory for determining claimable abatement provides a high level of robustness, as compliance is based on measurable data that is easily auditable. The collection of data by the project proponent is far simpler, which will reduce compliance and auditing costs. Gross abatement will be easily quantifiable from either methane gas destruction amounts from energy generation, methane gas flow volumes or VS measurement. The removal of a redundant baseline calculation that involves a significant amount of record keeping and complex modelling that is difficult to stringently audit will create a far simpler, more accurate and useable method that is based on real, quantifiable measurement.

7.4 Equation for New Method

Based on the above sections 7.1, 7.2 and 7.3, Table 21 summarises the equations supplied to the DEE to allow for the inclusion of avoidance technologies and simplification of calculations in a proposed Animal Effluent Management method.

Table 21. Equations used to calculate emissions from pH modification

Equation #	Equation	Description
1	$A_h = GA_h — IA_h — PE_h$	Project facility net abatement amount
2	$GA_h = \gamma \sum_i (MC_i + MA_i)$	Gross abatement amount for a project facility
3	$MC_i = Q_{biogas,i} \times W_{BG,CH4} \times DE_i$	Method A
4	$MC_i = QE_i$ *x CH4 conversion factor*	Method B
5	$QE_i = \frac{Q_{EG,i} \times EC}{Eff_i}$	QEi
6	$MA = MCF_1 * \sum w\ (VS\ Diverted, w * B_{0,Diverted})$	Methane avoided by removal of VS
7	$IA = \gamma \sum w\ (VSw \times B0,w)$	Ineligible abatement for a project facility
8	$PE = E_F + E_{Post\ Methane} + E\ Post\ Nitrogen$	Project emissions, including fuel, purchased electricity and post treatment emissions of methane and nitrous oxide
9	$E_F = \sum_i \sum_j \frac{Q_{F,i} \times EC_i \times EF_{ij}}{1\ 000}$	Emissions from fuel use, including transport
10	$E_{EP} = Q_{EP} \times \frac{EF_{EP}}{1\ 000}$	Emissions from purchased electricity use
11	$E_{Post,\ Methane} = \gamma \times \sum_n (MCF_{Post,\ n} \times \sum_w (VS_{Diverted,\ w,n} \times B_{0,w}))$	Emissions of methane from the post diversion of material diverted
12	$E_{Post,\ Nitrogen} = N_2O\text{-}N_{CF} \times \sum_n (INOEF_{Post,\ n} \times \sum_w N_{Diverted,\ w,n})$	Emissions of nitrogen from the post diversion of material diverted

Equations 11 and 12 have been written in generic format, so that integrated factors for both methane and nitrous oxide emissions can be input for different avoidance techniques. The integrated factors include all additional emissions (treatment, storage, land application, etc) that occur following the diversion of effluent to the avoided technology. That is, they are the emissions that would be produced above what would have occurred if the effluent had been treated in a traditional uncovered anaerobic pond. Integrated emission factors have been provided to DEE as part of the method development.

7.5 Addressing concerns raised by ERAC/ Federal Regulator

The ERAC raised concerns regarding the additionality of biogas methods for piggery projects. Specifically:

- Whether ponds are already being covered due to existing regulations (e.g. to address odour), and
- Whether electricity generation is making projects viable in the absence of carbon credits?

That is, the ERAC was concerned that current and possible new piggery project's emissions reductions would not go beyond what is common practice (i.e. installed to control odour) or would have occurred in the absence of the offset program for the pork industry (economically viable without carbon credits).

The authors further analysed and presented information to the regulator to address their concerns with piggery biogas project additionality. The following is a brief summary.

7.5.1 Additionally - Common Practice and Economic Viability

Currently, there is approximately 7.85% uptake of biogas technology – which was reported here http://porkcrc.com.au/wp-content/uploads/2013/08/BEA-27-June-2013-Tait-Biogas-Pig-Industry.pdf. The economic feasibility has depended on ERF (CFI) investment with about 30% of returns coming from this source. Even with the apparently positive economics the uptake hasn't been rapid. The uptake of biogas projects is not common practice. Furthermore, ponds are not being covered due to existing regulations. It should be noted that there has been a major 'gap' between the projected development costs and the actual development costs for biogas installations. While we do know of some 'low cost' installations (similar to the costs indicated by McGahan's work back in 2011), we also know some have costed far more (up to $4M for a hybrid covered pond/in ground digester). Obviously, the cost-benefit is heavily influenced by these large fluctuations in installation cost.

7.5.2 Additionally - Economic Viability

A copy of the summary report for the five piggeries assessed in 2011 as part of a Pork CRC project is reported here: http://porkcrc.com.au/wp-content/uploads/2013/08/4C-102-Final-Report-130420.pdf. The actual reports to the farmers were not made public as they contain financial information and details of the individual farms. A number of the scenarios for the farms in this study relied on the sale of ACCU's to be viable. While, these theoretical systems may not be reflective of the systems that have been installed since this report was commissioned, the CAPEX information was based on actual costs of equipment at the time (including project management costs), with relatively simple covered ponds systems that did not have internal lining, heating, stirring that is characteristic of some of the systems that have been installed in recent years. These systems have been installed by commercial companies and the disparity in the CAPEX cost of an "owner constructed" system and the "turn-key" systems that have been installed by commercial companies is large. Hence reducing the paybacks and financial viability of systems. These higher CAPEX costs and the uncertainty around the value of carbon credits may be what has reduced the current uptake of biogas in the pig industry.

8 Conclusions

The pig industry generates substantial GHG emissions from manure management, and industry members have been early adopters of ERF (previously CFI) methods for abating emissions and earning income via the sale of ACCUs. Industry and government funded research showed that additional, lower cost technologies could be applied to reduce emissions. The present project has outlined the technical basis for including these new technologies in a revised ERF method currently being developed by the Federal DEE. Additionally, improvements to the methods for handling covered ponds and digesters have been proposed and summarised in this report. The stakeholder engagement process conducted as part of this project has been successful in initiating development of a new method (currently being completed) and has been successful in presenting methods suitable for application in the pig industry.

During the development of the new animal effluent method the authors provided technical specifications to support the inclusion of additional approaches and technical support regarding development of the revised covered pond/digester method, supporting simplification by proposing removal of the current baseline approach (PigBal).

The new animal effluent method is currently under the final stages of development, and all technical material pertaining to inclusion of the short HRT/pH modification technique, and the solids separation technique, have been provided for inclusion in the method. The project team remains engaged in the method development process through to completion, which is currently anticipated in June 2018.

References

Abbasi, T., Tauseef, S. and Abbasi, S. (2012) 'A Brief History of Anaerobic Digestion and "Biogas"', *Biogas Energy*: Springer, pp. 11-23.

Al-Kanani, T., Akochi, E., MacKenzie, A. F., Alli, I. and Barrington, S. (1992) 'Organic and Inorganic Amendments to Reduce Ammonia Losses from Liquid Hog Manure', *Journal of Environmental Quality,* 21(4), pp. 709-715.

Amon, B., Kryvoruchko, V., Amon, T. and Zechmeister-Boltenstern, S. (2006) 'Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment', *Agriculture, ecosystems & environment,* 112(2), pp. 153-162.

Andersen, D., Harmon, J., Hoff, S. and Rieck-Hinz, A. (2014) *Overview of Manure Acidification for Odor and Emission Control.* Iowa: Iowa State University.

Atzeni, M., Casey, K. and Skerman, A. 'A Model to Predict Cattle Feedlot Runoff from Effluent Reuse Applications'. *Proceedings of MODSIM, 2001*, 1871-1876.

Baldé, H., VanderZaag, A. C., Burtt, S., Evans, L., Wagner-Riddle, C., Desjardins, R. L. and MacDonald, J. D. (2016) 'Measured versus modeled methane emissions from separated liquid dairy manure show large model underestimates', *Agriculture, Ecosystems & Environment,* 230, pp. 261-270.

Besson, J., Lehmann, V. and Roulet, M. (1985) 'Effect of slurry preparation on its composition and on nitrogen losses during its application', *Revue Suisse d'Agriculture,* 17(4), pp. 231-238.

Birchall, S. (2010) *Biogas production by covered lagoons - Performance data from Bears Lagoon Piggery. RIRDC Publication No. 10/023*, Canberra: Rural Industries Research and Development Corporation.

Boopathy, R. (1996) 'Isolation and characterization of a methanogenic bacterium from swine manure', *Bioresource Technology,* 55(3), pp. 231-235.

Bothi, K. L. (2007) *Characterization of biogas from anaerobically digested dairy waste for energy use.* Cornell University.

Chae, K., Jang, A., Yim, S. and Kim, I. S. (2008) 'The effects of digestion temperature and temperature shock on the biogas yields from the mesophilic anaerobic digestion of swine manure', *Bioresource Technology,* 99(1), pp. 1-6.

Commonwealth of Australia 2016. National Inventory Report 2014 (revised): Volume 1. Australia: Australian Government, Department of the Environment and Energy.

Conrad, R. and Schütz, H. (1988) 'Methods of studying methanogenic bacteria and methanogenic activities in aquatic environments', *Methods in Aquatic Bacteriology*, pp. 301-343.

Craggs, R., Park, J. and Heubeck, S. (2008) 'Methane emissions from anaerobic ponds on a piggery and a dairy farm in New Zealand', *Animal Production Science,* 48(2), pp. 142-146.

Cu, T., Nguyen, T., Triolo, J. M., Pedersen, L., Le, V., Le, P. and Sommer, S. G. (2015) 'Biogas production from Vietnamese animal manure, plant residues and organic waste: Influence of biomass composition on methane yield', *Asian-Australalasian journal of animal sciences,* 28(2), pp. 280.

Dairy Australia (2011) *Dairy Greenhouse gas Abatement Strategy Calculator (DGAS): Adviser version User Manual Version 1.4*, Australia: Dairy Australia with The Australian Department of Agriculture, Fisheries and Forestry. Available at https://www.environment.gov.au/system/files/pages/abe8ba83-58b2-46dd-85ae-821d177812c9/files/dgas-1-4-user-manual.pdf.

Dairy Australia (2013) *Is Biogas Technology right for Australian Dairy Farms?* , Southbank, Victoria: Dairy Australia. Available at http://frds.dairyaustralia.com.au/wp-content/uploads/2013/05/FINAL_Biogas-technology_A4-report-summary.pdf.

Dhevagi, P., Ramasamy, K. and Oblisami, G. (1992) 'In Biological Nitrogen Fixation and Biogas Technology', *Tamil Nadu Agricultural Unveristy, Coimbatore*, pp. 149-153.

Dong, H., J, M., TA, M., JL, H., DE, J., KR, L., LimaM, A. d., RomanovskayaA, D, B., DJ, G. and JHJ, M. (2006) 'Emissions from livestock and manure management.', in S Eggleston, L Buendia, K Miwa, T Ngara & Tanabe, K. (eds.) *IPCC guidelines for national greenhouse gas inventories. Vol. 4: agriculture, forestry and other land use*. Kanagawa, Japan: Institute for Global Environmental Strategies, pp. 10.1–10.87.

ECOregon (2009) *Dairy Manure Anaerobic Digester Feasibility Study Report*, Albany, Oregon: ECOregon.

El-Mashad, H. M. and Zhang, R. (2010) 'Biogas production from co-digestion of dairy manure and food waste', *Bioresource technology,* 101(11), pp. 4021-4028.
Frost, J., Stevens, R. and Laughlin, R. (1990) 'Effect of separation and acidification of cattle slurry on ammonia volatilization and on the efficiency of slurry nitrogen for herbage production', *The Journal of Agricultural Science,* 115(01), pp. 49-56.
Groot Koerkamp, P. and Klarenbeek, J. (1998) 'Emissievermindering van ammoniak uit varkensstallen door Bio-Aktief-Poeder', *IMAG nota*, pp. 74-98.
Hilhorst, M., Melse, R., Willers, H., Groenestein, C. and Monteny, G. (2002) 'Reduction of methane emissions from manure', *Non-CO2 greenhouse gases: scientific understanding, control options and policy aspects*, pp. 435-440.
Hudson, N., Duperouzel, D. and Melvin, S. (2006) 'Assessment of permeable covers for odour reduction in piggery effluent ponds. 1. Laboratory-scale trials', *Bioresource technology,* 97(16), pp. 2002-2014.
Husted, S., Jensen, L. S. and Jørgensen, S. S. (1991) 'Reducing ammonia loss from cattle slurry by the use of acidifying additives: the role of the buffer system', *Journal of the Science of Food and Agriculture,* 57(3), pp. 335-349.
IPCC (2006) *IPCC guidelines for national greenhouse gas inventories.* Japan: Prepared by the National Greenhouse Gas Inventories Programme, IGES.
Jensen, A. (2002) 'Changing the environment in swine buildings using sulfuric acid', *TRANSACTIONS-AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS,* 45(1), pp. 223-238.
Kavuma, C. (2013) 'Variation of methane and carbon dioxide yield in a biogas plant', *MSc., Department of Energy Technology, Royal Intitiute of Technology, Stockholm, Sweden*.
Kirk, D. and Bickert, W. (2004) 'The use of biochemical methane potential tests to evaluate the digestibility of processed dairy manure', *ASABE Paper,* (044066).
Kissinger, W. F., Erickson, G. E. and Klopfenstein, T. J. (2006) *Summary of manure amounts, characteristics, and nitrogen mass balance for open feedlot pens in summer compared to winter. Nebraska Beef Cattle Reports*, Nebraska: University of Nebraska.
Kruger, I. (2015) *Summary of 55 PigGas Reports, National PigGas Extension Project*, Australia: Australian Pork Limited, available at http://australianpork.com.au/wp-content/uploads/2013/10/APL-Website-Summary-of-55-PigGas-Reports.pdf.
Longfield, I. (2013) *Low Cost Methane Capture and Combustion from a Piggery Effluent Lagoon. Final Report APL Project 2009/2307*, Australia: Australian Pork Limited.
Lorimor, J., Melvin, S. and Adam, K. 'Settling basin performance from two outdoor feedlots'. *Proceedings of the 7th International Symposium on Agricultural and Food Processing Wastes, 1995. pp17-23*.
Lott, S. 1997. Feedlot Hydrology, PhD. Toowoomba, Australia: University of Southern Queensland.
Massé, D., Masse, L., Claveau, S., Benchaar, C. and Thomas, O. (2008) 'Methane emissions from manure storages', *Energy,* 17, pp. 6.
McGahan, E., Davis, R., Warren, B. and Cheallaigh, A. (2013) *Evaluation of Energy Usage and Ventilation Performance of Tunnel Ventilated Layer Sheds*, Australia: Australian Egg Corporation LimitedProject No. 1FS111). Available at: https://www.aecl.org/assets/www.aecl.org/outputs/1FS111A-Final-Report.pdf.
McGahan, E., Ouellet-Plamondon, C. and Watts, P. J. (2010) *Estimates of manure production from animals for methane generation.* Rural Industries Research and Development Corporation.
McGahan, E., Phillips, F. A., Wiedemann, S., Naylor, T. A., Warren, B., Murphy, C., Griffith, D. W. and Desservettaz, M. (2016) 'Methane, nitrous oxide and ammonia emissions from an Australian piggery with short and long hydraulic retention-time effluent storage', *Animal Production Science,* 56(9), pp. 1376-1389.
Misselbrook, T. and Powell, J. M. (2005) 'Influence of bedding material on ammonia emissions from cattle excreta', *Journal of dairy science,* 88(12), pp. 4304-4312.
Molloy, S. P. and Tunney, H. (1983) 'A Laboratory Study of Ammonia Volatilization from Cattle and Pig Slurry', *Irish Journal of Agricultural Research,* 22(1), pp. 37-45.
Murphy, C., McGahan, E. and Wiedemann, S. (2012) *Assessment of Treatment Technologies and Strategies to Mitigate GHG Emissions*, Australia: Australian Pork Limited.

Møller, H. B., Sommer, S. G. and Ahring, B. K. (2004) 'Biological degradation and greenhouse gas emissions during pre-storage of liquid animal manure', *J Environ Qual,* 33(1), pp. 27-36.

Nicks, B., Laitat, M., Farnir, F., Vandenheede, M., Desiron, A., Verhaeghe, C. and Canart, B. (2004) 'Gaseous emissions from deep-litter pens with straw or sawdust for fattening pigs', *Animal Science,* 78(01), pp. 99-107.

Oenema, O., Velthof, G. and Bussink, D. (1993) 'Emissions of ammonia, nitrous oxide, and methane from cattle slurry', *Biogeochemistry of Global Change*: Springer, pp. 419-433.

Pain, B. F., Thompson, R. B., Rees, Y. J. and Skinner, J. H. (1990) 'Reducing gaseous losses of nitrogen from cattle slurry applied to grassland by the use of additives', *Journal of the Science of Food and Agriculture,* 50(2), pp. 141-153.

Petersen, S. O., Olsen, A. B., Elsgaard, L., Triolo, J. M. and Sommer, S. G. (2016) 'Estimation of Methane Emissions from Slurry Pits below Pig and Cattle Confinements', *PloS one,* 11(8), pp. e0160968.

Philippe, F.-X., Canart, B., Laitat, M., Wavreille, J., Bartiaux-Thill, N., Nicks, B. and Cabaraux, J.-F. (2010) 'Effects of available surface on gaseous emissions from group-housed gestating sows kept on deep litter', *Animal,* 4(10), pp. 1716-1724.

Phillips, F. A., Wiedemann, S., Naylor, T. A., McGahan, E., Warren, B., Murphy, C., Parkes, S. and Wilson, J. (2016) 'Methane, nitrous oxide and ammonia emissions from pigs housed on litter and from stockpiling of spent litter', *Animal Production Science,* 56(9), pp. 1390-1403.

Poad, G., McGahan, E. and Redding, M. (2010) *Low cost options for reducing effluent pond methane. Final Report, Project No. 2009/2299*, Australia: Australian Pork Limited.

Prasad, R. D. (2012) 'Empirical study on factors affecting biogas production', *ISRN Renewable Energy,* 2012.

Safley, L., Nelson, D. and Westerman, P. (1983) 'Conserving manurial nitrogen', *Trans. ASAE,* 26, pp. 1166-1170.

Sharpe, R., Harper, L. and Byers, F. (2002) 'Methane emissions from swine lagoons in Southeastern US', *Agriculture, ecosystems & environment,* 90(1), pp. 17-24.

Skerman, A. (2017) *Practical options for cleaning biogas prior to on farm use at piggeries. Thesis*, Australia: School of Chemical Engineering, University of Queensland.

Skerman, A. and Collman, G. (2012) *Methane Recovery and Use at Grantham Piggery. RIRDC Publication No. 12/064, RIRDC Project No. PRJ-005672.*

Spiegel, R. J. and Preston, J. (2003) 'Technical assessment of fuel cell operation on anaerobic digester gas at the Yonkers, NY, wastewater treatment plant', *Waste management,* 23(8), pp. 709-717.

Stevens, R., Laughlin, R. and Frost, J. (1989) 'Effect of acidification with sulphuric acid on the volatilization of ammonia from cow and pig slurries', *The Journal of Agricultural Science,* 113(3), pp. 389-395.

Stevens, R., Laughlin, R. and Frost, J. (1992) 'Effects of separation, dilution, washing and acidification on ammonia volatilization from surface-applied cattle slurry', *The Journal of Agricultural Science,* 119(03), pp. 383-389.

Sánchez, M. and González, J. (2005) 'The fertilizer value of pig slurry. I. Values depending on the type of operation', *Bioresource technology,* 96(10), pp. 1117-1123.

Tucker, R. (2015) *APL project 2012/1028 - Piggery Manure and Effluent Management and Reuse Guidelines*, Australia: Australian Pork Limited. Available at: http://australianpork.com.au/wp-content/uploads/2013/10/PMEG_2014_14_lr.pdf.

Ukpai, P. and Nnabuchi, M. (2012) 'Comparative study of biogas production from cow dung, cow pea and cassava peeling using 45 litres biogas digester', *Advances in Applied Science Research,* 3(3), pp. 1864-1869.

Uzodinma, E., Ofoefule, A., Eze, J. and Onwuka, N. (2007) 'Optimum mesophilic temperature of biogas production from blends of agro-based wastes', *Trends in Applied Sciences Research,* 2(1), pp. 39-44.

Watts, P. and McCabe, B. (2015) *Feasibility of using feedlot manure for biogas production: Final Report No. B.FLT.0385*, Australia: Meat and Livestock Australia Limited.

Watts, P., McGahan, E., Bonner, S. and Wiedemann, S. (2012) 'Feedlot mass balance and greenhouse gas emissions–a literature review', *Meat & Livestock Australia, Sydney, Australia*.

White, L. P. and Plaskett, L. G. (1981) *Biomass as fuel.* Academic Press Ltd.

Wiedemann, S. (2016) *Greenhouse gas emissions from layer hen manure: a review. A report for the Australian Egg Corporation Limited. AECL Project No. 1IA151*, Australia: Australian Egg Corporation Limited.

Wiedemann, S., Cottle, D., Valentine, J., Watts, P. and McGahan, E. (2014a) *Opportunities for the feedlot sector to reduce greenhouse gas emissions under the Carbon Farming Initiative*, Australia: Meat and Livestock Australia Limited.

Wiedemann, S., McGahan, E. J. and Murphy, C. M. (2016a) 'Environmental impacts and resource use from Australian pork production assessed using life-cycle assessment. 1. Greenhouse gas emissions', *Animal Production Science,* 56(9), pp. 1418-1431.

Wiedemann, S., Murphy, C., McGahan, E. and Goonan, P. (2016b) *Benefit-cost Analysis of greenhouse gas mitigation opportunities for the feedlot, pork, chicken meat and layer hen industries. APL Project No. 2015/2215*, Australia: Australian Pork Limited.

Wiedemann, S., Phillips, F., Naylor, T., McGahan, E., Keane, O., Warren, B. and Murphy, C. (2015) *Poultry Greenhouse Gas Mitigation*, Australia: Department of Agriculture, Fisheries and Forestry.

Wiedemann, S., Phillips, F. A., Naylor, T. A., McGahan, E. J., Keane, O. B., Warren, B. R. and Murphy, C. M. (2016c) 'Nitrous oxide, ammonia and methane from Australian meat chicken houses measured under commercial operating conditions and with mitigation strategies applied', *Animal Production Science,* 56(9), pp. 1404-1417.

Wiedemann, S., Sullivan, T. and McGahan, E. (2014b) *GHG Prediction methods for feedlots, poultry and pigs, Technical report for the Department of Environment Greenhouse Gas Inventory Team*, Australia: Federal Department of the Environment.

Wu, W. (2007) 'Anaerobic co-digestion of biomass for methane production: recent research achievements', *Optimization,* 1.

Zeeman, G. (1994) 'Methane production/emission in storages for animal manure', *Fertilizer Research,* 37(3), pp. 207-211.

Bajpai, P. (2017) 'Basics of Anaerobic Digestion Process. In A*naerobic Technology in Pulp and Paper Industry.*', *Springer Singapore*., pp. 7-12.

Birchall, S. (2010) *Biogas production by covered lagoons - Performance data from Bears Lagoon Piggery. RIRDC Publication No. 10/023*, Canberra: Rural Industries Research and Development Corporation.

Chae, K., Yim, S., Choi, K., Park, W. and Lim, D. 'Anaerobic digestion of swine manure: Sung-Hwan farm-scale biogas plant in Korea'. *Latin American Workshop and Symposium on Anaerobic Digestion, 7*: UNAM, 8.

Craggs, R., Park, J. and Heubeck, S. (2008) 'Methane emissions from anaerobic ponds on a piggery and a dairy farm in New Zealand', *Animal Production Science,* 48(2), pp. 142-146.

DeSutter, T. M. and Ham, J. M. (2005) 'Lagoon-biogas emissions and carbon balance estimates of a swine production facility', *J Environ Qual,* 34(1), pp. 198-206.

Gunaseelan, V. N. (1997) 'Anaerobic digestion of biomass for methane production: a review.', *Biomass and bioenergy,* 13(1-2), pp. 83-114.

Kaparaju, P., Buendia, I., Ellegaard, L. and Angelidakia, I. (2008) 'Effects of mixing on methane production during thermophilic anaerobic digestion of manure: lab-scale and pilot-scale studies', *Bioresour Technol,* 99(11), pp. 4919-28.

Kruger, I., Taylor, G. and Ferrier, M. (1995) *Australian pig housing series - effluent at work.* New South Wales Agriculture and Pig Research and Development Corporation, New South Wales Agriculture.

McGahan, E., Phillips, F. A., Wiedemann, S., Naylor, T. A., Warren, B., Murphy, C., Griffith, D. W. and Desservettaz, M. (2016) 'Methane, nitrous oxide and ammonia emissions from an Australian piggery with short and long hydraulic retention-time effluent storage', *Animal Production Science,* 56(9), pp. 1376-1389.

Pham, C. H., Vu, C. C., Sommer, S. G. and Bruun, S. (2014) 'Factors Affecting Process Temperature and Biogas Production in Small-scale Rural Biogas Digesters in Winter in Northern Vietnam', *Asian-Australas J Anim Sci,* 27(7), pp. 1050-6.

Sharpe, R. R. and Harper, L. A. (1999) 'Methane emissions from an anaerobic swine lagoon.', *Atmospheric Environment,* 33(22), pp. 3627-3633.

Skerman, A. and Collman, G. (2012) *Methane Recovery and Use at Grantham Piggery. RIRDC Publication No. 12/064, RIRDC Project No. PRJ-005672*.

Tucker, R. W., McGahan, E., Galloway, J. L. and O'Keefe, M. F. (2010) *National environmental guidelines for piggeries - Second Edition*, Deakin, Australia: Australian Pork LtdAPL Project 1832).

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Appendix 1

Meeting 2
Location: Federal DEE
Date: 15/06/2017

Attendees List

- Stephen Wiedemann
- Eugene McGahan
- Ben Holt
- Des Rinehart
- Janine Price
- Andrew Gunst
- Scott Birchall
- Mark Asprin
- Penny Banks
- Ian Longfield
- Jock Charles
- Meagan Downes
- Elliott Curley
- Nadine Smith
- Benjamin Docker
- Marnie Telfer
- Robyn Tucker

Appendix 2

Outdoor Piggeries

Outdoor piggeries confine pigs within an outdoor area with housing provided for shelter where they are fed for the purpose of production, relying primarily on prepared or manufactured feedstuffs or rations to meet their nutritional requirements. Most of the excreta is spread by the pigs on the fields where they are confined. Outdoor housing is a common component of free range piggeries for the breeding component of pigs in Australia. However, the application of outdoor housing systems for the whole production cycle is not as common in Australia. Most outdoor pig production in Australia is rotational. As Figure 16 shows, the manure by-product of this system is spread by the pigs on the paddocks where they are confined.

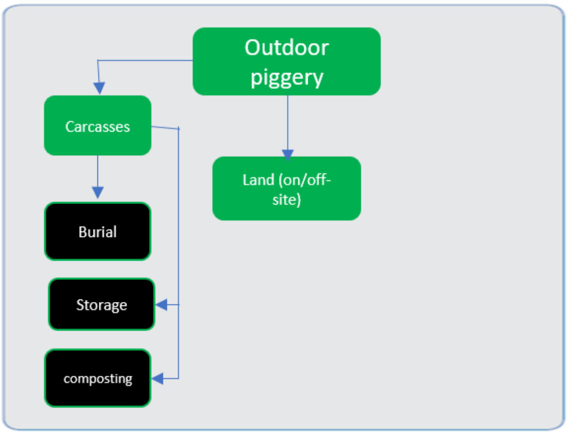

Figure 16. By-product management options- outdoor piggeries (adapted from Tucker, 2015)

Wiedemann et al. (2016a) found (breeding) outdoor housing resulted in a 13% less GHG emissions than conventional housing, but energy use was 8% higher. The treatment of manure in an aerobic environment aligns with the scope of the proposed new method by avoiding the production of GHG emissions leading to an overall abatement. Outdoor housing has the same advantage as deep litter for reducing manure emissions because the system is aerobic, however, this is partly offset by higher N_2O emissions from manure and embedded emissions from feed, because of the poorer feed conversion ratio (FCR). The poorer FCR results in higher embedded energy demand from outdoor breeding compared to conventional piggeries (Wiedemann et al., 2016a). Figure 17 shows the flow of manure management emissions for outdoor piggeries.

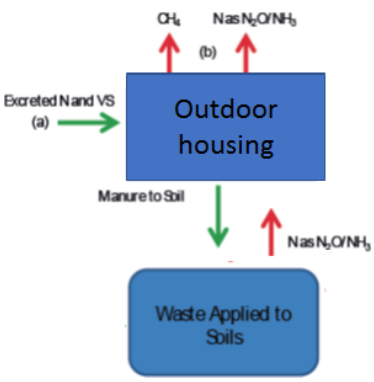

Figure 17. Mass flow method of estimating manure management emissions – outdoor piggeries (Commonwealth of Australia, 2016)

Generalised Abatement Approach and Feasibility
Conversion of conventional piggeries with anaerobic pond systems to outdoor housing systems can mitigate emissions considerably (Wiedemann et al., 2016a). The conversion of system results in changes to the treatment of waste from anaerobic to aerobic, thus avoiding the production of GHG from the use of anaerobic ponds.

The application of an outdoor housing system to the pig industries is feasible and GHG abatement is significant. This system has high land requirements, which may limit its application for small producers.

Abatement Potential and Supporting Evidence
Outdoor housing results in predominantly aerobic manure treatment resulting in lower emission factors (EFs) for CH_4, but not N_2O, in comparison to uncovered anaerobic ponds (Dong et al., 2006). According to Dong et al. (2006), outdoor housing has a maximum MCF of 2%, while a conventional uncovered anaerobic pond system has a maximum MCF of 80%. While outdoor housing has a maximum emission factors for N_2O of 0.02%, a conventional uncovered anaerobic pond system has a N_2O emission factors of 0%. This indicates significant emission abatement potential, though nitrous oxide emissions are an important consideration as these will be more significant.

Requirements
The conversion of conventional piggeries with anaerobic pond systems to outdoor housing system would be required for emission abatement.

GHG Emission Sources
As shown in Figure 18, outdoor housing systems only have emissions from land application areas.

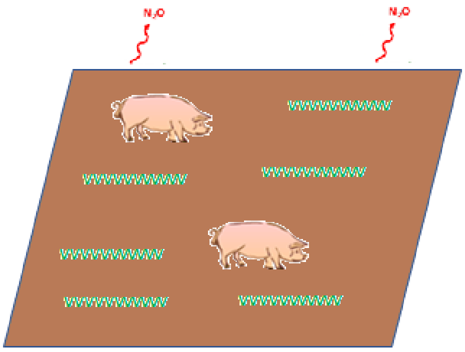

Figure 18. Possible GHG emissions sources from an outdoor housing system.

Leakage
Possible leakage from an outdoor housing system would include potential N emissions from system, and emissions from application of all pig excreta directly to land.

Boundaries
GHG emissions from the outdoor housing system and dispersal of manure on land must be included in project boundary.

Table 22. Generalised GHG assessment boundary for the baseline and project activities (Outdoor Housing)

	Source	Greenhouse gas/carbon pools
Baseline	Emissions from the animal house	Ammonia (NH_3)
	Anaerobically treated waste in project lagoons	Methane (CH_4), Ammonia (NH_3)
	Effluent and solids applied to land	Nitrous oxide (N_2O)
	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils	Ammonia (NH_3), Nitrous oxide (N_2O)
Project activity – outdoor housing	Indirect emissions arising from the volatilisation of ammonia and re-emission of nitrous oxide from soils	Ammonia (NH_3), Nitrous oxide (N_2O)
	Direct emissions	Nitrous oxide (N_2O)

Considerations

There are several considerations about outdoor housing systems that will need consideration. They are as follows:

- *Quantification of Nitrous oxide emissions (direct and indirect emissions):* This could be achieved by using conservative emission factors aligned with the NIR (Commonwealth of Australia, 2016),
- *Nutrient management:* outdoor housing can increase the risks of nutrient leaching into soil and groundwater contamination (nitrate leaching and ammonia emissions) and facilities would need to meet environmental licence requirements, and
- *Land requirements*: system requires more land per head of livestock. Reduced production intensity.

Table 23 shows the workshop outcomes for the assessment of technical, practical and economic feasibility for the Outdoor housing system. The Outdoor housing system was not supported.

Table 23. Review and workshop outcomes: assessment of technical, practical and economic feasibility for the Outdoor housing system

Item	Decision	Notes and considerations
Review summary		
Technical feasibility (scientific evidence, compliance with method requirements)	Yes	A number of requirements have been identified that need to be specified in the method to ensure abatement. With these requirements met, the technique is considered technically feasible to the pig industry taking into account the ERF abatement integrity requirements. This system has high land requirements, which may limit its application for small producers. Specific points are outlined below.
Additional	Yes	Traditional anaerobic pond to an outdoor housing system
Real and Permanent	Yes	Offsets represent actual reductions in GHG emissions and are non-reversible and will not cause an increase in GHG emissions other sectors.
Measurable, Verifiable	Yes	Emission reductions are quantifiable. Emission abatement would be predictive.
Transparent and Conservative	Yes	Transparency ensured by using NIR compliant published calculation techniques based on Australian research. Conservativeness ensured by using emission factors based on research together with project requirements that ensure conditions will not be suitable for emission generation.
Workshop Summary		
Practical Feasibility (could this technique be taken up?)	No	Major production system change, with new markets required for the pigs, new land, changed staff and pig management.
Economic Feasibility (is it worthwhile taking this technique up?)	No	If outdoor housing is chosen, it will be based on other financial drivers, not the sale of ACCUs
Expected uptake of the method	Low	In response to the above