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AUSTRALIAN Pork

Assessment of Treatment Technologies and Strategies to Mitigate GHG Emissions

Final Report
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Executive Summary

The Australian pork industry generates a small but none-the-less significant amount of greenhouse gas (GHG) emissions from pig farming that totals 1.6 Mt of CO_2 equivalents per annum. This represents 1.1% of agricultural emissions or 0.3% of Australia's total emissions. Almost all of the direct emissions from pig farming arise from the manure management system (MMS) at the farm. Pork producers can select from several different types of MMS for their farm, and this choice provides the farmer with scope to influence the amount of gaseous losses to the atmosphere and hence reduce them. This report aims to i) evaluate the most recent information and understanding of how different systems can affect both direct (N_2O, and CH_4) and indirect GHG emissions (N_2O from NH_3) on Australian piggeries via a literature review and modelling approach, and ii) to conduct economic modelling to investigate the costs/benefits associated with different mitigation strategies.

This final report consists of i) a literature review on manure management systems that pork producers may use to minimise GHG emissions, and ii) a series of case studies with an economic assessment of a range of manure management systems that show the greatest potential in terms of reducing GHG emissions and providing economic return. These case studies cover a range of piggery sizes to enable ready adoption by producers.

The literature review aimed to conduct a comprehensive analysis on manure management systems applicable to the pig industry that have the possibility of minimising greenhouse gas emissions from pork production. This includes current systems, systems that could be readily adapted in the pig industry and combined systems.

These systems were grouped into different case studies and evaluated on their ability to reduce GHG emissions relative to a baseline case. The baseline selected was a flushed piggery system, with an uncovered anaerobic pond for effluent treatment. The GHG emissions produced for each of the case studies were reported in kg CO_2-e/SPU/year. Table 1 shows the case studies examined and highlights the GHG abatement potential of each relative to the baseline. It should be noted that these results are preliminary and may change once data are available on to validate the mitigation potential and methane yields from various manure treatment systems.

Table 1: Case study GHG emissions (kg CO_2-equiv/SPU/year) and mitigation potential relevant to baseline

Case Study Unit	Direct emissions kg CO_2/SPU/year	Percentage less than baseline
1 – Baseline	587	
2 – Trafficable sedimentation basin/Uncovered pond/Stockpile	250	58%
3 – Screen/Uncovered pond/Compost	461	22%
4 – CAP[a]/flare	202	66%
5 – CAP/generator	167	72%
6 – CAP/boiler	200	66%
7 – CAP/CHP[b]	165	72%
8 – Engineered Digestion system/CHP system	64	89%
9 – Short HRT[c] system	166	72%

a - Covered Anaerobic Pond (CAP)
b - Combined Heat and Power (CHP)
c - Hydraulic Retention Time (HRT)

From this analysis, it was shown that all of the energy generation options reduced the GHG emissions relative to the baseline by a significant amount – 66% to 89%. A change of to a short HRT system reduced GHG emissions by 72%. The addition of a solids separation step such as a trafficable sedimentation basin or static rundown screen to the baseline scenario can reduce emissions by 58% and 22% respectively, based on current knowledge.

In addition to this comprehensive analysis, simplistic GHG modelling was performed for a deep litter system with composting or stockpiling of the spent litter. This showed that there is the potential to reduce the CO_2-equiv emissions by approximately 45% in comparison to the baseline.

This analysis highlighted the clear abatement opportunity that exists with a change from the industry standard to a number of alternative manure management systems.

An economic analysis was carried out for the systems which displayed the most potential in terms of reducing emissions and providing attractive financial returns. The economic modelling showed that the most profitable systems included the trafficable sedimentation basin with uncovered pond combination, the CAP with a generator or CHP unit and the engineered digestion system with CHP. These systems all displayed high cumulative profits over the assumed ten year lifetime of the project and short payback periods.

The feasibility of the CAP system with a boiler could be increased if there was higher energy demand at the facility (such as where a feed mill was located on site) or where there was another way to utilise heat at the piggery to generate income. This option should be considered by larger pig producers. Similarly, the economics of installing combined heat and power would improve if there was another economically viable use for heat beyond what the piggery is able to utilise.

The CAP-generator system had a payback period of 2.8-7.8 years for farms ranging in size from 75 000 SPU down to 3500 SPU respectively. The CAP-CHP system has payback of between 2.8 and 8.1 years for the range of piggery sizes investigated. These short paybacks are very promising for piggeries of all sizes. It should be noted that the revenue streams for both systems are heavily influenced by government legislation however. Approximately 48-51% of the revenue was assumed to come from Australian Carbon Credit Units (ACCUs) and Large-scale Generation Certificates (LGCs). These revenue streams are subject to a high degree of uncertainty within the timeframe of the analysis (10 years).

The engineered digestion system with the CHP unit was feasible only at larger piggeries because of the large investment costs. The system has a payback period ranging from just over 12 years at the 10 000 SPU piggery size to 4.7 years for the largest piggeries. The payback period is longer than the CAPs due to the larger investment costs associated with this system. However, an engineered digestion system typically has a lifetime of between 20 and 50 years. This means that the plant infrastructure does not need to be replaced after ten years, making the long term (20+ year) feasibility of these facilities more attractive. It is not clear what additional maintenance expenses would arise from the CAP system in this time In addition to this, engineered digesters are highly controlled, with constant production of methane gas. Therefore, pig producers at the larger end of the scale should not disregard this system because it is not as economically favourable as the CAP systems reviewed. The added benefits of ease of control, longer life and constant methane gas production may outweigh the higher costs over the first 10 years.

Estimated profits (net cash flow) for the energy generation systems were between $34,000 (small piggeries) and $1 million per year for large piggeries (with the CAP-CHP system). These are significant returns and clearly would be of benefit to pig producers in Australia.

Manure management is the largest emission source from Australian piggeries and offers the best options for mitigation. This study showed that the pork industry has many opportunities for reducing GHG emissions, whilst also increasing the turnover of individual farmers. The use of CAPs and capture/utilisation of biogas as a GHG mitigation opportunity is especially interesting for pig producers as it is now a recognised abatement methodology under the Carbon Farming Initiative (CFI). Technologies which have not yet been considered for methodology development under the Carbon Farming Initiative (CFI), such as trafficable sedimentation basins, screens and short HRT systems may also significantly reduce emissions from piggeries. There is a clear opportunity for these to be included under the CFI. This report shows that pork producers can profit while reducing their negative impact on the environment.

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1. Introduction

The Australian pork industry generates a small but none-the-less significant amount of greenhouse gas (GHG) emissions from pig farming, totalling 1.6 Mt of CO_2 equivalents per annum. This represents 1.1% of agricultural emissions or 0.3% of Australia's total emissions (Garnaut 2008). Almost all of the direct emissions from pig farming arise from the manure management system (MMS) at the farm. Research by Wiedemann et al. (2010) identified that the largest single emission source from the piggery manure management system was from the anaerobic breakdown of effluent at the pig farm. This process produces methane and contributed in the order of 66% of emissions for one case study supply chain investigated. Therefore, in the context of reducing GHG emissions for pork producers, the reduction of CH_4 emissions from the pond is the most important.

Pork producers can select from several different types of MMS for their farm, and this choice provides the farmer with scope to influence the amount of gaseous losses to the atmosphere and hence reduce them. This report aims to i) evaluate the most recent information and understanding of how different systems can affect both direct and indirect GHG emissions (N_2O, NH_3 and CH_4) on Australian piggeries via a literature review and modelling approach, and ii) to conduct economic modelling to investigate the costs/benefits associated with different systems. The economic modelling has been done in the context of the Carbon Farming Initiative (CFI), which may enable pig farmers to sell carbon offset credits to Australian buyers and Renewable Energy Certificates through the sale of electricity.

Manure management systems begin at the manure generation stage and continue to storage and treatment and finally to land spreading. There is potential at each stage of this system for CH_4, NH_3 and N_2O emissions to be reduced. For estimating the emissions from each MMS, published standard values are available via the Department of Climate Change and Energy Efficiency (DCCEE) and Intergovernmental Panel on Climate Change (IPCC). These manuals state that the most accurate (preferred) approach is to use a mass balance methodology. The mass balance approach allows for the determination of the change in emissions throughout the whole manure management system if one stage of the manure management system is modified. This is important, as the impacts of reducing emissions at earlier stages of the MMS can then be taken into account for downstream stages.

For the majority of pig farms in Australia, the treatment of the manure stream involves anaerobic digestion of the organic component of the manure stream. This process is a low cost and successful method of handling the large volumes of piggery manure produced in these facilities. This process can sometimes be preceded by pre-treatment systems to remove solids from the effluent stream. Anaerobic treatment options include: uncovered and covered anaerobic ponds, engineered liquid mixed digesters, liquid plug flow digesters and solid phase leach beds. Aerobic treatment includes the composting of solids, with other alternatives including combustion, gasification and pyrolysis. Some mechanical aeration is used in the treatment of piggery liquid manure streams; however this is not in the primary treatment stage due to the high organic matter content of the raw effluent.

A well designed and operated anaerobic treatment system will reduce the organic load of the manure stream, but can also produce significant quantities of greenhouse gases (GHG) in the form of direct emissions (methane) and indirect emissions (nitrous oxide via ammonia loss). As a result of climate change science and the known effects of GHG emissions on the world's climate, there is increasing pressure to reduce the level of GHG emissions from all sources. The Australian agricultural industries are exploring options available to improve GHG emission performance and is demonstrating commitment to this objective by conducting research projects, such as this.

There are two pathways for pork producers to follow to address their methane emissions. The first step is mitigation, where the emissions are reduced by some mechanism without energy generation. The second pathway is to utilise the methane by capturing this and using it to offset fossil fuel energy sources. Energy generation can be expected to be more expensive than mitigation. Utilisation technology is reasonably well established to capture methane from a pond surface using an impermeable pond cover and transforming the gas into a renewable energy source (heat and electricity) using a combined heat and power (CHP) unit. The high capital cost of this technological solution means that it is generally only economically viable for medium to large pig farming operations. In order for the whole of the pig industry to reduce GHG emissions, there is also a need to find low cost mitigation options that can be successfully implemented by smaller operations.

An important consideration in the investigation of methane mitigation options is the effect on the whole GHG emission profile. For example, a treatment option that reduces methane emissions may increase other GHG emissions (nitrous oxide) and subsequently cause an increase in overall GHG emissions.

This research project is a desk-top study and so the scope of this report does not allow for transport of piggery manure for use offsite. Only conventional flushing systems have been considered for this report.

1.1 Project Objectives

The first objective of this project was to conduct a comprehensive literature review on manure management systems applicable to the pig industry that have the possibility of minimising greenhouse gas emissions from pork production. This includes current systems, systems that could be readily adapted in the pig industry and combined systems. The systems under review for this project are:

- Mechanical solids separation.
- Separation of solids utilising sedimentation and settling.
- Evaporation pond systems.
- Covered anaerobic ponds (CAPs).
- Engineered digestion systems.
- Aerobic treatment systems .

Another objective of this project was to assess the systems identified in the literature review, for their ability to reduce GHG emissions relative to the industry standard of a flushing piggery with an uncovered anaerobic pond for effluent treatment – termed the baseline case. This analysis was carried out using carbon assessment methodology with the Life Cycle Assessment (LCA) software SimaPro.

The final objective of this study was to conduct economic modelling on the range of manure management systems that displayed the greatest potential in reducing GHG emissions relative to the baseline case. The possibility of flaring the biogas to gain Australian Carbon Credit Units (ACCUs) under the Carbon Farming Initiative (CFI) was explored, as was the utilisation of biogas for the production of energy onsite. The economic analysis used the payback period, return on investment after five years and cumulative cash flow over ten years as economic indicators. The economic analysis was conducted for a range of piggery sizes, from 3500 to 75 000 SPU. This meant that the results of the study are applicable to most pork producers.

2. Literature Review

2.1 Screening of Treatment Systems

This literature review aims to provide assumptions for both the GHG and economic modelling carried out in the latter stages of this report. In order to ensure that this report was made as comprehensive as possible and to reduce the vast number of likely permutations of systems that could be modelled, a screening methodology was developed in order to eliminate specific manure management systems. The literature review clearly documents which systems will be modelled further and provides justifications for screening systems from the modelling stages of this report.

The screening methodology used in the literature review had the following requirements, in order for systems to be modelled further:

- The technology had to be mature and easily accessible.
- The system had to be suitable for the treatment of piggery by-products.
- There had to be suitable amount of fundamental research previously carried out in the field of the chosen technology.
- The system had to be considered to have a likely expected benefit by experts in the field.

If a system failed for one or more of these screening requirements during the literature review section of this report, then it was not analysed further. After each of the systems passed this initial screening process, GHG modelling was carried out, followed by a comprehensive economic analysis.

2.2 Current Manure Handling Management Practice in Australia

The conventional method of intensive pig farming in Australia is to house pigs in sheds. The sheds are often separated into breeding sheds where boars, gilts and gestating sows are housed, and farrowing sheds where sows give birth and suckle the young pigs until they reach weaning age. The weaner pigs are then moved to weaner, grower and finishing accommodation.

A pig farm can be a farrow to finish piggery or specialise in pig breeding, weaners, growers and finishers or a combination of these.
Table **2** shows the typical pig classes found in piggeries in Australia (Tucker et al. 2010).

Table 2: Typical pig classes

Pig Class	Mass Range (kg)	Age Range (weeks)
Gilt	100-160	24-30
Boar	100-300	24-128
Gestating sow	160-230	-
Lactating sow	160-23	-
Sucker	1.4-8	0-4
Weaner	8-25	4-10
Grower	24-55	10-16
Finisher	55-100	16-24
Heavy finisher	100-130	24-30

2.2.1 Conventional Piggeries

A 'conventional piggery' which is often called a flushing piggery, typically has sheds with a drainage system that consists of slatted floors and under-floor channels. The manure stream produced by pigs which includes faeces, urine, water, and spilt feed, accumulates in the underground drainage channels. A well managed piggery would flush or empty the drains and channels regularly to remove the manure stream from the sheds.

The liquid effluent from the flushing piggery can be collected in a common sump, which is pumped out to the primary effluent pond, or the shed drains by gravity to the primary effluent pond. This effluent is generally treated and stored in a pond system prior to recycling in the piggery as flushing water, irrigated on-farm or evaporated.

The composition of effluent from a conventional piggery can vary widely depending upon the design and management strategy employed to run the piggery and the feed composition. Therefore, piggery effluent can contain differing amounts of faeces and urine, shed drainage water, wasted feed and spilt drinking water. This results in wide variations in its characteristics. There is also little reliable Australian data available on piggery effluent characteristics due to difficulties in sampling and analysis techniques.

For the conventional shedding system, the quality and quantity of flushing water will have an impact on the manure stream characterisation.

Table **3** shows typical manure characterisation data sourced from American piggeries.

Table 3: Typical conventional shed manure characterisation

Component	Unit	Flushed from shed	Expressed as mg/L
Moisture	%	98[a]	
Total Solids	%	2[a]	20,000
Volatile Solids	%	1.6[b]	16,000
Total Kjeldahl Nitrogen	%	0.20[a]	2000
Ammonia-N	%	0.14[a]	1400
Phosphorus	%	0.07[a]	700
Potassium	%	0.17[a]	1700
Calcium	%	0.04[a]	400
Sodium	ppm	300[a]	300
Magnesium	ppm	290[a]	290
Sulphur	ppm	155[a]	155
Zinc	ppm	33.6[a]	33.6
Manganese	ppm	14.4[a]	14.4
Copper	ppm	31.2[a]	31.2

Source: a) (ASAE 2005)
b) FSA Consulting estimate

Effluent characteristics are often grouped into physical, microbiological and chemical headings. The characteristics of effluent are determined by piggery herd structure, ration type, the method used to collect and remove fresh manure from the piggery shed and the management practices used within the shed. In Australia, variable volumes of water are used to flush effluent from sheds. This produces effluent with a solids content that ranges from about 0.5% to 3.5% TS.

The amount and type of solids present in effluent is important, as this affects the quantity of sludge produced and the type of land application systems required. Effluent solid fractions can be divided into seven distinct groups:

1) Total Solids
2) Settleable Solids
3) Dissolved Solids
4) Suspended Solids
5) Volatile Solids
6) Volatile Suspended Solids
7) Fixed Solids

The chemical characteristics of piggery effluent are highly variable. Nitrogen losses are variable from one shed system to another. Hence, no 'standard' figures for the chemical composition of piggery effluent can be developed. A large proportion of the total nitrogen remains in the suspended and dissolved phase and cannot be removed by settling or mechanical separation. This has the potential to increase odour generation from anaerobic ponds by increasing ammonia concentrations and inhibiting organic matter breakdown. A larger proportion of the total phosphorus has the potential to be removed by mechanical separation and more particularly, gravity settling. A significant amount of phosphorous is attached to the colloidal fraction which is difficult to remove in a cost effective manner. Thus, the best mechanisms for phosphorus removal are generally physio-chemical treatment processes.

2.2.2 Deep Litter Piggeries

Deep litter housing makes up a significant proportion of all of Australia's piggeries. Typical deep litter housing typically consists of concrete or clay floors with a fabric roof. The bedding material is typically straw, sawdust or rice husks and this results in solid waste manure rather than the liquid effluent produced by conventional piggeries.

The pigs within the deep litter housing are reared in a batch manner, with each batch lasting for about 8-15 weeks. Bedding is added at a rate of 0.3-1.8 kg material per pig. Deep litter is usually stockpiled or composted and then applied to land as a fertiliser replacement. However, anaerobic digestion of the spent bedding is also a potential treatment option. Table 4 shows the typical characteristics of spent bedding from a range of fresh bedding materials (Tucker et al. 2010).

Table 4: Nutrient content of spent bedding from deep litter piggeries

	Unit	Straw	Rice Hulls	Sawdust
Moisture	% wb	41.6 (18 - 64)	36 (21 - 53)	40.8 (21 - 50)
pH		6.8 (5.7 - 8.5)	7.1 (7 - 7.3)	6.3 (6.2 - 6.3)
Total Nitrogen	% db	0.8 (0.2 - 1.3)	0.7 (0.1 - 1.6)	0.9 (0.6 - 1.3)
Ammonium Nitrogen	% db	0.5 (0 - 1.2)	0.3 (0.1 - 0.5)	0.6 (0.4 - 1)
Total Phosphorus	% db	1.1 (0.2 - 2.5)	0.9 (0.6 - 1.3)	1 (0.4 - 1.3)
Ortho-Phosphorus	% db	0.4 (0.2 - 0.6)	0.4 (0.3 - 0.6)	0.4 (0.2 - 0.5)
Potassium	% db	1.8 (0.6 - 2.8)	1.8 (1.2 - 2.1)	1.8 (1.6 - 1.9)
Sulphur	% db	0.4 (0.1 - 0.7)	0.4 (0.3 - 0.5)	0.5 (0.4 - 0.5)
Copper	% db	0 (0 - 0.1)	0 (0 - 0)	0 (0 - 0)
Iron	% db	1.3 (0.1 - 3.2)	1 (0.7 - 1.6)	1.1 (0.5 - 1.6)
Manganese	% db	0.1 (0 - 0.8)	0.2 (0 - 0.8)	0.3 (0 - 0.8)
Zinc	% db	0.2 (0 - 0.4)	0.1 (0 - 0.3)	0.1 (0.1 - 0.2)
Calcium	% db	1.9 (0.4 - 3.1)	1.4 (1 - 2.1)	2.4 (2.1 - 2.7)
Magnesium	% db	0.7 (0 - 1.8)	0.4 (0 - 0.6)	0.4 (0 - 0.7)
Sodium	% db	0.4 (0.1 - 0.7)	0.3 (0.1 - 0.4)	0.4 (0.4 - 0.5)
Chloride	% db	0.8 (0.3 - 1.3)	0.6 (0.4 - 0.8)	0.7 (0.4 - 1.1)
Conductivity	dS/m	11.7 (6.6 - 15.6)	9.6 (9.2 - 10)	13 (12.6 - 13.4)

NOTES: *Data provided as average and range (in brackets).*

From (Tucker et al. 2010)

2.3 GHG Emissions from Piggery Systems

2.3.1 Emission sources

The three main gases that are of significance in terms of GHG emissions that are formed in piggeries are:

- Methane (CH_4) – for the GHG modelling carried out in this study, a Global Warming Potential (GWP) of 21 was used for methane as this is the value assumed by the DCCEE for the Carbon Farming Initiative.
- Nitrous Oxide (N_2O) – for the GHG modelling carried out in this study, a GWP of 310 was used for nitrous oxide as this is the value assumed by the IPCC.
- Ammonia (NH_3) – this gas is not considered a greenhouse gas, however ammonia contributes to indirect N_2O emissions via deposition to land and the transformations which occur before re-emission as N_2O.

Conventional pig production systems have various emission sources and these include:

- The effluent and manure collection system within the shed itself.
- Effluent ponds.
- Solids separation, stockpiles, and pond sludge stockpiles.
- Land application area.

2.3.2 Methane Processes and Emissions

The production of methane from piggeries is dependent on the volatile solid (VS) flow in the system. The DCCEE (2010) recommend predicting VS using the mass balance program PIGBAL (Casey et al. 2000). PIGBAL requires inputs of herd data, diet characteristics (digestibility, crude protein, amount ingested and estimated feed wastage) and effluent treatment system design. PIGBAL has been described elsewhere (Casey et al. 2000) and is the subject of a current validation project with APL. PIGBAL was also used for the LCA project by Wiedemann et al. (2010). Hence, a detailed description is not provided here.

A method for estimating methane emissions has been developed by the Intergovernmental panel for climate change (IPCC), and this has been adopted by the Australian national greenhouse gas inventory (NGGI). This method involves predicting VS, then multiplying this by two factors, the ultimate methane yield (B_o) and a methane conversion factor (MCF). This is shown in the following formula, reproduced from the DCCEE (2010) for liquid effluent treatment at Australian piggeries.

$$M_{IJ} = VS_{IJ} \times B_O \times MCF \times P$$ **EQUATION 1**

Where:

M_{ij}	= methane production for the waste (kg)
VS_{ij}	= volatile solids production (kg)
B_o	= Methane potential (0.45 m³ methane/kg VS – DCCEE 2010)
MCF	= Methane Conversion Factor. (90% for uncovered anaerobic ponds)
ρ	= density of methane (0.662 kg/m³)

Figure 1 shows the VS flow and CH_4 emissions from a conventional flushing piggery.

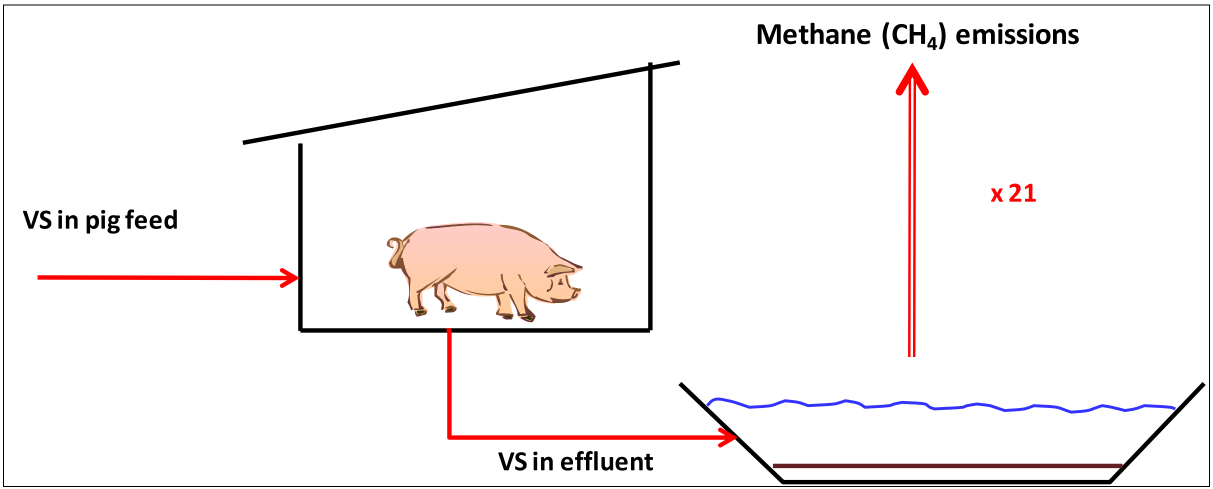

Figure 1: VS flow and CH_4 emissions from flushing piggery

2.3.3 Methane Yield

Theoretical and Ultimate Methane Yield

The theoretical methane yield describes the methane yield if all of the VS contained in the manure is converted to methane. Moller et al. (2004) note that "methane productivity" from manure can be measured in terms of volatile solids (VS) destroyed, VS loaded, volume, or animal production. Methane productivity measured in terms of VS destroyed (m^3 CH_4/kg VS_{DES}) corresponds to the theoretical methane yield (B_u) if there is complete degradation of all organic components of the manure.

The ultimate methane yield (B_o) is the amount of methane that is produced under laboratory conditions and it is determined by anaerobically digesting a sample of manure and measuring the methane yield. It has units of m^3 CH_4/kg VS (IPCC 2006). The ultimate methane yield will always be lower than the theoretical methane yield because a fraction of the substrate is used to synthesize bacterial mass, a fraction of the organic material will be lost in the effluent, and lignin-containing compounds will only be degraded to a limited degree (Moller et al. 2004). Inhibition of the biological process by inhibitors such as ammonia and volatile fatty acids (VFA) is another factor contributing to the ultimate methane yield being lower than the theoretical yield which would be obtained if inhibition was not present. It has been observed that the ultimate methane yield (B_o) of manure from different origins can be extremely variable. Moller et al. (2004) note that the ultimate methane yield (m^3 CH_4/kg VS) is affected by various factors, including:

- Species, breed and growth stage of the animals
- Feed
- Amount and type of bedding material
- Degradation processes during pre-storage.

IPCC (2006) provides typical B_o values for different livestock species and locations.
Table **5** shows IPCC values for B_o for pigs, dairy cattle and beef cattle in Australia (Oceania).

Table 5: Ultimate methane-producing capacity of the manure (B_o) - Oceania (IPCC 2006)

Animal	**B_o (m^3 CH_4/ kg VS)**
Swine	0.45
Dairy cattle	0.24
Non-dairy cattle	0.17

This discussion about the definition of B_o by Moller et al. (2004) highlights the lack of clear definitions in this area. Most researchers assume that B_o refers to fresh manure directly from the animal prior to any breakdown and without additions from bedding and wasted feed. This is a parameter that is intrinsic to the animal and independent of the housing and feeding system. However, the discussion by Moller et al. (2004) suggests that B_o takes into account housing and feeding systems.

Vedrenne et al. (2008) point out that there is no standard methodology for the determination of B_o and different researchers have used different methodologies. The variations in methodology include:

- Incubation temperature (varies from 35°C to 55°C).
- Source and amount of inoculums added.

- Timing and amount of mixing of the sample.
- Amount of dilution of the sample.
- Incubation time (50 to 157 days).

Not surprisingly, both (Vedrenne et al. 2008) and (Karim et al. 2005) have found that variation of any of these parameters affects ultimate methane yield. Hence, apart from variations between species and feed type, B_o data will vary depending on experimental protocol and should be evaluated with knowledge of the experimental procedures adopted.

Methane Conversion Factor (MCF)
MCF is methane conversion factor (MCF) that reflects the portion of B_o that is achieved (IPCC 2006). The system MCF varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100%. Both temperature and retention time play an important role in the calculation of the MCF. Manure that is managed as a liquid under warm conditions for an extended period of time promotes methane formation. These manure management conditions can have high MCFs, of 65 to 80%. Manure managed as dry material in cold climates does not readily produce methane, and consequently has an MCF of about 1%.

Actual Methane Yield
The actual methane yield is found using Equation 1 and will be much lower than the theoretical and ultimate methane yields.

2.3.4 Nitrogen Processes and Emissions
Conventional Piggery Effluent
The nitrogen content of piggery effluent is high and mainly in the form of organic nitrogen and ammonium. N_2O and NH_3 are the most important N emissions from the piggery system. Figure 2 shows these main N emission sources from a conventional system.

Ammonia volatilisation is a significant nitrogen loss inside a piggery shed. Urea is one of the main nitrogenous wastes of pigs. Urea is converted to amino acids and then ammonium ions (NH_4^+-) through the process of deamination. The ammonia volatilisation process occurs because ammonium-N (NH_4^+-N) is converted to dissolved ammonia gas (NH_{3g}). Equation 2 shows the chemical reaction which results in ammonia volatilisation.

EQUATION 2

Denitrification is the process which converts nitrates to nitrous oxide or nitrogen gas. It is an anaerobic process and can only occur when there is no oxygen or very low quantities of oxygen present. This process requires a source of carbon as an electron donor, and the presence of nitrite (NO_2^-), nitrate (NO_3^-), nitric oxide (NO), or nitrous oxide (N_2O).

Nitrous oxide is an intermediate by-product of the denitrification process.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad \textbf{EQUATION 3}$$

Nitrous oxide may also be produced during the nitrification process when oxygen supply is limited.

There is little published data on nitrous oxide emissions generated inside a piggery shed. Chadwick et al. (2011) discuss how in piggery houses that do not use bedding materials, the manure remains in a chiefly anaerobic state with little chance for the NH_4^+ to be nitrified. As a result, little or no N_2O emissions are likely to occur from such systems. With regards to ammonia emissions, it has been assumed that 8-10% of the total N excreted is lost as ammonia in conventional flushing piggeries.

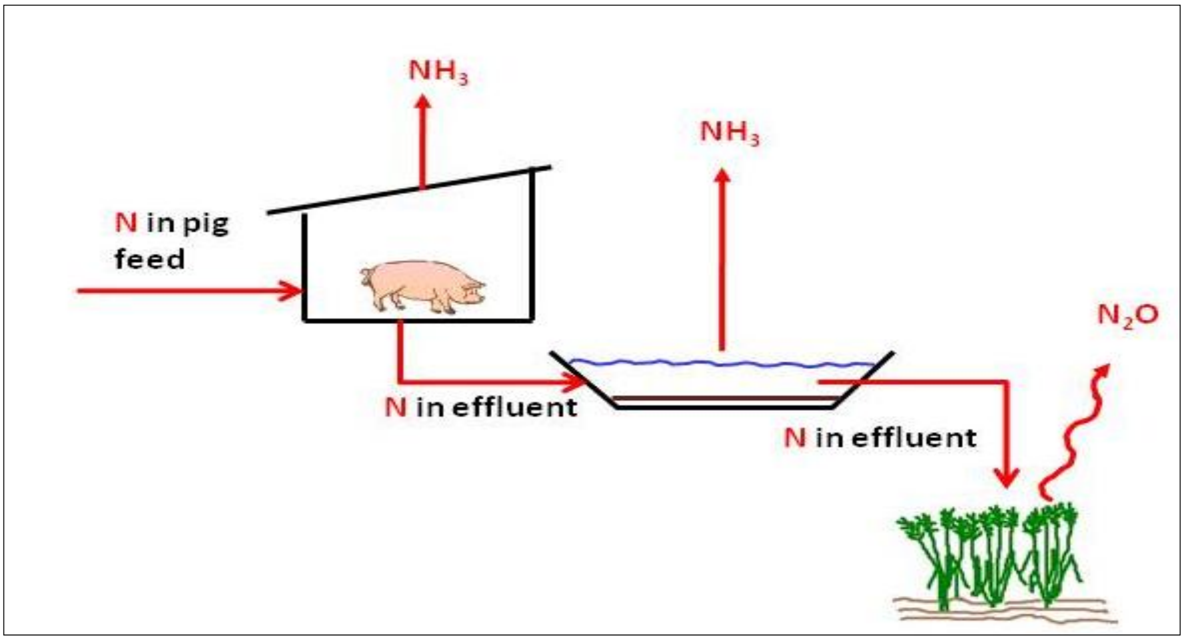

Figure 2: N Flow and N_2O and NH_3 emissions from flushing piggery

Piggery Deep Litter
Most ammonia in the deep litter system originates from urine excretion in the form of urea:

EQUATION 4

Which is readily converted to ammonia in the presence of the urease enzyme. Depending on a range of other conditions, this ammonia can be lost through volatilisation, or can be transformed to the aqueous ammonium ion in a pH dependent, reversible reaction (Equation 5).

EQUATION 5

EQUATION 6

These reactions may take place within a very short time of excretion and can result in ammonia volatilisation from the system. Strictly, ammonia loss is a temperature dependent reaction where $NH_{3(l)}$ is transferred to $NH_{3(g)}$. High temperature conditions in the litter mat will influence this relationship, as will factors influencing other pathways for ammonia (i.e. the ammonium pathway).

In deep litter systems, ammonia may follow through multiple pathways depending on conditions. This can lead to further losses of other nitrogen gases, notably N_2O and N_2. This requires transformation of ammonium to nitrate (nitrification) and then the process of denitrification to produce N_2 as the end product. Apportioning all gaseous nitrogen losses to ammonia is therefore likely to over-estimate the true emission rate from the deep litter shed.

To assist in the estimation of N losses from deep litter piggeries in Australia, (FSA Consulting 2007a) performed a mass balance on a deep litter piggery in southern Australia. This piggery had detailed piggery production, feed input, bedding input and litter production to enable an estimation of N losses from the system. This mass balance study concluded that 17% of the excreted nitrogen was lost in the gaseous form from the shed before the litter was removed.

The report concluded that it was not possible to accurately quantify the ammonia portion of the total gaseous N loss in Australian conditions without further research. It is estimated that 15% of the total N excreted is lost as ammonia in deep litter sheds.

Nitrous oxide is generated by nitrification which occurs in the soil following land application of manure. Emissions can also occur from livestock bedding and solid manure stores, in addition to the surface layer of stored slurry (Chadwick et al. 2011). Nitrogen is deposited on the litter mat in deep litter systems in the form of organic N in solids and urea in urine. It has been suggested that 15% of the N fed will be excreted in the faeces, while 55% is excreted in the urine (Harper et al. 2004). When manure (solids and urine) is deposited on the litter mat it is exposed to the processes of ammonification, nitrification, denitrification and transformation into organic nitrogen depending on the initial form of nitrogen supply, the presence of urease enzymes, pH, oxygen availability, temperature and microbial activity. There are several pathways for nitrogen output and loss from the shed, as displayed by Figure 3 below. The loss pathways relevant to the estimation of ammonia emissions are discussed below.

It is estimated that the amount of gaseous N lost as direct nitrous oxide (N_2O) emissions is 2% of the total N excreted. Indirect N_2O emissions which arise as a consequence of the deposition of NH_3 on land is assumed to be 0.01 kg N_2O-N/kg NH_3-N for all systems under investigation for this report.

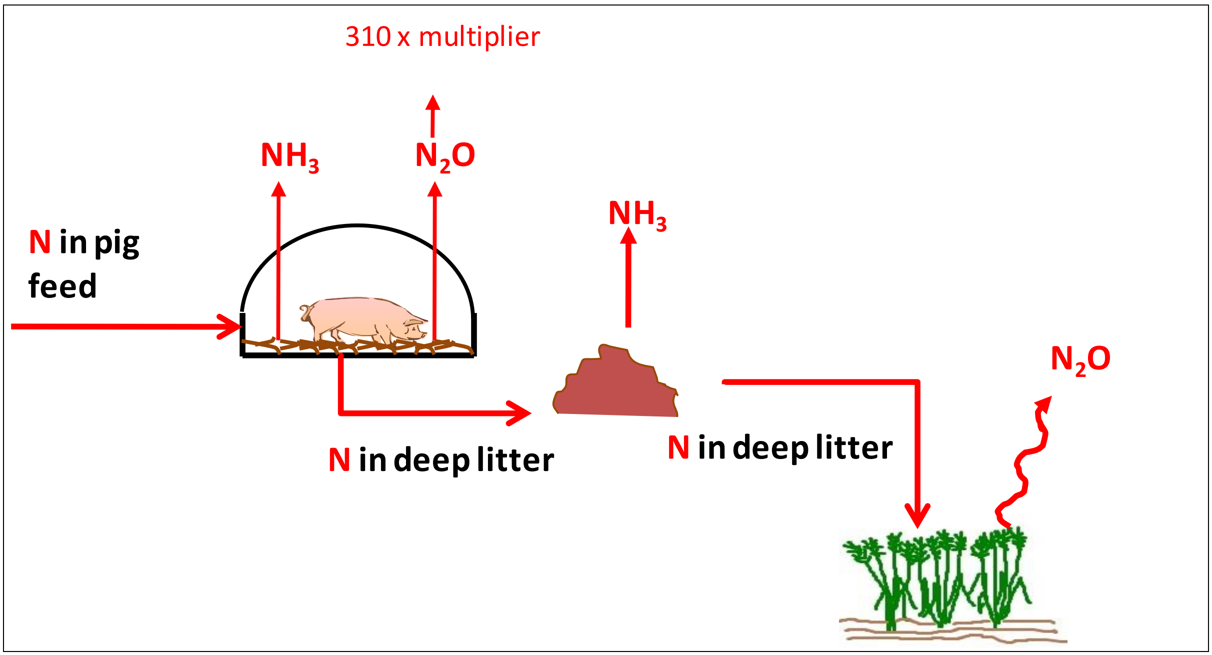

Figure 3: N Flow and N_2O and NH_3 emissions from deep litter piggery

2.4 Short Hydraulic Retention Time (HRT) Systems

2.4.1 Description of System

The storage of piggery manure in short HRT tanks or pits is common practice in Europe and North America. The IPCC defines short HRT systems as "*Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.*" For this analysis it is assumed that the manure is stored for a period of less than 1 month.

Short HRT systems are sometimes used with small to medium sized piggeries where the volumes of manure are not that large. The manure storage pits may be separate structures from the piggery housing or be below the housing itself. The manure may be scraped into the pit or tank on a regular basis or the housing may have slatted floors. This type of system is not common in Australia. Pump-out pits are usually for smaller piggeries due to their limited capacity – the manure can then be pumped to larger storage structures. For this analysis, it is assumed that only piggeries up to 10 000 SPU can install short HRT systems onsite, due to the volume constraints of handling large amounts of manure.

2.4.2 GHG Performance Data

There is little data available on the GHG emissions that arise from short HRT systems. Griffing et al.(2007) conducted an analysis of twenty six experimental studies of ammonia emissions from pig buildings that have some type of pit/slurry system in place. Ammonia emissions were compared on a percent loss of excreted TKN basis (emissions were assumed to be linearly related to live weight (LW)). In order to account for seasonal and daily changes in emission factors correction factors were applied. Emission factors in the United States and Europe were found to be 22 and 21% loss of TKN excreted from the animal.

The IPCC reports N_2O emission factors to be 0.002 kg N_2O/kg N and the NH_3 emission factor as 0.25 kg NH_3/kg N (range 0.15-0.30). The DCCEE and IPPC also report methane conversion factors (MCF) of 0.5 (range 0.35-0.65) and 0.135 (range 0.03-0.30) respectively for pig manure stored in pits or tanks and spread on a weekly basis. Table 30 and Table 35 in Appendix A show a more detailed explanation of the emission factors assumed for this system.

2.4.3 Capital and Operating Costs

The capital cost of a short HRT system (pit or tank) capable of storing 25 000 L of piggery effluent was assumed to be approximately $2500. From previous feasibility studies, FSA Consulting determined that the average monthly effluent volume per SPU is 319 L. This means that this volume can store effluent from 78 SPU for 1 month. Therefore the capital cost per SPU of this system were assumed to be $32 for a 3500 SPU piggery. However in order to account for agitators in the tank, the cost was increased by 40%, to $45/SPU/annum. The costs for the 10 000 SPU piggery are slightly reduced to $42/SPU. The annual costs for this system were assumed to be the same as those for a trafficable sedimentation basin (discussed in detail in section 0)

Table 6: Capital and annual costs for short HRT system

Short HRT System	3500 SPU	10 000 SPU
Capital Costs ($/SPU)	45	42
Annual Costs ($/SPU/yr)	1.46	1.44

These costs mean that the total capital infrastructure costs for the short HRT system are assumed to range between $156 800 and $420 000 for the 3500 SPU and 10 000 SPU piggeries respectively.

2.5 Pre-Treatment Systems – Solids Separation

A significant reduction in the treatment pond methane emissions can be achieved by implementing solids separation technology in the management of piggery effluent. Pre-treatment systems partition the VS and nutrients between different manure management stages. They are just as important as emission factors with regards to changing the GHG profile from piggeries. For example, the removal of 25% of VS before entering the pond will reduce pond methane emission by 25% reducing overall manure emissions by 23% (Poad et al. 2010). The separated solids would require good compost management to avoid additional GHG emissions occurring from the wet solids produced by the solids separator. It is claimed solid separation plus aerobic treatment can decrease greenhouse gas emissions by about 97%, and conserve much of the manure nitrogen for by-product streams (Vanotti et al. 2008).

There are many different methods used for removing solids from liquids. These methods can be grouped according to the basic removal mechanism:

- Gravitational Settling
- Perforated Screens
- Presses (confinement and squeezing)
- Centrifugal Separation
- Dissolved Air Flotation
- Chemical Flocculation
- Combined Systems
- Dry Scraping

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 et al. 2010). 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 and VS (McGahan et al. 2002). The solids produced are expected to be dry, easily handled and readily compostable.

To achieve an overall reduction in GHG emissions for farms using solids separation technology, the separated solids must be treated in an aerobic manner to avoid further methane production.

Each of the previously mentioned removal methods have different solid separation devices associated with them. The four solid separation systems that have been looked at for this project are:

1) Trafficable sedimentation basins
2) Sedimentation and Evaporation Pond Systems (SEPS)
3) Static rundown screens

4) Screw press

Trafficable sedimentation basins and SEP systems fall under gravitational settling, static rundown screens are a form of a perforated screen and a screw press is from the press category of solid separation system.

2.5.1 Trafficable Sedimentation Basin

Description of the System

Trafficable sedimentation basins are large tanks, which separate solids based on gravitational settling. For a complete description of this system, please see the report by Watts et al. (2001) – *Low cost alternatives for reducing odour generation,* Final report of Project No. 1629, Australian Pork Limited, June 2001, Canberra.

Figure 4 illustrates the basic design considerations of a trafficable settling basin system (Watts et al. 2001).

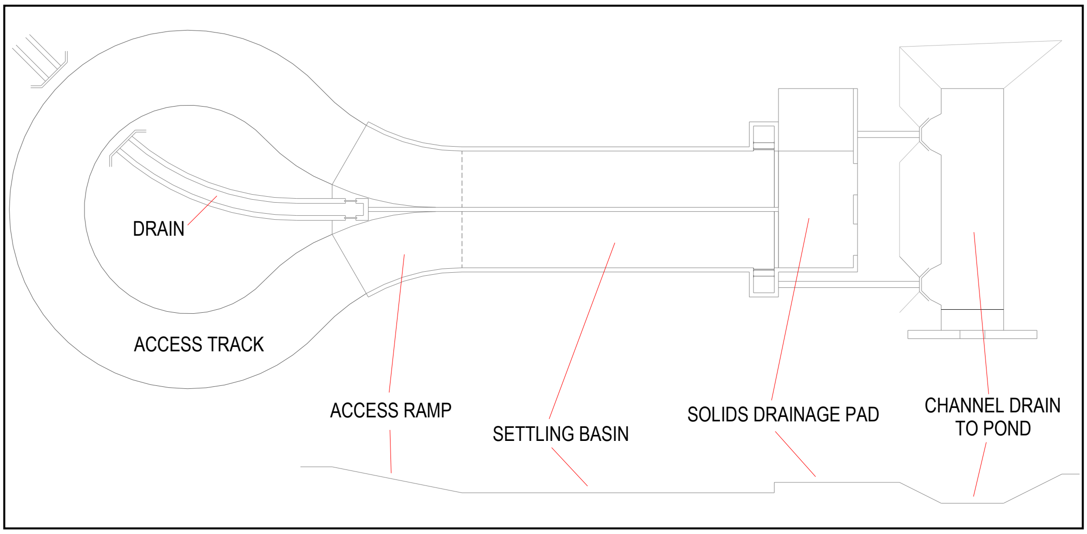

Figure 4: Typical basin configuration

GHG Performance Data

Settling has the potential to remove more solids than most mechanical separation alternatives. These systems enable about 80% of the volatile solids (VS) in effluent to be settled relatively easily (Kruger et al. 1995).

As is shown in Equation 1, the total amount of methane emissions from pig manure is directly dependent on the VS content of the effluent. If up to 80% of the VS can be settled out in the trafficable sedimentation basin, this means that the treated manure will have enhanced environmental quality with regards to greenhouse gas mitigation and carbon sequestration. Table 31 and Table 36 in Appendix A show a more detailed explanation of the partition factors assumed for this system.

Capital and Operating Costs

In 1999, E.A. Systems Pty Limited designed a trafficable settling system for a piggery in central NSW. Two trafficable settling systems were designed to meet the needs of the 24 000 SPU farrow to finish facility (Watts et al. 2001). At this time, the capital cost of installing one sediment basin such as that shown in Figure 4 was about $15 000 for the facility (Watts et al. 2001). It is estimated that these costs may have doubled since this time and as such for this report, it is assumed that the costs are $30 000. The capital cost of a dual basin system ranges between $16 000 and $60 000 to $70 000 for different sized piggeries. The capital cost for a dual basin system was assumed to range between $3.50 and $8.00 per SPU. The cost per SPU is smaller for larger operations due to economies of scale. These indicative costs per SPU mean that the total capital infrastructure costs for the trafficable sedimentation basin system were assumed to range between $28 000 and $262 500 for the 3500 SPU and 75 000 SPU piggeries respectively. These costs should be approached with caution as they are highly variable due to differences in site characteristics and the type of production system used.

From the information gathered at the piggery, it was assumed that it takes approximately 7.5 hours per week (390 hours per year) from a labourer to manage a dual basin. This involves removing solids using a front end loader which was assumed to be owned by the piggery. These costs range between $75 and $90 per hour. These values equate to $1.2-$1.5 per SPU per annum (this is based on the piggery size of 24 000 SPU).

2.5.2 Sedimentation and Evaporation Pond Systems

Description of the System

Sedimentation and Evaporation Pond Systems (SEPS) consist of a long continuous ditch or basin, which follows the contour and is designed to store sludge solids for a six or twelve month period. For a complete description of this system, please see the report by Watts et al. (2001) – *Low cost alternatives for reducing odour generation,* Final report of Project No. 1629, Australian Pork Limited, June 2001, Canberra.

GHG Performance Data

There is currently very little research on the greenhouse gas mitigation potential of SEPS and as such, it would not be feasible to carry out a GHG mitigation analysis of this system, therefore it has not been studied further.

2.5.3 Static Rundown Screens

Description of the System

Static run-down screens or stationary screens use gravity flow and particle size properties to collect the solids on the surface of the inclined screen. Photograph 1 shows a typical static rundown screen in operation. For a complete description of this system, please see the report by Watts et al. (2001) – *Low cost alternatives for reducing odour generation,* Final report of Project No. 1629, Australian Pork Limited, June 2001, Canberra.

Photograph 1: Collection of thickened solids from a static screen

GHG Performance Data

The work carried out by Shutt et al.(1975) determined that low flow rates and small mesh sizes result in more TS and VS being captured on the screen. This study found that that the percentage of TS retained on the screen was 35.2%, and VS was 21.5%, at a volumetric flow rate of 123 L/min and a mesh size of 1.0 mm. At the higher flow rate of 313 L/min and larger mesh size of 1.5 mm, the concentrations of TS and VS retained on the screen were much lower at 4.2 and 5.6% respectively.

The study by Piccinini & Cortellini (1987) used a static rundown screen to separate solids from a piggery influent stream which had TS concentrations of 1, 2.5 and 4.5% respectively. The flow rate was held constant at 70 L/min (4.2 m^3/hr). The maximum removal efficiency of TS and VS was found to be 30.8 and 37.6% respectively, while the minimum removal percentages removed were 5.7 and 5.4%.

Charles (2000) used a static rundown screen of aperture diameter 0.5 mm and an effluent flow rate of 250 L/min. The TS concentration of this piggery effluent was 1.02%. In the two runs analysed, the percentage removal of the TS was 10.8% and 9.8% respectively. The authors comment that these results are a third of that reported by (Shutt et al. 1975) using a similar flow rate, but with a larger screen aperture. This is most likely due to the very small particle size of the piggery effluent in this study – only 6% of the TS in the effluent tested had a diameter greater than 0.5 mm. The solids concentration of the fraction retained on the screen was only 11.2%. At this concentration both pumping and shovelling would be difficult.

Tucker et al. (2010) determined that the solids removal efficiency for static rundown screens to be 20% for TS concentrations of 1.2% (typical) and 3.1% (high). This leads to a reduction in the GHG potential of the effluent flowing to the anaerobic treatment stage. Metcalf & Eddy Inc. (2003) report TS removal rates of 5-30% for fixed parabolic rundown screens and BOD removal rates of 5-20%.

Clearly there is a wide variation reported in the literature for the solids removal efficiency of static rundown screens. It has been determined that at low effluent flow rates, small mesh aperture sizes and relatively larger solids particle sizes, the removal efficiency is increased. Handling of the solid retained on the screen is made easier if the solids concentration of this fraction is high. In order to minimise GHG emissions using this pre-treatment phase, it is necessary to remove a high concentration of the solids with the screen. Table 31 and Table 36 in Appendix A show a more detailed explanation of the partition factors assumed for this system.

Capital and Operating Costs

In the case study carried out by (Watts et al. 2001), four piggery case studies were analysed. These were a 2000 SPU and a 20 000 SPU unit operated under low flushing (5 L/SPU/day) and high flushing (25 L/SPU/day) regimes. It was determined that the capital cost ranged between $35 000 and $53 000 for small and large piggeries. It should be noted that the actual data used to confirm these prices is from the year 2000, therefore they were increased to reflect the rise in costs over time. This includes the stationary screen and infrastructure, collection sump, agitator and pump. This means that the capital costs range from $2.7-17.5 per SPU, with the lower costs seen for larger piggeries due to economies of scale.

The operating costs could range from $210 to $500 per ML of effluent treated for a 2000 SPU piggery to $90 to $195 per ML of effluent treated for a 20 000 SPU piggery. For the purposes of this report, it was assumed that the operating costs ranged between $90 and $500 per ML. The average annual flow of effluent per SPU is equal to approximately 0.0038 ML. This means that that the average annual expenses for this system ranged between $0.34 and $1.9 per SPU per annum.

2.5.4 Screw Press

Description of the System

The screw press system uses the build-up of sludge solids on the screw to press the water through the solids plug (see
Figure **5**). For a complete description of this system, please see the report by Watts et al. (2001) – *Low cost alternatives for reducing odour generation,* Final report of Project No. 1629, Australian Pork Limited, June 2001, Canberra.

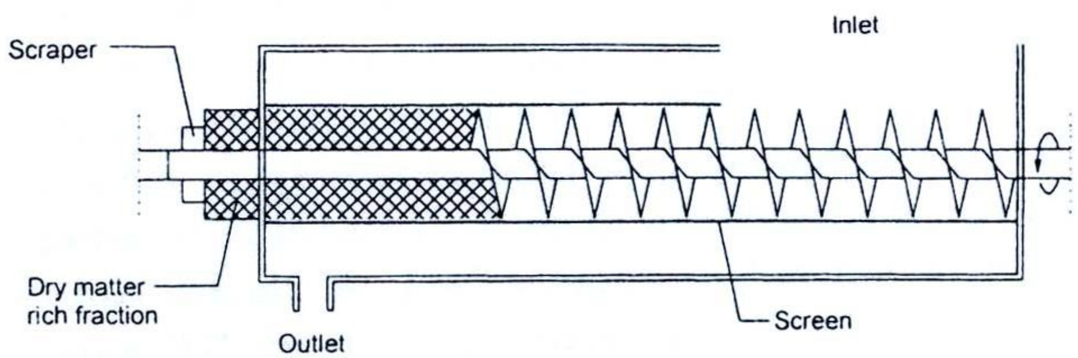

Figure 5: Schematic diagram of a screw press (Moller et al. 2000a)

GHG Performance Data

A trial was carried out by (Converse et al. 1999) to evaluate the solids removal efficiency of two screw presses (a FAN and a Vincent), for dairy effluent from both flushing and scraping manure collection systems. The manure used was from a recycled flushing stall system with a small amount of lime added to the floor. The manure for the Vincent press was from dairy stalls using chopped straw and recycled manure as bedding. The manure was removed using a scraping system.

Both screw-presses produced solids with a high TS concentration (26% and 29% for the FAN and Vincent respectively). Removal efficiencies of 24% and 33% calculated on concentrations, and 26% and 38% based on mass balance were obtained for the FAN and Vincent presses respectively. However, comparisons of the data are not particularly useful given that the TS concentration of the influent, the manure composition, the back-plate pressure and the influent flow rates all vary. Hence the higher removal efficiency of the Vincent machine most likely reflects the higher TS concentration and lower influent flow rate.

The study by Rico et al. (2011) looked at the performance of the only dairy manure biogas plant in Cantabria on the northern coast of Spain, and was evaluated in terms of liquid-solid separation using a screw press. After running the screw press separator, the investigation found that 18% of the manure mass was found in the solid fraction, which implies that 50% and 56% of the TS and VS were removed from the liquid fraction. It was also determined that 21% and 22% of total phosphorous and organic nitrogen was removed from the liquid fraction. The TS removal efficiency (50%) results are considerably higher than those reported by Tucker et al. (2010) (10-20%). This can be explained by the fact that the performance data of screw presses is extremely variable, caused by different waste characteristics. Table 31 and Table 36 in Appendix A shows the partition factors assumed for this analysis.

Capital and Operating Costs

As was described in Section 0, in the case study carried out by Watts et al. (2001), four piggery case studies were analysed. These were a 2000 SPU and a 20 000 SPU unit operated under low flushing (5 L/SPU/day) and high flushing (25 L/SPU/day). This study determined that the capital cost of a screw press could be $84 000 for a 2000 SPU piggery and $186 000 for a 20 000 SPU piggery (actual data is from 2000, therefore the prices have been increased to reflect the rise in costs over time). Capital costs include a FAN separator, shed, pumps, sumps and agitators. Therefore, the capital costs range from approximately $8 to $24 per SPU. These costs are again highly variable and as such should be approached with caution.

The operating costs could range from $220 to $455/ML of effluent treated for the 2000 SPU case studies and $120 to $215/ML of effluent treated for the 20 000 SPU case studies. For the purposes of this report, it was assumed that the operating costs ranged between $120 and $455 per ML. The average annual flow of effluent per SPU is equal to approximately 0.0038 ML. This means that that the average annual expenses for this system ranged between $0.5 and $1.7 per SPU per year.

Although the screw press is a well researched solids separation technology and there is good data with regards to costs and GHG performance, it was decided to omit this from the manure management systems under review in the latter stages of this report due to its similarity with the static rundown screen in terms of VS and N removal efficiencies.

2.5.5 Summary of Capital Costs and Annual Expenses for Pre-Treatment Systems

Table 7 and Table 8 summarise the capital costs and annual expenses for the three pre-treatment systems investigated for this report.

Table 7: Capital costs for pre-treatment systems

$/SPU Pre-treatment System	SPU 3500	10 000	20 000	50 000	70 000
Trafficable Sedimentation Basin	8.0	6.0	5.0	3.7	3.5
Static rundown screen	17.5	12.0	9.0	3.8	2.7
Screw press	24.0	15.0	9.3	8.4	8.0

Table 8: Annual expenses for pre-treatment systems

$/SPU/yr Pre-treatment System	SPU 3500	10 000	20 000	50 000	70 000
Trafficable Sedimentation Basin	1.5	1.4	1.4	1.3	1.2
Static rundown screen	1.9	1.3	1.0	0.5	0.3
Screw press	1.7	1.5	1.1	0.8	0.5

2.6 Effluent Treatment Options

There are a range of different treatment methods for treating effluent from conventional liquid based piggery systems. Most primary effluent treatment systems are designed to operate under anaerobic conditions, there are aerobic treatment systems also. A well designed anaerobic system provides enough volume to support a colony of anaerobic microbes, which digest a significant proportion of the volatile solids. This improves the quality of the liquid effluent stream and produces a stable organic sludge.

2.6.1 The Anaerobic Digestion Process

Anaerobic digestion is a biological mechanism that converts organic material, into methane, and carbon dioxide. The energy in the material being digested is retained in the produced gas as methane. Anaerobic digestion is a natural process that takes place in the absence of external electron acceptors such as oxygen. The key steps involved in anaerobic digestion include (Monnet 2003):

a. Hydrolysis – This is a chemical process where hydroxyl groups break down complex organic molecules into sugars, amino acids and fatty acids. This step can often limit the rate of the digestion process due to the nature of the feed stream. To reduce the possibility of rate limitation the feedstock should be reduced to a small particulate size. Significant rate limitation in this step will lead to an overall poor digester performance. This would be evident with undegraded material being washed out.
b. Acidogenesis / Fermentation – This is a biological process in which sugars and amino acids are converted into volatile fatty acids, alcohols, and carbon dioxide. It is almost never rate-limiting, but will decrease pH, and may inhibit other steps.
c. Acetogenesis – Organic acids and alcohols are converted to acetic acid, and hydrogen in this biological process. It is generally only rate-limiting in very high rate processes.
d. Methanogenesis – There are two different biological processes occurring in which (i) acetate is converted to methane (aceticlastic methanogenesis - 70% of methane produced), and (ii) hydrogen and carbon dioxide is converted to methane. The first process is highly impacted by potential inhibitors, including ammonia, pH (stops at pH < 7.0), and specific issues. Normally reactor failure is initiated by failure of process (i)(Batstone et al. 2002). Aceticlastic methanogens are the organisms which contribute to the majority of methane

production and are also the slowest growing. These organisms can be washed out of the digestion system if retention times are below ten days.

2.6.2 Anaerobic Digester Operating Conditions

The performance of the anaerobic digestion process is strongly temperature dependant.. Applications of the process can occur at ambient temperatures also known as psychrophilic (15-20°C), mesophilic (25-40°C), or thermophilic temperatures (50-60°C). Typically, most digesters are designed for either mesophilic or thermophilic conditions, with low cost digesters being mesophilic (Lansing et al. 2008). The rate of anaerobic digestion increases with increasing temperature and the ideal range is 30°C to 45°C (Kruger et al. 1995). Biogas plants which use tanks and reactors for digestion typically operate in the mesophilic temperature range 30°C-40°C or thermophilic range from 50°C-60°C.

Ammonia inhibition has a strong impact on the final step of aceticlastic methanogenesis, and in the short term, will cause inhibition. In the long term, it will cause a fundamental change in microbiology that causes the system to operate in a sub-standard way (Karakashev et al. 2006).

2.6.3 Types of Anaerobic Digestion

The design of the anaerobic digester needs to provide sufficient retention time to allow for hydrolysis of particulate substrates, and provide beneficial conditions for methanogenesis where acetate is converted to methane. This also includes maintaining the digester pH above 7.0.

Anaerobic digestion technologies have developed into two broad areas. Long hydraulic retention times with extended sludge retention, such as anaerobic lagoons, liquid mixed digesters, plug flow digesters and leach bed digesters, provide beneficial conditions for the methanogenesis step where acetate is converted to methane. A short hydraulic retention time with extended solids retention to promote hydrolysis of the feed stream is a feature of the high rate digester. Figure 6 shows the grouping of the anaerobic digestion technologies in two broad areas.

From Figure 6 it is clear that plug-flow digesters and solid-phase leach beds are suited to handling manure with relatively high solids concentrations – typically found with manure from deep litter piggeries, while anaerobic ponds, liquid mixed digesters and high-rate AD are more suited to manure from conventional piggeries.

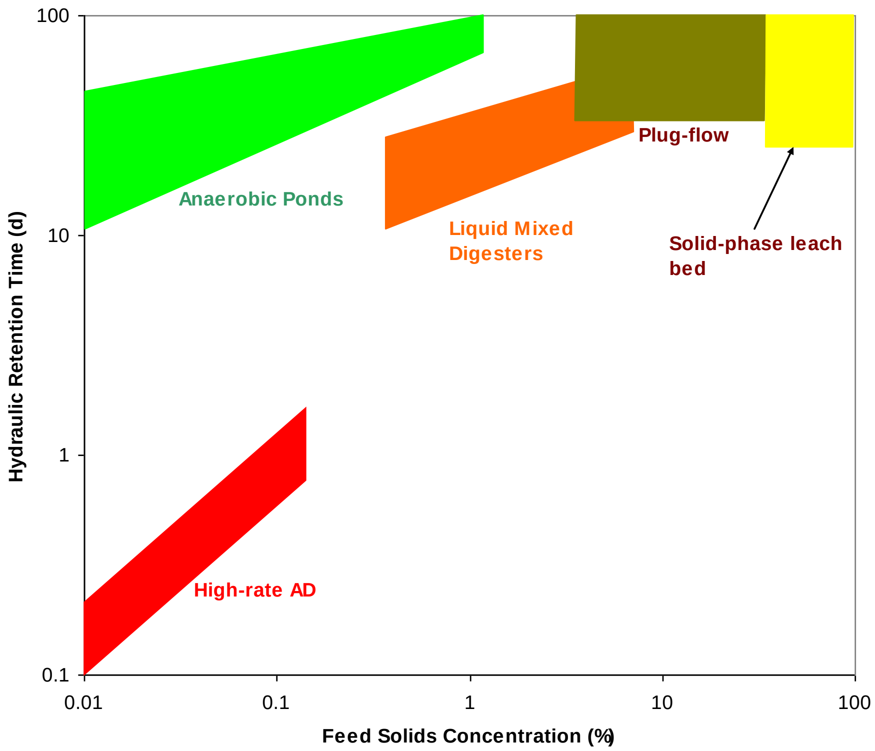

Figure 6: Operating conditions (HRT and feed solids concentration)
Source: (Batestone 2009)

2.6.4 Uncovered Anaerobic Ponds
Description of System
The IPCC defines uncovered anaerobic ponds as:

"A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields."

The majority of effluent treatment systems at Australian piggeries are uncovered anaerobic ponds. This system operates naturally from the microbial population that is already present in piggery effluent. The activity of these ponds will vary depending on ambient temperature, and may be affected by some feed additives. However, in general anaerobic ponds are resilient, effective for reducing VS and require low maintenance. Primary anaerobic ponds are designed to reduce VS loading by around 70% according to the National Environmental Guidelines for Piggeries (Tucker et al. 2010).

Uncovered anaerobic ponds provide a long retention time and are perceived as a low capital cost option. These type of ponds can only achieve partial treatment and so materials such as phosphorus, nitrogen and VS accumulate in the bottom of the pond as a sludge layer.

Large ponds tie up land and can be a source of odour problems and require desludging approximately every 10 years. Desludging can be extremely expensive and may require a plant shut down or alternative manure handling system in operation while desludging occurs.

The primary effluent pond is sometimes followed by a facultative pond, which provides a mixture of anaerobic (oxygen starved) treatment at lower levels and aerobic (oxygen rich) treatment nearer to the surface of the pond. A range of microbial processes in the facultative pond further breakdown the remaining organic material. This further improves the liquid effluent stability and reduces odour emissions. Treated effluent can be used as a source of flushing water to clean the drains in conventional sheds or irrigated onto farm land.

Aerobic ponds can be used to further polish the liquid effluent. Aerobic ponds are either shallow with a large surface area to enhance the natural movement of oxygen into the liquid phase or are equipped with aerators to mechanically force air containing oxygen into the liquid phase. The aerobic process does not produce methane but converts organic material into carbon dioxide.

Pond size selection is usually based upon the VS load produced by the piggery. A minimum treatment volume is determined plus an additional volume for sludge build up. The primary anaerobic pond volume can be split into two or more ponds operating in parallel to allow for the effluent treatment operation to continue while one pond is being de-sludged.

The design of the minimum treatment volume for anaerobic ponds has conventionally been based upon the Rational Design Standard (RDS) which determines a minimum volume through a combination of a pond loading rate (100 g VS/m^3/day) and a climate based K factor. The National Environmental Guidelines for Piggeries (Tucker et al. 2010) suggests a maximum VS loading rate to match the regional variations in the Australian climate ranging from 450 g VS/m^3/day for the cool climates to 750 g VS/m^3/day for the hot climate regions.

GHG Performance Data

The performance of the anaerobic pond is measurable by determining the reduction in VS from pond inlet to outlet. When VS reduction falls below 50% or the VS content of the treated effluent exceeds 1% then the performance of the pond should be investigated and de-sludging should be considered along with factors that may interfere with the performance of the pond (Tucker et al. 2010).

Methane emissions are estimated by multiplying the ultimate methane by a factor that reflects the proportion of ultimate yield that is achieved in the given system, the methane conversion factor – MCF. For piggery effluent treated in an anaerobic pond, the MCF is 90% for Australia (DCCEE 2010). The IPCC determined a more conservative MCF of 73% (range 66-80%).

Nitrous oxide emissions from an uncovered anaerobic pond are estimated as 0.1% and 0% of nitrogen to the pond (DCCEE 2010) and (IPCC 2006) respectively. The ammonia (NH_3) emission factor is 40% (IPCC 2006) and (DCCEE 2010). The remaining N flows to the secondary pond for treatment. Table 32 and Table 37 in Appendix A show a more detailed explanation of the emission factors assumed for this system.

Capital and Operating Costs

The main capital costs associated with anaerobic ponds are the earthwork costs. The cost for the earthworks for anaerobic ponds is based on the pond dimensions and earthworks work rates of $5 /m^3. In addition to these costs, if the effluent needs to be screened prior to digestion then additional costs associated with holding, screening and pumping the effluent need to be factored in. These costs can range between $25 000-75 000 for small to large piggeries. The indicative capital costs of an uncovered pond that is sized for ten years of sludge retention were equal to $15-21 per SPU. Therefore the total capital costs ranged between $73 500 and $1 125 000 for the 3500 SPU and 75 000 SPU respectively. The indicative operating costs for this pond are equivalent to $1.2-1.4 per SPU per annum.

2.6.5 Covered Anaerobic Ponds (CAPs)

Description of System

Covered anaerobic ponds (CAPs) are designed in much the same manner as uncovered anaerobic ponds. Current recommendations for designing a CAP are to construct a steep sided, 6 m deep pond with a length to width ratio of 3:1. Pre-treatment (solids separation) of the effluent stream is optional, but is recommended when diets contain high proportions of husky type grains such as barley. This is because the coarse, undigested material in the effluent stream tends to float on the surface of the pond and contribute to rapid build up of undigested floating material that can block the system. These ponds are designed with a HRT of 40-50 days and a variable sludge accumulation period between 6 months and the life of the cover. The target solids loading rate is ~ 400 g $VS/m^3/day$. Larger piggeries may install two CAPs that operate in parallel. Figure 7 shows a typical covered pond system.

Figure 7: A covered anaerobic pond (CAP) installation at an Australian facility

Recommended pond covers are constructed from 1.0-1.5 mm high quality geo-membrane cover such as low density polypropylene (LDPE) or polypropylene (PP). High density polyethylene (HDPE) is generally more difficult to install and there are problems associated with heat expansion. The material should have a guarantee of ten to twenty years, in particular with regards to resistance to deterioration due to heat stress and UV radiation.

The pond perimeter cover should be sized to cover the full surface area of the pond. It must also be sized to cover the pond freeboard slope, a portion of the berm crest and the biogas collection pipe. Biogas is captured under the pond cover and collected in a ring piping system which sits inside the cover perimeter area. This pipeline is generally made from 100 mm PVC or polyethylene (PE) perforated pipe, although some rectangular piping is available. Several transfer pipelines are connected to this biogas ring pipeline under the cover during the initial installation stages. These transfer lines are usually made from PVC or PE, however other materials such as stainless steel can also be used.

The edge of the cover is generally trenched in to a depth of at least 600mm to avoid being blown off in high winds and avoid leakages. Water filled PE pipe is generally used to provide ballast to the cover. Access points within the cover will facilitate attachment of piping for flushing (blowing) and to permit gas flow through a flow meter. Biogas is extracted from the cover through a flame arrestor by a small fan and blown to a flare or an energy recovery system. A number of alternative systems can be used to destroy methane, and these are discussed in following sections of this report.

GHG Performance Data

The VS reduction rate in a CAP is expected to be similar to an uncovered anaerobic pond. (Birchall 2009) reported a 70% VS reduction in a piggery CAP in southern Australia. Methane production from two recent covered pond studies in Australia and New Zealand are shown in Table **9**. Few other studies were found in the literature, and these were considered most relevant to Australian conditions and designs.

Table 9: Methane generation rates from covered anaerobic ponds (piggeries)

System Characteristics	**Methane Production (m^3 CH_4 / kg VS)**	**Reference**
Covered pond – screened piggery effluent (New Zealand)	0.279	Craggs et al. (2008)
Covered pond – screened piggery effluent (Australia)	0.48	Birchall (2009)
DCCEE comparison value for uncovered ponds		
DCCEE – B_o of 0.45, MCF of 90%	0.405	DCCEE (2010)

It is not clear at the present time if the very high yields measured by (Birchall 2009) were representative of the system investigated or if there were confounding factors, such as methane arising from residual VS that was in the pond prior to the trial. Current advice from NIWA in New Zealand suggests that studies should use lower yields (slightly lower than Craggs et al. 2008) as a starting point for assessing the performance of CAPs in Australia (S. Heubeck, pers. comm.).

With regards to nitrous oxide and ammonia emission factors, these are assumed to be zero. Table 32 and Table 37 in Appendix A show a more detailed explanation of the emission factors assumed for this system.

Capital and Operating Costs

The main costs associated with a CAP are earthworks, covering the pond, biogas piping, biogas blower, scrubbing equipment, flare, and engineering, procurement and construction management (EPCM) costs. There were also additional unallocated costs for safety and 10% contingency on the equipment.

The cost of the LDPE (low-density polyethylene) cover (including material price, the cost of the inlet and outlet piping, the cost of the rainwater collection / and installation costs) were assumed to be \$15-25 per m^2.

The cost of earthworks were assumed to be the same as for uncovered ponds at $5/m^3. Capital costs are greatly influenced by the earthworks required to construct the pond. Therefore, if there is a pond onsite that is suitable for the anaerobic digestion of piggery effluent, this will greatly reduce the costs associated with this system.

In order to transfer biogas to the piggery at low pressures, rotary type biogas blowers are used. The biogas blower for this study was assumed to range in cost from $5000 to $40 000 for small to large piggeries. The cost of biogas cooler and water knockout ranges between $1000 and $15 000, while the costs of the biogas scrubbing vessel were between $5000 and $35 000.

In order to transfer the biogas from the anaerobic pond to the point of use, biogas transfer pipelines are needed. The biogas transfer pipeline should be constructed from 90 mm (3.5 inch) polyethylene pipe which transports the gas at low pressures (150 mbar). This large pipe size was recommended to combat issues associated with high temperatures in smaller pipelines. The cost of the biogas pipeline was assumed to range between $5 000 and $30 000.

The EPCM costs relate to the management of the construction of the pond systems, CHP unit, piping and flare; and electrical contracting. This process requires a technical manager (typically an engineer), who will oversee all of the work involved with installing this equipment onsite and will produce an as constructed inspection, monitoring system and certification report. These costs were assumed to range between $10 000 and $50 000. However, these can be significantly reduced if the farm owner was to carry out the work themselves.

The operation and maintenance costs of a CAP are highly dependent on the site itself, and for how many years of sludge accumulation the pond has been sized for. Therefore, it was difficult to determine exact costs as every site's practices and management will differ so drastically.

If a pond was sized for sludge removal every year, then the sludge removal and management costs will dominate the annual costs. It was assumed that the pipes that are used to remove sludge from the pond are constructed from 315 mm diameter HDPE piping material with a class rating of PN10. This class rating is needed to protect against damage from rocks and high traffic. The costs per metre of pipe are $100. Because annual desludging is at this point unproven in Australia, and the costs of the pipes negate the reduced earthwork and cover costs, a one year CAP was not investigated for this report.

For this report, only CAPs sized for ten years of sludge accumulation were investigated. Table 10 shows the main capital infrastructure and costs for CAP systems with energy generation over a wide range of piggery sizes. In order to determine the capital costs of the CAP infrastructure on its own, the costs of the energy generation equipment and contingencies must be removed. This results in the capital costs ranging between $30-51 per SPU. The costs of the energy generation equipment are discussed in detail in Section 0.

Table 10: Main capital costs associated with CAP system for range of piggery sizes

Capital Costs of Pond	**3500**	**10 000**	**20 000**	**50 000**	**75 000**
Earth works ($/m³)	5	5	5	5	5
Cover ($/m²)	25	20	18	16	15
Capital Costs of Gas Line Assembly ($)					
Biogas blower	5000	10 000	20 000	25 000	40 000
Biogas cooler and water knockout	1000	3000	5000	10 000	15 000
Scrubbing vessel	5000	10 000	15 000	22 500	35 000
Biogas transfer to energy recovery unit (installation and equipment costs)	5000	7500	12 000	20 000	30 000
Capital Costs of Flare ($)	6000	6000	6000	12 000	14 000
Capital Costs of Energy Recovery Equipment					
Electrical switchgear ($)	20 000	20 000	20 000	20 000	20 000
Generator unit ($)	82 914	82 914	222 316	222 316	355 539
CHP unit ($)	110 524	110 524	296 347	296 347	473 933
Boiler unit ($)	2888	7720	14 375	31 944	46 319
Grid connection consultancy fee ($)	20 000	20 000	20 000	20 000	20 000
EPCM ($)	10 000	20 000	30 000	40 000	50 000
Unallocated					
Safety ($)	10 000	20 000	30 000	40 000	50 000
Contingencies non-pond parts @ 10% Generator	12 491	13 941	30 032	33 182	50 954
Contingencies non-pond parts @ 10% CHP	15 252	16 702	37 435	40 585	62 793
Contingencies non-pond parts @ 10% Boiler	2489	4422	7238	12 144	18 032
Contingencies non-pond parts @ 10% Flare	2200	3650	5800	8950	13 400

The main operating and maintenance costs that should be considered when implementing a biogas capture and utilisation system with a CAP include the costs associated with monitoring and maintaining the generator/boiler/CHP unit, replacement of biogas filter media, motor oil, spark plugs, and safety certificates and inspections. The annual operating costs for this CAP can range between $8500 and $164 000 depending on the piggery size. These indicative costs were equivalent to $2.2-2.4 per SPU per annum.

2.6.6 Engineered Anaerobic Digesters

Description of System

The IPCC describes anaerobic digesters as:

"*Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as a fuel.*"

The products of the anaerobic digestion process which occurs in the digester are:

- Biogas (principally methane (CH_4) and carbon dioxide (CO_2))
- A solid residue (fibre or digestate) that is similar, but not identical, to compost
- Liquid liquor that can be used as a fertiliser.

Engineered mixed tank digesters are the most common type of anaerobic digester in the world. These systems can be batch or continuous and run in one or two stages. Single-stage digesters are simple to design, build, and operate and are generally less expensive however there are issues with inhibition of the organic loading rate. Two-stage digesters have higher loading rates but require additional reactors and handling systems. In Europe, about 90% of the installed AD capacity is from single-stage systems and about 10% is from two-stage systems.

The mixed digester operates at a TS concentration range of 3-6%. The digester is operated as a fully mixed system, with either gas recirculation, or mechanical mixers incorporated in the design. The feedstock can be continuous or batch fed with retention times of approximately 15-20 days. For these complete-mix anaerobic digesters the hydraulic retention and solids retention times are equal. The typical volumetric organic loading rate is 1.0-5.0 kg COD/m^3/day (Metcalf & Eddy Inc. 2003). The mixed digester produces a liquid digestate. Some of the key features of this system are:

- Relatively straight forward process control due to the well mixed and homogenous process liquid.
- In order to achieve 50% VS reduction, the solids concentration in the effluent must be between 6-8%.

Figure 8 shows a typical farm-based engineered anaerobic digester.

Figure 8: Engineered anaerobic digester

In order to thicken the solids from to the required concentration (6-8%), a dissolved air flotation (DAF) separation system is used. In a DAF system, air is dissolved under pressure in a saturator containing a portion of the wastewater to be treated. The supersaturated water is then introduced into the base of the DAF tank. As the bubbles rise, they adhere to fine particles in suspension and float to the surface. The resulting scum is then skimmed off. Heavy solids form sediment that is discharged from the base of the tank via an outlet. Clarified liquid discharges via a weir. DAF performance can be improved by using flocculating or coagulating chemicals . It has a TS removal efficiency of 70%, which would be sufficient to thicken the substrate entering the digester (Tucker et al. 2010).

GHG Performance Data

Engineered anaerobic digesters have some advantages over covered ponds that are likely to result in higher methane yields. This is necessary to justify the greater expense. The first advantage is the capacity to operate at a standard temperature range that is conducive to methanogenesis. Temperatures of 55°C promote digestion. These temperatures can be achieved using heat exchangers and excess heat from electricity generation. It is reasonable to assume that 100% of B_o is converted to methane in a designed digester. It is assumed that for this analysis an engineered digester with a solids retention time (SRT) of 30 days.

With regards to direct N_2O emissions and ammonia emissions, these were assumed to be the same as for covered anaerobic ponds. Table 32 and Table 37 in Appendix A show a more detailed explanation of the emission factors assumed for this system.

Capital and Operating Costs

This is an established technology, which is used across many industries. However, the costs are relatively high to establish the plant and the tanks provide poor volumetric loading. The systems have high methane production yields due to the high degree of process control, although this impacts on the costs.

DAF units are considered very expensive to run, due to the compressed air requirement (15 kW pump) and the cost of polyelectrolyte for flocculation. Ferric chloride and polyelectrolyte polymer can be used to improve flocculation, producing a thickened slurry. The use of the flocculants would be required to capture the finer particle fraction associated with the COD of piggery wastewaters (Hill & Tollner 1980). In general high rate anaerobic digestion systems operate best on effluents with a very high soluble COD, and a very low concentration of suspended solids. Ideally, the biodegradable COD concentration should be within the range of 2,000 to 20,000 mg/L (McLean 1996).

Abery (1994) estimated polymer costs at around $45 per ML (inflation rate is applied from 1994 to 2012 for all costs listed) of piggery wastewater. In addition to the compressor required for the DAF dissolver unit, a polymer activation and dosing unit would also need to be purchased. Estimates for a DAF system range from AU$280 000 to $315 000 (Watts et al. 2002).

The operating costs could range from $900 to $2350 per ML of effluent treated for a 200-sow piggery to $330 to $790 per ML of effluent treated for a 2000-sow piggery (Watts et al. 2002). The lower costs reflect economies of scale with larger piggeries. Operating costs include power, labour, routine maintenance of pumps and agitators, and static screen cleaning. DAF systems require a significant amount of power for the production of compressed air.

From information gathered from previous biogas feasibility studies carried out by FSA Consulting, the total capital costs of an engineered digestion system treating effluent from a 75 000 SPU piggery were approximately $3 900 000. This analysis assumed the cost of an engineered system ranged from $52-81 per SPU to reflect economies of scale. The annual operating costs for the same engineered system were equal to $221 340. The DAF system had the most significant annual operational costs at $130 000. Therefore, the annual expenses for an engineered system were assumed to be equivalent to $2.9-21.2 per SPU per annum to reflect economies of scale.

2.6.7 Secondary Ponds

For each of the effluent treatment systems investigated, it is necessary to allow the treated effluent to flow onto further treatment in an anaerobic pond. For CAPs and engineered systems, the dominant emission sources are the residual emissions from secondary ponds.

Methane emissions from secondary ponds can be calculated using a revised B_o and the standard MCF factor for covered ponds from the DCCEE (2010). The B_o of the effluent is assumed to be partially digested, hence the B_o factor for effluent flowing to the secondary pond is reduced from 0.45 m^3 CH_4/kg VS to 0.3 m^3 CH_4/kg VS. With regards to nitrous oxide and ammonia emissions, these were assumed to be the same as for uncovered anaerobic ponds.

2.6.8 Summary of Capital Costs and Annual Expenses for Effluent Treatment Systems

Table 11 and Table 12 summarise the capital costs and annual expenses on a SPU basis for the anaerobic treatment systems investigated for this report.

Table 11: Capital costs for anaerobic treatment systems

\$/SPU	**SPU**				
Anaerobic treatment System	**3500**	**10 000**	**20 000**	**50 000**	**75 000**
Uncovered Anaerobic Pond	21.2	17.6	16.3	15.2	15.1
CAP	51.2	40.0	35.5	31.2	30.0
Engineered Digester	80.6	64.8	58.8	53.1	51.9

Table 12: Annual expenses for anaerobic treatment systems

\$/SPU/yr	**SPU**				
Anaerobic treatment System	**3500**	**10 000**	**20 000**	**50 000**	**75 000**
Uncovered Anaerobic Pond	1.4	1.4	1.4	1.3	1.2
CAP	2.4	2.4	2.4	2.3	2.2
Engineered Digester	21.2	9.7	6.2	3.6	3.0

2.7 Solids Treatment Systems – Composting

2.7.1 Description of System

Composting of piggery manures is a cost effective and environmentally friendly method of stabilising biosolids. During the composting process organic material undergoes biological degradation to a stable end product. The material that is produced at the end of the composting process is stable and humus like. If the manure has been composted correctly, 20-30% of the VS fraction is converted to carbon dioxide and water.

Aerobic conditions accelerate material decomposition and result in higher temperatures that are needed for pathogen destruction; however the process is never 100% aerobic with slight anaerobic conditions found. Temperature is the most important factor when composting solids, mesophilic temperatures of 45-55 C are needed for maximum biodegradation.

For the purposes of this report it was assumed that the solid manure waste stream is treated using passive windrow composting. This is defined by the IPCC as:

"Composting in windrows with infrequent turning for mixing and aeration."

There are disadvantages with this process in that the pile must be monitored on a regular basis to avoid odour problems; however there are advantages in that it uses no electricity.

2.7.2 GHG Performance Data

Composting pig manure generates nitrous oxide emissions. In a study carried out by Szanto et al.(2007), it was found that the nitrous oxide emissions ranged from 2.5-9.9% of total N for turned and unturned compost piles respectively. The study by Wolter et al.(2004) found that nitrous oxide was the most significant greenhouse gas emission from the deep litter manure stockpile (78 % of CO_2-equivalent emissions). Total nitrous oxide emissions from the composting trial amounted to 1.9% of total N. The amount of methane lost was equivalent to approximately 1% of the VS in the compost pile (IPPC 2006). Table 33 and Table 38 in Appendix A show a more detailed explanation of the emission factors assumed for this system.

2.7.3 Capital and Operating Costs

The cost involved in building and operating a passive windrow composting pile will vary considerably for different sites. The annual expenses depend on the volume of material that is to be composted. The use of bulking agents such as sawdust will require additional capital investment and labour inputs. The capital costs include compost pads, grinder, compost mixer, trommel screen, front-end loader and windrow turner.

For this analysis it was assumed that the total costs (both capital and operating) to produce one tonne of compost from a conventional flushing piggery in a passive windrow pile was equal to $55. This was equivalent to $1.5 per SPU per annum. For deep litter piggeries the cost was equal to $6 per SPU per annum.

2.8 Solids Treatment Systems – Stockpiling

2.8.1 Description of System

For this report, it was assumed that stockpiling falls under the IPCC's category of solid storage. It is defined as

"*the storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation."*

Manure collected from piggeries in Australia is commonly stored in stockpiles prior to spreading. Stockpiles vary greatly in their ability to conserve N. Solid manure stored in compacted stockpiles is subject to anaerobic decomposition, which generates a substantial amount of heat. N losses from stockpiles may be in the form of nitrate leaching, or volatilisation of nitrogen gases (N_2O, N_2 or NH_3).

2.8.2 GHG Performance Data

Current data suggests that stockpiled litter has about 70% of the total N in the organic form, while the remainder is in the inorganic ammonium-N form. Ammonium-N levels reported by (Nicholas et al. 2006) ranged from 8-39% of the total N. Ammonium can readily be transformed to NH_3 in a temperature and pH dependent reversible reaction. NH_3 is readily volatilised from the liquid form at high temperatures and high pH. However, if the stockpile is not exposed to drying, this ammonium nitrogen may remain in the pile for extended periods (Nicholas et al. 2006).

Ammonia gas losses reported in the literature vary. Moller et al.(2000b) report losses of 16.3% of the total N excreted in the litter during the pig fattening phase. Based on the small amount of available data, (FSA Consulting 2007a) in a report to the National Pollutant Inventory (NPI) for deep litter piggeries suggested that 20% of the N added to the stockpile in spent litter is lost as gaseous N emissions.

Table 33 and Table 38 in Appendix A show a more detailed explanation of the emission factors assumed for this system.

2.8.3 Capital and Operating Costs

The costs for stockpiling screened solids from a flushing piggery have been assumed to be 1/3 the cost of composting i.e. $0.50 per SPU per annum for a conventional piggery and $2 per SPU per annum for deep litter piggeries.

2.9 Land Application

2.9.1 Liquid Effluent Irrigation

The short HRT system produces liquid effluent that requires irrigation. The liquid irrigation system assumed for this report was a mobile irrigation system (
Photograph **2**). The equipment needed for liquid irrigation includes a pit for storing the effluent prior to being irrigated, suction and discharge fittings, electrical switchgear with a soft start and float switch, trenching and installation, a pump and motor unit, a poly pipe main line with a length of 1km and diameter of either 63 or 90 mm (depending on flowrate) and a travelling boom irrigator. Low pressure travelling boom irrigators are used to reduce the overall system cost, the risk of air-borne diseases and odour issues.

The liquid effluent that is stored in the short HRT system under the piggery housing needs to be pumped to the travelling irrigator at 5% TS concentration. The distance pumped was assumed to be 1km. It was assumed that the amount of effluent that was irrigated from the short HRT system is 5 L/SPU/day. This was based on water balance modelling carried out by FSA Consulting for Australian piggeries.

Photograph 2: Mobile liquid effluent irrigator

Significant direct N_2O emissions are seen when treated effluent is applied to the land. Table 34 and Table 39 show a more detailed explanation of the emission factors assumed for this report.

It was assumed that a 63 mm mainline system with a flowrate of 7m³/hr was used. This costs $49 940 including 10% for contingency. The annual costs for this system range from $820 to $2340. Table 13 and Table 14 summarise the capital costs and annual expenses for the short HRT system which utilises liquid irrigation investigated. These costs were based on information provided by Total Eden Pty Ltd.

Table 13: Capital costs for liquid irrigation

$/SPU	3500	10 000
Short HRT System	14.3	5.0

Table 14: Annual expenses for liquid irrigation

$/SPU/yr	3500	10 000
Short HRT System	0.23	0.23

2.9.2 Solids Application

Manure may be applied directly to land, although consideration must be given to the timing of the application, nutrient needs of the crop, nutrient availability of the spent bedding and pollution control. Spreading fresh manure on land can cause 'nutrient drawdown' if the spread material composts on or within the soil. This may temporarily disrupt plant growth, particularly during crop emergence.

Methane emissions occur immediately after the manure is applied to land. However, the emissions are generally short-lived as methanogenesis is sensitive to O_2 and therefore formation of CH_4 is inhibited. Volatile acids which are used to form CH_4 decrease after a few days following application and hence the emissions of CH_4 are negligible (Chadwick et al. 2011). However, when slurry is injected into the soil via shallow injection, higher CH_4 emissions are seen due to potential anaerobic conditions in the soil.

The GHG emissions potential of solid application to land, in terms of NH_3 and direct and indirect N_2O emissions, and CH_4 emissions have been assumed to be the same as for direct liquid effluent application to land. Table 34 and Table 39 show a more detailed explanation of the emission factors assumed for this report.

The annual cost associated with hiring a contractor to carry out manure spreading range from $7-$13/tonne of solids depending on the size of the piggery.

2.10 Energy Generation

The biogas that is produced from anaerobically digesting piggery manure typically consists of 50-75% methane, 25-50% carbon dioxide, 0-10% nitrogen, 0-1% hydrogen and 0-3% hydrogen sulphide. The quality of the biogas is improved by filtering it through limewater to remove carbon dioxide and through iron filings to remove corrosive hydrogen sulphide. The remaining methane gas has an energy density of about 35.8 MJ/m³ (Payne 2009). This biogas can then be used to generate electricity and/or heat onsite, or can simply be flared to reduce the global warming impacts of the gas. When choosing between these options, the factors that must be considered include the financial implications and the labour and equipment requirements.

2.10.1 Flaring

Flaring of the methane gas that is generated in anaerobic digesters eliminates its global warming potential, as flaring converts the methane to non-fossil carbon dioxide and water vapour. The basic reaction which converts the methane to energy, CO_2 and H_2O is:

EQUATION 7

The flaring technology can be:

1) Open flare – devices where the residual gas is burned in open air with or without any auxiliary fuel assistance. This is the system that is assumed for this analysis due to its simplicity and low costs (Photograph 3).

Photograph 3: Open flare system

2) Enclosed flare – devices where the residual gas is burned in a cylindrical or rectilinear enclosure that includes a burning system and a damper where air for the combustion reaction is admitted.

In order to inhibit the formation of undesirable compounds such as nitrous oxide, dioxins and furans, and carbon monoxide, the temperature range of the flare should be in the range 850-1200 C, and the minimum residence time should be 0.3 seconds.

Figure 9 shows the basic required features that are responsible for the safe operation of a flare.

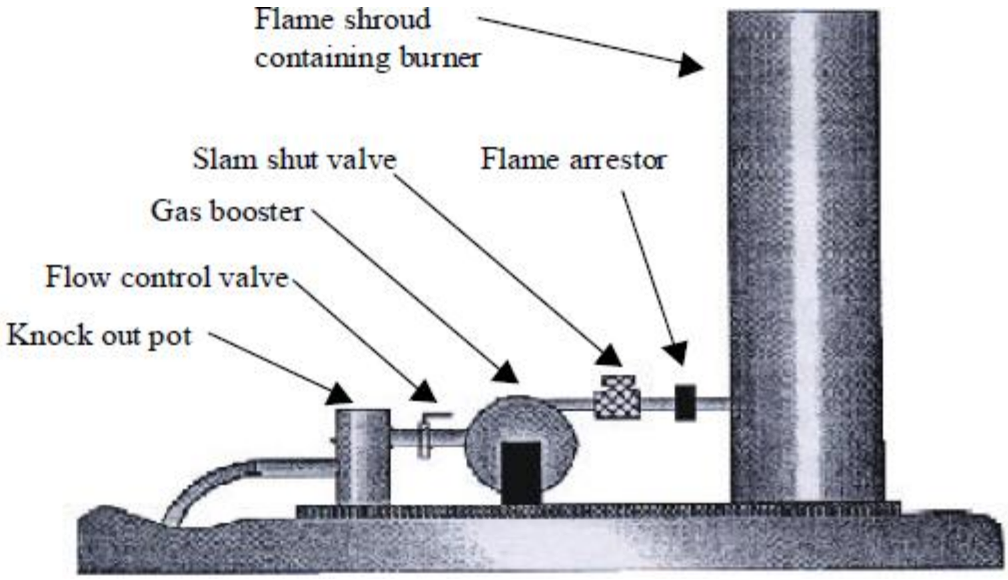

Figure 9: Schematic drawing of an enclosed flare

Flaring of the methane gas will not result in LGCs being awarded to the piggery. In addition to this it does not provide any extra income to the farm in terms of energy supply. However it is a low cost option and the farm will be entitled to carbon credits under the Carbon Farming Initiative (CFI) if a flaring system is put in place onsite. For the purposes of this report, Australian Carbon Credit Units (ACCUs) under the CFI were costed at $15 /tonne CO_2-equivalent. This will be the "floor" price for carbon credits after 2015 and so was used so as to provide conservative estimates of potential revenue from ACCUs. Under the CFI, the flaring system must either use a frequently sparking flare (approximately every 2 seconds) for the continuous destruction of methane or include a control system that prevents gas flow through the flare when it's not in operation (DCCEE 2011b). For this analysis, it was assumed the cost of installing a flaring system onsite ranges from $6000-14 000 for different sized piggeries. This is equivalent to $0.2-$1.7 per SPU.

2.10.2 Electricity Production

In Australia the power generation units which are suitable for use in the piggery industry are spark-type gas engines and micro-turbines. Biogas can be converted to electricity onsite using these engines, which can be assumed to operate with efficiencies of 23-30%. For this analysis, the efficiency of the generator was assumed to be 30%. The lifetime of these generators can range between five (for low-end devices) and twenty years (for more sophisticated equipment).

This option will allow for the provision of LGCs ($0.04 /kWh) and carbon credits under the CFI. It will also reduce the annual electricity bill for a piggery by utilising electricity generated onsite instead of grid-purchased electricity. There is also the potential for selling any surplus generated electricity back to the grid. For this analysis, the capital costs of generators were assumed to be equal to those presented in

Table **15**. The quotes were provided by Quantum Ltd. The most suitable generator sizes were determined based on the electricity consumption of the different sized piggeries.

Table 15: Generator sizes and prices

Size	600 kW	200 kW	120 kW	100 kW	80 kW	50 kW	25 kW
Generator ($/kW)	875	1112	1110	1304	1606	1658	2900
Generator ($)	524 916	222 316	133 223	130 373	128 473	82 914	72 491

2.10.3 Heat Generation

Another option for the biogas produced from the anaerobic digester is burning it in a boiler to produce heat and hot water for the piggery. A typical boiler was assumed to have an efficiency of 90% and this is the value assumed for this report. The methane can be used to offset the annual fuel usage of the site leading to reductions in the energy expenditure of the piggery.

This option does not allow for the provision of LGCs, but does allow for the provision of carbon credits under the CFI. It will also reduce the annual heating bill for the farm by utilising the methane generated onsite instead of fossil fuels. The capital costs of a biomass boiler were assumed to range between $116 and $155/kW (Chau et al. 2009). This range was assumed to reflect economies of scale and so the costs range between $0.6 and $0.8 per SPU.

2.10.4 Combined Heat and Power Generation (CHP)

Cogeneration is also known as combined heat and power (CHP) generation. A variety of reciprocating engines can be used, including spark ignition and compression ignition engines. Biogas is burnt in a reciprocating gas engine to drive an alternator to produce electrical energy (see above). Simultaneously the heat energy exhausted by the engine (engine coolant and exhaust gas) is recovered, usually in the form of hot water (80 – 90°C).

The conversion of biogas energy into electrical energy is approximately 25-35%. An additional 45-55% of biogas energy can be recovered as heat energy if the gas engine is fitted with an efficient heat recovery package (engine coolant and exhaust gas). For this analysis, the electrical efficiency was assumed to be 30% and the thermal efficiency was 55%. Photograph 4 shows a typical spark ignition CHP biogas generator at a piggery in New Zealand.

Photograph 4: 48/40 kW 6-cylinder spark ignition CHP biogas generator at the Lepper piggery in Taranaki, New Zealand.

Where a constant use for hot water can be found only 10-20% of the energy contained in biogas is lost within the CHP system, compared to often over 65% in an electricity generation only set-up. The efficient conversion of the energy available in biogas is therefore greatly enhanced where heat energy can be used.

In the larger European biogas plants, the generated electricity is sold at a premium price and the generated heat is supplied to a local residential community scheme. CHP technology is well developed and there is a range of European suppliers with equipment to offer. The European equipment is also available in Australia. Some CHP plants do not run continuously and operate for 16–20 h/day.

To evaluate the economic viability of a CHP system, many different criteria must be considered; such as the electrical and thermal outputs, fuel inputs, power to heat ratio, overall efficiency, investment cost, electricity cost, heat cost and service life.

In order to size the CHP unit correctly it would be necessary to have detailed knowledge of the hour-by-hour and day-by-day energy demand for space heating at the chosen piggery, along with the heated volume, the temporal details of thermal losses and the amount of heat due to occupants, appliances, lights and solar radiation. After this data was extracted and compiled, a building performance modelling and simulation tool would be required (Rainieri & Pagliarini 2010). This process is well beyond the scope of this study and so a more simplified approach is taken.

The cost of the CHP units were assumed to be 33% higher than that of a generator unit –

Table 15. However, as was stated previously, these costs can vary widely depending on the type of unit used.

2.10.5 Infrastructure Requirements

The main infrastructure requirements associated with setting up energy recovery infrastructure for a piggery include:

- *Biogas blower* - in order to transfer biogas to the energy generation unit at low pressures, rotary type biogas blowers should be used.
- *Scrubber* – a system which utilises iron sponge to reduce the amount of H_2S and NH_3 in the biogas can be used. This type of filter is relatively simple to construct and the use of old stainless steel milk tanks has been shown to be successful as a scrubbing vessel in New Zealand (Heubeck 2011).
- *Biogas transfer pipelines* – in order to transfer the biogas from the anaerobic digestion system to the point of use, biogas transfer pipelines are needed. The biogas transfer pipeline should be constructed from 90 mm (3.5 inch) polyethylene pipe which transports the gas at low pressures. This large pipe size is recommended to combat issues associated with high temperatures in smaller pipelines. It has been determined that using 2 inch diameter pipe results in high pressures and temperatures of 4-5 bar and 50-60°C which can lead to the degradation of the piping material. Due to the relatively low pressures in the pipeline, there can be issues with condensation, which is undesirable. Therefore it is necessary to install additional equipment at the entry way to the biogas transfer pipeline, to remove this moisture.
- *Energy Recovery Unit* – this could be a generator or boiler system, or a CHP unit.

3. Methodology

3.1 Manure Management Systems under Review

In order to determine the housing and manure management systems which will be reviewed in terms of GHG emissions a screening methodology was applied to the systems discussed in the literature review. This screening methodology was used to remove options where insufficient data were available regarding the abatement potential or technical feasibility. Two systems (screw presses and SEPs) were removed because of a lack of data regarding the mitigation potential at this point. The housing and manure management systems modelled for GHG emissions were:

Housing systems

- Flushing Piggery
- Short HRT systems

Pre-treatment systems

- Trafficable sedimentation basin
- Static rundown screen

Effluent treatment systems

- Uncovered anaerobic pond
- Covered anaerobic pond (CAP)
- Engineered system

Aerobic treatment systems

- Composting

Alternative treatment systems

- Stockpiling

Land Application

- Liquid effluent irrigation
- Solids application

While not included as one of the main modelling approaches, a simple assessment of deep litter systems was included for interest. The main reason for not including a detailed assessment was that, unlike the other systems, changing to deep litter requires a major re-configuration of the housing system and may result in changed performance of the pigs. There is definite capacity for future work with regards to GHG modelling from deep litter piggeries, however this was outside the scope of this report.

The GHG modelling results were used as a tool to further screen the manure management systems before they are economically modelled. As a method of ensuring that there was a fair comparison made between systems, any costs or revenue that were associated with the uncovered anaerobic pond have been removed. The only system which uses a significantly different manure management system to the baseline is the short HRT system. This system produces liquid effluent which is notably different than the baseline in nutrient value. Therefore, it was necessary to track the nutrient N, P and K for this system to determine the costs of land application, and also the revenue associated with the offset of fertiliser.

3.2 Case Study Selection

In order to provide meaningful comparisons between piggery systems, it was decided to define different case studies. These case studies comprised of a range of permutations of the systems which were identified in Section 0. Case study 1 is the reference or baseline scenario. This comprises of a flushing piggery system an uncovered anaerobic pond for effluent treatment with no pre-treatment system. Eight of these studies were based on the flushing piggery housing system and one on short HRT systems. Four of the studies investigated energy recovery from biogas also. The aim of modelling GHG emissions from these options was to ensure that the results would provide information to all sectors of the industry and would be all-inclusive. Table 16 shows the case studies used to model piggery GHG emissions.

Table 16: Case studies modelled for GHG emissions

Case Study	Housing System	Pre-treatment	Anaerobic treatment	Aerobic or alternative treatment	Land Application	Biogas Option
1	Flushing Piggery	N/A	Uncovered pond and secondary pond	N/A	Solid/liquid application	N/A
2	Flushing Piggery	Trafficable Sedimentation Basin	Uncovered pond and secondary pond	Stockpiling	Solid/liquid application	N/A
3	Flushing Piggery	Static rundown screen	Uncovered pond and secondary pond	Composting	Solid/liquid application	N/A
4	Flushing Piggery	N/A	CAP and secondary pond	N/A	Solid/liquid application	Flare
5	Flushing Piggery	N/A	CAP and secondary pond	N/A	Solid/liquid application	Generator
6	Flushing Piggery	N/A	CAP and secondary pond	N/A	Solid/liquid application	Boiler
7	Flushing Piggery	N/A	CAP and secondary pond	N/A	Solid/liquid application	CHP
8	Flushing Piggery	N/A	Engineered Digester and secondary pond	N/A	Solid/liquid application	CHP
9	Short HRT system	N/A	N/A	N/A	Liquid application	N/A

3.3 Piggery System Model

3.3.1 Pig Numbers

In order to allow small, medium and large pig producers to readily adopt the most economically viable and environmentally friendly manure management system, a range of piggery sizes was analysed for this study. The piggery sizes investigated for this project were 3500, 10 000, 20 000, 50 000 and 75 000 SPU.

3.3.2 Piggery Effluent Characterisation and Mass Flow

In order to fully characterise the manure waste stream, the TS, VS, N, P and K fractions were analysed. Table 17 shows the TS, VS, N, P and K flow rates per SPU. The mass flows of VS and N were needed to estimate the GHG emissions at each stage of the MMS. In addition to this, P and K flows were needed for the short HRT system in order to determine the amount of nutrients flowing to land application stage.

Table 17: Mass of TS, VS, N, P and K per SPU per year in piggery manure

Solids present in Effluent	kg/SPU/yr
Total TS production	110
Total VS production	90
Total N production	9.2
Total P production	3
Total K production	2.4

3.3.3 Piggery Energy Consumption

Average piggery energy consumption was required to determine the amount of electricity and heat that can be replaced by energy produced through the combustion of methane onsite. This offset can then be quantified in economic terms for each of the energy generation options investigated.

In order to determine the average energy use at a piggery, annual electricity and heat consumption data were collected from a range of piggeries across Australia from recent projects carried out by FSA Consulting. From this information, the average electricity usage was equivalent to 31 kWh/SPU/year, while the average heat usage (generally supplied by either LPG or natural gas) was determined to be 23 MJ/SPU/year. It should be noted that these values can vary widely for specific piggeries. Table 18 shows the average electricity and heat consumption of piggeries ranging in size from 3500 to 75 000 SPU.

Table 18: Average electricity and heat consumption for different sized piggeries

SPU	3 500	10 000	20 000	50 000	75 000
Piggery Electricity Consumption (kWh/year)	108 500	310 000	620 000	1 550 000	2 325 000
Piggery Heat Consumption (MJ/year)	80 500	230 000	460 000	1 150 000	1 725 000

3.4 Estimation of GHG Emissions

In order to estimate the GHG emissions from each of the systems used in the case studies, a mass balance approach was taken. Figure 10 shows an example of the mass balance for the baseline scenario described previously, showing the major emission sources and the flows of carbon. This is specific to a flushing piggery however; the same mass principles can be applied to an array of systems.

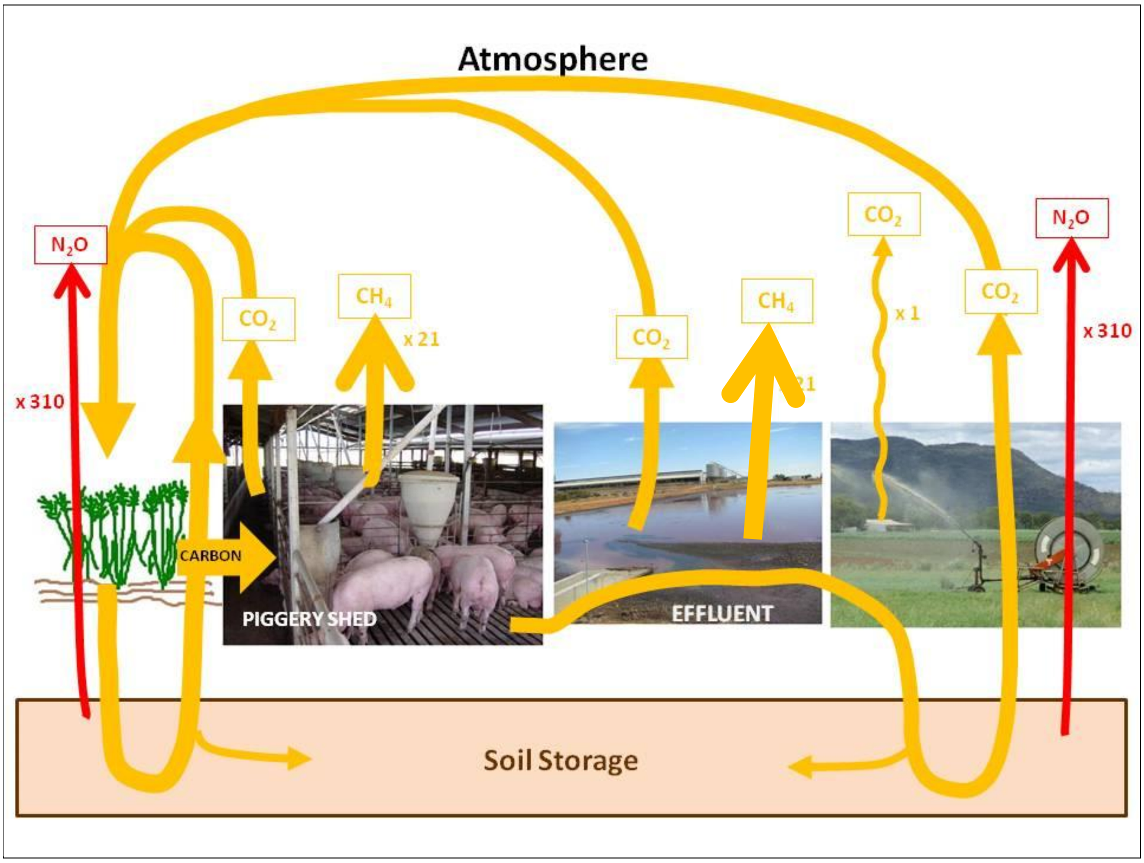

Figure 10: Main emissions from flushing piggery

The mass balance approach was applied to each of the VS, N, P and K flow rates into and out of each of the systems. The factor of interest when conducting a VS mass balance was the emission of CH_4 to the atmosphere. With regards to nitrogen, the factors of interest include nitrogen losses to the atmosphere (as ammonia (NH_3) and nitrous oxide (N_2O) and the proportion of N remaining in effluent and sludge which may be utilised as a fertiliser. P and K are conservative elements and thus are not lost to the atmosphere; however they are partitioned if a solids separation pre-treatment system is used.

To enable the prediction of emissions from the nine case studies over the range of piggery sizes investigated for this report, the Life Cycle Assessment (LCA) software tool SimaPro was used. This software enables straightforward and robust modelling of emissions from different systems. Each of the systems under review for this report were modelled as a unit process within SimaPro, using the emission and partition factors described in the following paragraphs and listed in Table 30 to Table 39 in

Appendix A. Within SimaPro all of the scenarios were run using a GWP for methane of 21 and for N_2O of 310.

3.4.1 GHG Emission and Partitioning Factors

For many of the systems investigated there was no comprehensive reference for emission and partitioning factors. Hence, these were drawn from numerous sources based on the best available science These come from the Australian National Greenhouse Gas Inventory manual (DCCEE 2010), the IPCC 2006 manuals and reliable literature references. A full list of the emission and partitioning factors used, along with the range in values and references is included in

Appendix A.

Housing Systems

The housing systems investigated are flushing and short HRT systems. It is assumed that there are no CH_4 and N_2O losses from flushing systems, while the amount of NH_3 volatilised is equal to 0.08 kg/kg N excreted. Short HRT systems have an MCF of 0.135, while the amount of NH_3 and N_2O volatilised is equal to 0.25 kg/kg N and 0.002 kg/kg N respectively.

Pre-Treatment

The pre-treatments systems investigated are trafficable sedimentation basins and static rundown screens. The VS removal fraction of a rundown screen is equal to 0.25, while that of N is equal to 0.027. The VS removal fraction of a trafficable sedimentation basin is equal to 0.7, while that of N is equal to 0.4.

Effluent Treatment

The effluent treatments systems investigated are uncovered anaerobic ponds, covered anaerobic ponds, secondary ponds and engineered digestion systems. Uncovered anaerobic ponds are assumed to have a B_o of 0.45 and an MCF of 90%, while the amount of N lost as NH_3 and N_2O is equal to 0.4 kg/kg N and 0 kg/kg N respectively. The CAP has similar emission and partitioning factors to the uncovered anaerobic pond, however it is assumed that the MCF is equivalent to 65% in this case, while all other factors remain the same. The secondary pond is again similar to the uncovered anaerobic pond, however the B_o is reduced to 0.3 in this case. The engineered digestion system is assumed to have an MCF of 100% due to the highly controlled nature of digestion within a heated vessel. The N emissions are the same as for the pond systems. The engineered digestion system is assumed to use DAF technology to thicken the effluent prior to digestion. This system is assumed to remove approximately 30% of the VS during the thickening process (Tucker et al. 2010).

Stockpiling

It is assumed that NH_3 emissions from the stockpiling stage are 0.45 kg/kg N, while the direct N_2O emission factor is 0.005 (range 0.005-0.01) (IPCC 2006). The MCF is 0.035 and this ranges from 0.02-0.05 depending on the temperature experienced by the piggery. P and K are retained in the stockpile and there is no loss to atmosphere.

Composting

For the purposes of this report, it is assumed that the MCF is 0.01 (range 0.005-0.015) (IPPC 2006). The N_2O emission factor was determined to be 0.01 (range 0.01-0.02) (IPPC 2006), and the NH_3 emission factor is 0.2 (FSA Consulting (2007)).

Solid and Liquid Land Application

This analysis assumed that the MCF for manure directly applied to land is 0 (Prapaspongsa et al. 2010). The emission factor for NH_3 volatised from the soil is 0.2 with a range of 0.05-0.5 kg NH_3 per kg N applied. The emission factor for direct N_2O is 0.02 with a range of 0.007-0.06. There is no loss of P and K to the atmosphere with land application.

3.5 Energy Generation

The amount of energy produced for each of the energy generation options is based on the methane produced using each system, and the efficiencies of the energy generation equipment. The energy produced is found by multiplying the volume of methane produced by the energy density of methane (34.2 MJ/m^3 – (DECC 2011)). It is then necessary to multiply this total annual potential energy by the electrical and thermal efficiency (h) of the energy system (h_{elec} = 30% for generator, h_{ther} = 90% for boiler, h_{elec} = 30% and h_{ther} = 55% for CHP). Conservative electricity efficiency factors were used to reflect lower cost generators / CHP units. These may be significantly higher (up to 42%) for more expensive generators. These values were fixed for all piggery sizes modelled.

3.6 Economics

Following GHG modelling a second screening process was undertaken to remove options that did not significantly reduce GHG. This included any systems that failed to reduce GHG by 25% and under In order to carry out a comprehensive economic comparison of each of the remaining case studies, it is necessary to evaluate the capital costs, annual expenses and revenue for each. This allows for the determination of the feasibility of each of the systems at each piggery size, showing which technologies are suitable for small, large and medium producers.

As a method of ensuring that there is a fair comparison made between systems, any costs or revenue that are associated with the uncovered anaerobic pond (baseline) have been removed. This is because this system is the industry standard and as such; farmers will already have this system in place, meaning that only changes to this system should be considered as additional costs. For example, capital expenditure for the construction of pond systems (baseline), the annual expenses relating to land application and revenue from the replacement of fertiliser onsite with the nutrients produced from each of the treatment systems is not included in the costing. For the covered anaerobic pond system (CAP) scenarios, the cost of the earthworks for the construction of the pond is included as an additional cost.

The only system where the liquid effluent is handled in a totally different manner to the baseline case is the short HRT system. The costs associated with handling the liquid effluent from this system have been discussed previously.

3.6.1 Case Studies: Capital Costs, Annual Expenses and Revenue

The capital costs and the annual expenses associated with each system have been discussed at length and tabularised in the previous sections of this report. In order to carry out a full economic analysis of the systems under review, it is necessary to predict the revenue stream from each. Each of the systems will gain revenue from one or more of the following six cash inputs:

- replacement of grid purchased electricity with electricity generated onsite,
- the export and sale of electricity to the grid,
- replacement of purchased LPG with heat generated onsite,
- the awarding of small-scale technology certificates (LGCs) under the Australian Government's Large-scale Renewable Energy Target (LRET) scheme (see appendices for more information),
- the receival of Australian carbon credit units (ACCUs) under the Carbon Farming Initiative (CFI) for the destruction of methane from CAPs (see appendices for more information),
- the sale of nutrient by-products – N, P and K – this revenue stream is only applicable to the short HRT system as the land application of nutrients from this system is different from the baseline

The price of electricity was assumed to be fixed at \$0.20 per kWh for the ten year lifetime of the project. To predict the amount of revenue that can be generated from the production of electricity onsite, it is simply a matter of multiplying this unit price by the electricity consumption values in Table 18.

It was assumed that the price of excess electricity that is sold back to the grid is fixed at \$0.045 per kWh. In order to determine the amount of electricity that can be resold to the grid, it is necessary to subtract the total energy consumption of the system from the total energy produced (as detailed in Section 0). This value is then multiplied by \$0.045.

From previous work in this area, the price of LPG was assumed to be fixed at \$0.68 per L or \$0.03 per MJ. To predict the amount of revenue that can be generated from the production of heat onsite, it is simply a matter of multiplying this unit price by the heat consumption values in Table 18.

With regards to the financial incentives provided by the government, the price of LGCs was assumed to remain fixed at 0.04 \$/kWh. The amount of renewable electricity (kWh) that replaces the conventional energy systems on the farm is only equal to the total amount of kWh used onsite, not the total potential energy that could be used onsite. LGCs are only awarded for renewable electricity generation and so any heat produced using biogas onsite is ineligible for these certificates.

The price of Australian Carbon Credit Units (ACCUs) under the CFI was fixed at the conservative "floor" value of \$15/tonne CO_2-equivalent. Carbon credits are based on the total amount of methane captured and destroyed using a flare, boiler of internal combustion engine.

The project baseline for CAPs is the amount of methane that would have been generated and released to the atmosphere from an uncovered pond included in the project, each year of the project, in the absence of the abatement activity. The project baseline will be used to cap the amount of captured and combusted methane that can be claimed as emissions abatement.

Under the CFI, a standard methane yield and methane conversion factor are defined. For an uncovered pond the ultimate methane yield (B_o) is the amount of methane that is produced under laboratory conditions and is equal to 0.45 for pigs. It has units of m^3 CH_4/kg VS (IPCC 2006). The methane conversion factor (MCF) for uncovered ponds is 90% (DCCEE 2010). To predict the baseline methane emissions, the following equation is used:

This volume is then converted to CO_2-equivalents. This gives the baseline CO_2 that would have been generated in the absence of the CAP project. . ACCUs can only be awarded for emissions up to this baseline amount. The methane destroyed during a project cannot exceed this amount. For this analysis, the MCF for the CAP systems was assumed to be 65%. This was to ensure that the predicted methane yield and resulting ACCU revenue stream was conservative.

For the engineered digestion system (Case Study 8), there is a CFI methodology for the destruction of methane. The baseline case is the same as that for the CAP methodology and this is what is assumed for this report. However, it should be noted that this type of system has not yet been proven to be economically feasible in an Australian context and as such, the economics should be approached with caution.

For the short HRT system and trafficable sedimentation basin/uncovered pond/stockpiling case studies, it was assumed that there are methodologies developed which allow for the receival of ACCUs. This is not the case in reality; however, it was deemed the most appropriate method of comparing the systems economically. There is the possibility that these methodologies will be developed in the future and therefore, this was taken into account. The baseline CH_4 emissions for each of these systems were based on the reduction in emissions (kg CO_2-e) which occur when these systems are implemented as compared to the baseline case (uncovered pond with no solids separation).

The sale of nutrient by-product is based on an N value of \$0.485/kg, P value of \$0.51/kg and a K value of \$0.59 (FSA Consulting 2007b). These prices are then multiplied by the mass of the nutrients applied to land for the short HRT system case study in order to predict the annual revenue.

3.6.2 Cost/Benefit Analysis

The systems under investigation for this report were analysed to determine and compare their economic feasibilities and help determine which options are the best choice for piggeries in Australia. The economic feasibility was examined using the return on investment (ROI) over the first five years of the project, the pay-back period on the initial investment as well as the cumulative net profit over the 10 year lifespan of the project.

The return on investment for the first five years was determined in order to show the percentage return on the initial investment after the first five years of the project. The ROI was calculated as follows.

The payback period on the initial investment was then calculated. This calculation shows the amount of time it will take the project to earn a cumulative net profit greater than the initial investment. It shows how long it will take the project to earn enough money to pay back the initial investment. This figure was calculated by examining the cumulative net profit figures. It was noted after what year the cumulative figure was greater than that of the initial investment. Once this figure was noted the pay-back period was calculated as follows:

CNP Y1 = cumulative net profit at year before initial investment was first surpassed
CNP Y2 = cumulative net profit at year initial investment was first surpassed
Y1 = year at which initial investment was first surpassed.

4. Results

4.1 GHG Modelling

The systems were modelled in SimaPro using the emission factors described in Section 0. The energy generation potential of each of the biogas recovery options was determined and finally, an economic comparison of the chosen case studies was carried out.

4.1.1 Estimated GHG Emissions

The GHG emissions produced for each of the case studies were reported in kg CO_2-e/SPU/year. Table 16 shows these emissions along with the mitigation potential relative to the baseline. Figure 11 displays this information graphically.

The CAP systems and engineered digestion system with energy generation showed a large reduction in overall GHG emissions relative to the baseline. The large emissions reduction potential of the engineered digestion system can be explained by the fact that it is assumed 100% of the VS is broken down in this primary treatment stage. Therefore, the residual emissions from the secondary pond are extremely small. In addition to this, it is assumed 30% of the VS is pulled out of the system using the DAF technology prior to digestion and this analysis assumed that there are no methane emissions from liquid irrigation of the effluent. In reality, these factors may be different and so the elevated GHG performance of this system may be overestimated.

Case study 2 shows that with a trafficable sedimentation basin pre-treatment system the emissions of the baseline scenario can be reduced by 58% which is a substantial decrease with very little modification to existing systems needed.

With regards to the simplistic GHG modelling of deep litter systems, the study identified significant differences in emissions between deep litter and conventional housing systems. Deep litter housing was shown to reduce the CO_2-e emissions by approximately 45% in comparison to the baseline. This suggests that a change from conventional housing to deep litter is a potential mitigation strategy which could be incorporated into a methodology under the CFI.

Table 19: Case study GHG emissions (kg CO_2-equiv/SPU/year) and mitigation potential relevant to baseline

Case Study Unit	Direct emissions kg CO_2 e/SPU/year	Percentage less than baseline
1 - Baseline	587	
2 – Trafficable sedimentation basin/Uncovered pond/Stockpile	250	58%
3 – Screen/Uncovered pond/Compost	461	22%
4 – CAP/flare	202	66%
5 – CAP/generator	167	72%
6 – CAP/boiler	200	66%
7 – CAP/CHP	165	72%
8 – Engineered Digestion system/CHP	64	89%
9 – Short HRT system	166	72%

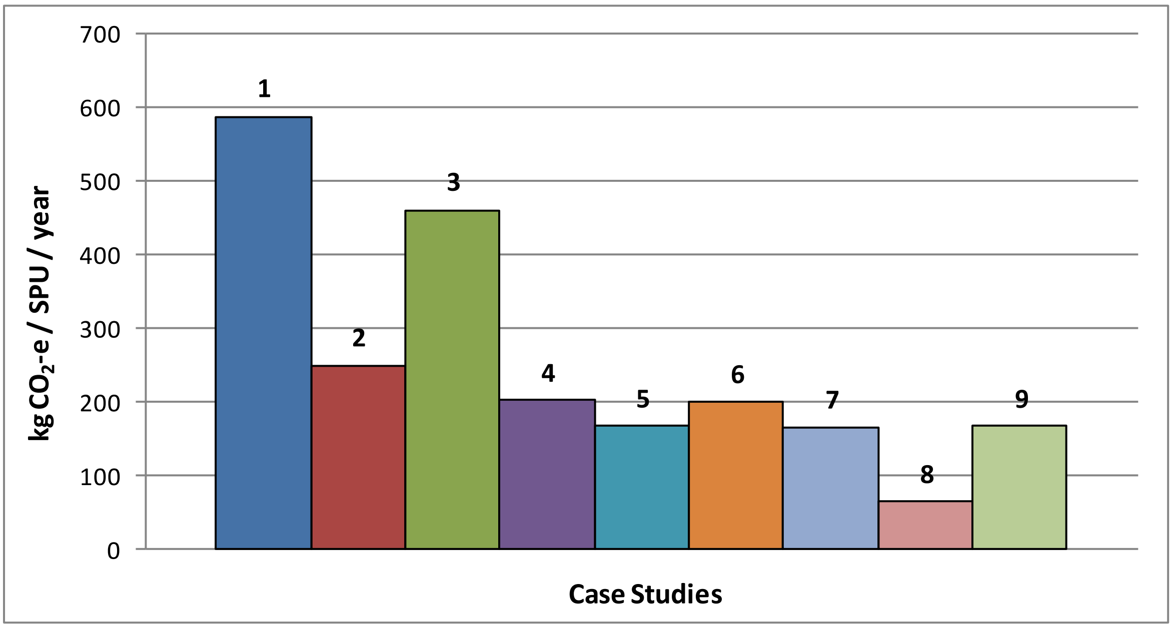

Figure 11: Case study GHG emissions

The results of this GHG modelling were used to further reduce the number of case studies investigated for the subsequent sections of this report. The studies modelled further include:

- Case Study 2 – Trafficable sedimentation basin/Uncovered pond/Stockpile
- Case Study 4 – CAP/flare
- Case Study 5 – CAP/generator
- Case Study 6 – CAP/boiler
- Case Study 7 – CAP/CHP
- Case Study 8 – Engineered digestion system/CHP
- Case Study 9 – Short HRT system

4.2 Mass Balance Modelling

4.2.1 VS, N, P and K Mass Flows

It was relatively easy to track the mass flowrates of the VS, N, P and K throughout each of the case study systems. Table 20 and Table 21 show the VS and N flowrates throughout each of the manure management systems investigated. Table 22 shows the P and K flows for the short HRT system.

Table 20: VS flowrates (kg/SPU/yr)

Case study	VS mass flow per SPU after treatment (kg/SPU/yr)	Solids Application	Liquid Irrigation
2	TSB/Uncovered Pond/Stockpile	41.8	0.3
4	CAP/flare	0	3.2
5	CAP/generator	0	3.2
6	CAP/boiler	0	3.2
7	CAP/CHP	0	3.2
8	Engineered/CHP	0	0
9	Short HRT system	0	77.9

Table 21: N flowrates (kg/SPU/yr)

Case study	N mass flow per SPU after treatment (kg/SPU/yr)	Solids Application	Liquid Irrigation
2	TSB/Uncovered Pond/Stockpile	4.3	0.7
4	CAP/flare	3.4	2.4
5	CAP/generator	3.4	2.4
6	CAP/boiler	3.4	2.4
7	CAP/CHP	3.4	2.4
8	Engineered/CHP	1.9	3.1
9	Short HRT system	0	6.8

Table 22: P and K flowrates (kg/SPU/yr) for short HRT system

Element	Solids Application	Liquid Irrigation
P (kg/SPU/yr)	0	3.0
K (kg/SPU/yr)	0	2.4

4.2.2 TS Mass Flow

The TS mass balance for the short HRT system was determined by summing the VS, N, P and K flows shown in Table 20 to Table 22. Table 23 shows the TS production for the short HRT system.

Table 23: TS production for short HRT system over range of piggery sizes

	TS production (kg/yr)				
Case Study	**3 500**	**10 000**	**20 000**	**50 000**	**75 000**
Short HRT System	315 350	901 000	1 802 000	4 505 000	6 757 500

4.3 Energy Production

4.3.1 Total Energy Production

The energy production potential of case studies 5, 6, 7 and 8 was determined using SimaPro. The energy produced is found by multiplying the volume of methane produced by the energy density of methane (34.2 MJ/m^3 – (DECC 2011)). It is then necessary to multiply this total annual potential energy by the electrical and thermal efficiency. Table 24 shows the predicted methane production for the energy recovery case studies.

Table 24: Methane production potential for biogas energy recovery case studies (m^3/yr)

Biogas Production (m^3/yr)	**3 500**	**10 000**	**20 000**	**50 000**	**75 000**
CAP/generator	92 138	263 250	526 500	1 316 250	1 974 375
CAP/boiler	92 138	263 250	526 500	1 316 250	1 974 375
CAP/CHP	92 138	263 250	526 500	1 316 250	1 974 375
Engineered/CHP	99 225	283 500	567 000	1 417 500	2 126 250

The potential methane production for case studies 5, 6 and 7 are equal because it is based on the production of methane from a CAP. There are no pre-treatment stages for any of these case studies and so the same amount of VS is flowing into each system. In addition to this all of the emission factors used are equal. Case study 8 is the engineered digestion system and therefore it has a different methane production potential than the other three case studies. This is because a DAF system removes some of the VS before it flows into the digester. In addition, the emission factors are higher for this system.

Table **25** shows the predicted energy production for each system.

Table 25: Energy production over range of piggery sizes

Case study	**Energy production**	**3500 SPU**	**10 000 SPU**	**20 000 SPU**	**50 000 SPU**	**75 000 SPU**
CAP/generator	Electricity (kWh/yr)	262 592	750 263	1 500 525	3 751 313	5 626 969
CAP/boiler	Heat (MJ/yr)	2 835 992	8 102 835	16 205 670	40 514 175	60 771 263
CAP/CHP	Electricity (kWh/yr)	262 592	750 263	1 500 525	3 751 313	5 626 969
	Heat (MJ/yr)	1 733 106	4 951 733	9 903 465	24 758 663	37 137 994
Engineered/CHP	Electricity (kWh/yr)	282 791	807 975	1 615 950	4 039 875	6 059 813
	Heat (MJ/yr)	1 866 422	5 332 635	10 665 270	26 663 175	39 994 763

4.3.2 Electricity Available for Sale to Grid

In order to determine, the amount of electricity that was available to be sold to the grid from the systems, it was necessary to subtract the total energy production from the predicted energy consumption of the piggery. Table 26 shows the electricity that was assumed to be resold to the grid.

Table 26: Electricity resold to grid

Excess electricity (resale to grid)			**kWh/yr**		
Case Study	**3 500**	**10 000**	**20 000**	**50 000**	**75 000**
CAP/generator	154 092	440 263	880 525	2 201 313	3 301 969
CAP/CHP	154 092	440 263	880 525	2 201 313	3 301 969
Engineered/CHP	152 346	435 275	870 550	2 176 375	3 264 563

4.4 Economic Modelling

4.4.1 Payback Period, Return on Investment and Cumulative Net Profit

The payback period, ROI after five years and cumulative net profit after the 10 year life span of the projects were then calculated and compared.

Table **27** shows the payback period on the initial investment, Table 28 shows the return on investment over 5 years and Table 29 shows the cumulative net profit after ten years for the systems.

Table 27: Payback period on initial investment

			Payback Period (years)		
Case Study	**3500 SPU**	**10 000 SPU**	**20 000 SPU**	**50 000 SPU**	**75 000 SPU**
2 - Trafficable sedimentation basin/Uncovered pond/stockpile	8.3	5.9	4.6	3.0	2.7
4 - CAP with flare	44.9	25.3	19.5	14.5	11.8
5 - CAP with generator	7.8	5.4	4.1	3.0	2.8
6 - CAP/Boiler	25.7	16.4	11.6	10.1	9.3
7 - CAP/CHP	8.1	4.4	4.2	2.9	2.8
8 - Engineered digester/CHP	Never	12.0	8.1	5.0	4.7
9 - Short HRT system	9.1	7.1	N/A	N/A	N/A

Table 28: Return on investment over 5 years

			Return on investment over 5 years (%)		
Case Study	**3500 SPU**	**10 000 SPU**	**20 000 SPU**	**50 000 SPU**	**75 000 SPU**
2 - Trafficable sed basin / Uncovered pond/stockpile	-44.6%	-16.4%	8.5%	68.7%	91.7%
4 - CAP with flare	-94.2%	-85.1%	-78.9%	-28.0%	-19.6%
5 - CAP with generator	-40.3%	-8.7%	22.2%	259.9%	275.1%
6 - CAP/Boiler	-85.4%	-73.7%	-66.1%	-56.9%	-52.2%
7 - CAP/CHP	-42.6%	15.0%	20.5%	77.3%	84.1%
8 - Engineered digester/CHP	-135.5%	-68.3%	-42.3%	0.4%	8.2%
9 - Short HRT system	-51.3%	-32.4%	N/A	N/A	N/A

Table 29: Cumulative net profit over 10 years

Case Study	Cumulative net profit over 10 years ($) 3500 SPU	10 000 SPU	20 000 SPU	50 000 SPU	75 000 SPU
2 - Trafficable sed basin / Uncovered pond/stockpile	35 198	109 348	232 009	651 821	1 045 619
4 - CAP with flare	49 891	183 969	412 874	1 137 118	1 829 207
5 - CAP with generator	403 911	1 033 884	2 561 359	6 640 273	10 079 560
6 - CAP/Boiler	84 357	282 637	610 597	1 632 875	2 573 423
7 - CAP/CHP	429 403	1 356 282	2 737 427	7 120 753	10 797 612
8 - Engineered digester/CHP	-234 551	615 555	1 954 656	6 438 144	10 182 011
9 - Short HRT system	232 253	705 609	N/A	N/A	N/A

4.4.2 Most Economically Favourable Systems

The most economically favourable systems are the trafficable sedimentation basin/uncovered pond/stockpile system (Case Study 2), CAP with generator or CHP system (Case Studies 5 and 7) and the engineered digester/CHP system (Case Study 8). Apart from the engineered digestion system, all of these case studies display payback periods that are less than ten years for the entire range of piggery sizes investigated.

Figure 12 shows the payback periods for each of these systems. The system with the shortest payback period is Case Study 2. This is because the capital costs and annual expenses for this system are extremely low and with a revenue from ACCU of $3.20/SPU and $1.40 per finished pig, the returns look favourable. Therefore, if the appropriate methodology was developed, the ACCUs received for installing this system would be considerable. For the relatively small investment costs, the profits from this system could be considerable. It is a viable abatement option for all piggery sizes and may be attractive to smaller piggeries which do not have the resources to invest hundreds of thousands of dollars in energy recovery infrastructure. However, the assumptions for VS removal from the trafficable sedimentation basin (70% reduction in VS) would need to be validated further under field conditions to confirm these returns.

Both of the CAP systems have very similar payback periods, ranging from approximately eight years at an SPU size of 3500 to 2.8 years for an SPU size of 75 000. These short paybacks are very promising for piggeries of all sizes. These systems have such short paybacks due to the large electricity offset and export, and the revenue from ACCUs and LGCs.

It was determined that between 48 and 51% of the revenue from these two systems comes from sources heavily influenced by government policy (i.e. the ACCUs and LGCs). Therefore, if the price paid for these credits reduces over the next few years or is removed, the feasibility of installing these systems will decrease significantly. The effect will be greatest for the smaller piggeries, whereas large piggeries (50 000-75 000 SPU) would be less affected.

The engineered digestion system with the CHP unit was not feasible at the smallest piggery size because of the large investment costs associated with this system. The payback period ranges from 12 down to 4.7 years for the 10 000 and 75 000 SPU piggeries respectively.

With the engineered digester and CHP there is the potential of returning $6.1 per SPU or $2.6 per finished pig under the CFI. The payback period is longer than the CAPs due to the larger investment costs associated with this system. Similar to the boiler system, this system could have a reduced payback period if another economic use for the excess heat existed at the piggery.

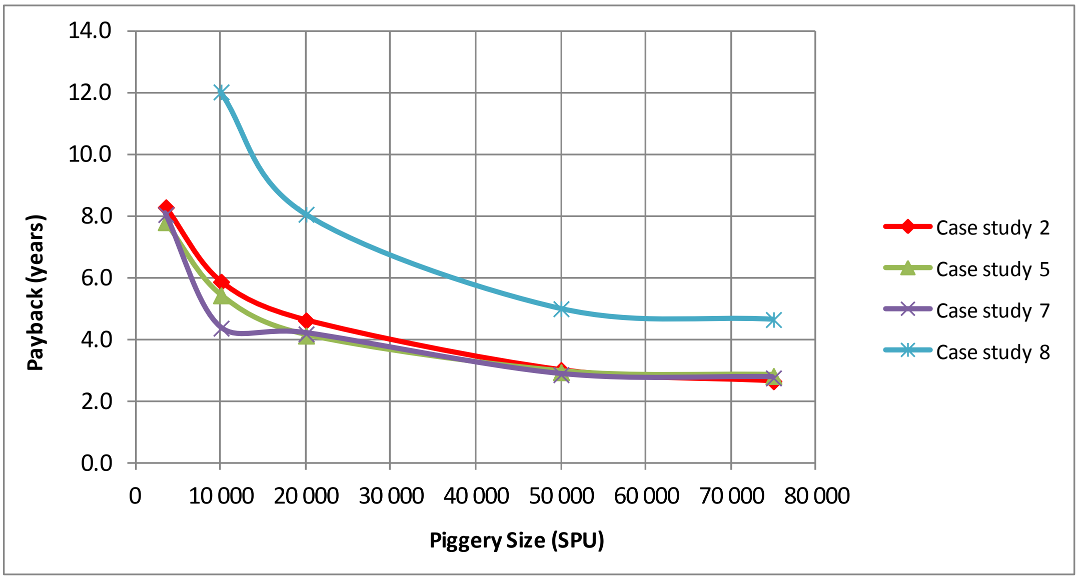

Figure 12: Payback period for most economically favourable systems

Figure 13 shows the cumulative cash flow after ten years for the four case studies with the most favourable economics. The trafficable sedimentation basin system has far lower financial returns than the other three systems despite its shorter paybacks.

With regards to the CAP and engineered digestion systems, at the larger end of the SPU scale, the estimated profits (net cash flow) were as high as $1 million per year, and even at the smallest piggery sizes, the estimated profits were in the order of $34 000 per year. These are significant profits and clearly would be of benefit to pig producers in Australia.

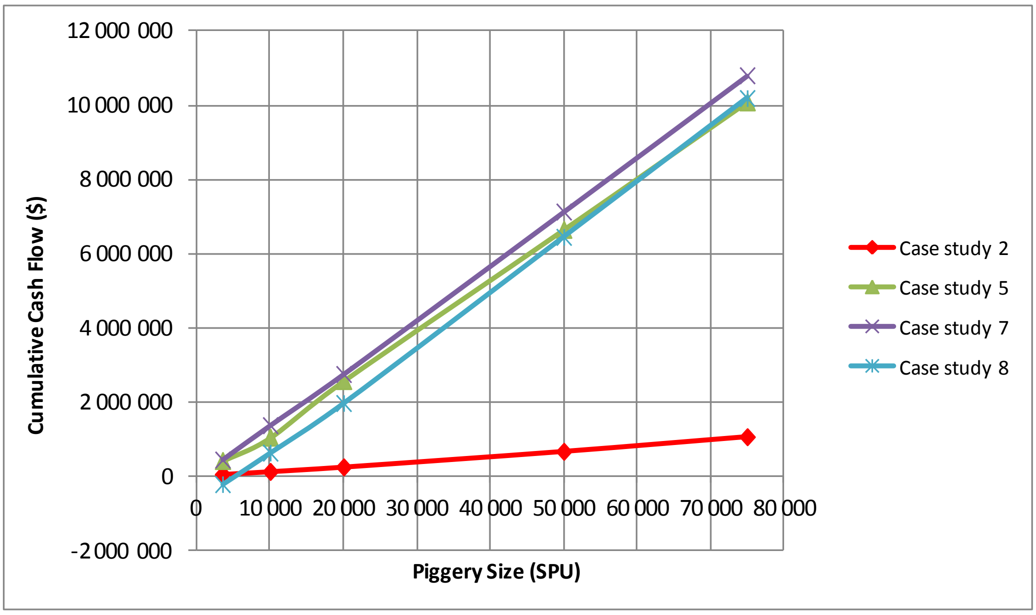

Figure 13: Cumulative cash flow after 10 years for most economically favourable systems

For small piggeries (3500-10 000 SPU), the manure management systems that give the highest return on investment and provide the shortest payback periods are the trafficable sedimentation basin and

CAP/generator systems. For medium and large producers both CAPs with generators and CHP units, or an engineered digestion system with a CHP gives the best financial returns.

A system which was not fully economically modelled due to its relatively low GHG mitigation potential relative to the other systems under investigation was Case Study 3. This was comprised of a static rundown screen, uncovered pond and compost pile, and reduced emissions by 22% relative to the baseline case. This may represent one of the easiest abatement opportunities for pig producers and could be developed into a CFI methodology with little difficulty. However, it is not yet clear if the abatement potential would be realised under commercial operating conditions, because the coarse material removed by the screen is likely to have a much lower methane potential. This would require further analysis to be confident of the mitigation potential.

4.4.3 Systems with Relatively Low Economic Feasibilities

The case studies which appear to be the least favourable in economic terms include the CAP system with a boiler or a flare and short HRT system. Each of these systems have relatively low ROIs over five years and cumulative profits after the ten year lifetime of the project, as compared to the other systems under investigation. In addition to this, the payback period for each of these systems is greater than five years at all piggery sizes.

Case Study 4 – CAP/Flare

The CAP/flare system has a smaller initial investment cost than the other CAP systems, however the revenue stream for this system is based solely on the sale of ACCUs. The returns from this system, even at smaller piggeries were less than the boiler, CHP or generator systems.

A sensitivity analysis was carried out for this system, in order to determine the effect of reduced management costs on the feasibility. The costs associated with managing the construction of a new CAP-flare system that have been assumed for this study are very conservative. However, it is possible that many farmers would have the capacity to manage the projects themselves and carry out many of the equipment installations required. This study found that if these costs were reduced, then the payback period for the CAP-flare system decreased by 33% – ranging from 7.9-30.0 years.

Case Study 6 – CAP/Boiler

With regards to the CAP/boiler system, it should be noted that this system's economic feasibility would be greatly increased if the heat demand of the generic piggery assumed for this study was larger. The heat demand for piggeries is generally low as electric heating is favoured over a boiler system. Farmers should be aware that installing a boiler system has a much lower degree of complexity and cost than both generator and CHP units. If a boiler is already in place onsite, it is a simple case of pumping the gas to the heat production unit, with very little or no modifications needing to be made to the system already in place.

Therefore, this system should not be disregarded because of the results presented in Section 0, particularly where a piggery has higher demand for heat energy than modelled here. This may be the case if a feedmill was located onsite, or if a system was designed to use heat rather than electricity wherever possible. In these situations, farmers should consider the installation of a boiler onsite as a relatively cheap and favourable energy recovery option.

Case Study 9 – Short HRT System

The feasibility of installing the short HRT system for both 3500 SPU and 10 000 SPU is lower than for the majority of the other systems investigated. In addition to this, due to different management practices in Australia, it may only be possible to practice short HRT for half of the year, meaning an uncovered anaerobic pond would be used for the remainder. This would essentially halve the amount of ACCUs that could be sold under the CFI if a methodology was developed. It means that the payback period for the 3500 SPU is increased from 9.1 years to 12.5 years, while the payback period of a 10 000 SPU piggery is increased from 7.1 to 9.5 years. However it is a relatively simple system to install and manage and can reduce GHG emissions by 72% relative to the baseline. Potentially, it could return a price of $4.00 per SPU or $1.70 per finished pig under the CFI. Therefore, it should be investigated further in terms of methodology development under the CFI.

5. Conclusions

This analysis provided a comprehensive literature review which showed that a wide range of manure management systems are available to the pig industry to reduce their GHG emissions. Of this large number of systems, nine case studies were reviewed for their ability to reduce GHG emissions relative to the baseline case – the industry standard comprising a flushing piggery with an uncovered anaerobic pond. The case studies which proved to reduce emissions by the greatest amount were then modelled to assess the economic feasibility of pig producers adopting them. This study found:

- A change from the baseline to a short HRT system reduced GHG emissions by 72%.
- CAPs with energy generation can reduce GHG emissions by between 66 and 72%.
- A change to an engineered digestion system can lead to an overall reduction in GHGs by 89%.
- The installation of a solids separation step such as a trafficable sedimentation basin or static rundown screen with the baseline scenario may reduce emissions by 58% and 22% respectively.
- A change from a flushing system to deep litter has the potential of reducing emissions by 45%.

It should be noted that these results are preliminary and further research is needed to confirm the findings of this study. However, this analysis does show that there may be opportunities for the development of CFI methodologies for several different manure management systems provided the portioning and emission factors used in this report were considered sufficiently robust. These could be developed relatively easily by industry and then used to generate additional revenue for farmers.

With regards to the simple GHG modelling of deep litter systems, the study identified significant differences in environmental performance between deep litter and conventional housing systems. Deep litter housing was shown to reduce the CO_2-e emissions by approximately 45% in comparison to the baseline. Therefore, it is clear that the change from conventional housing to deep litter represents a potential pathway for the development of a methodology under the CFI.

The economic modelling showed that the most profitable systems included the trafficable sedimentation basin with uncovered pond combination, the CAP with a generator or CHP unit and the engineered digestion system with CHP. These systems all displayed high cumulative profits over the assumed ten year lifetime of the project and short payback periods.

The CAP-generator system had a payback period of 2.8-7.8 years for farms ranging in size from 75 000 SPU down to 3500 SPU respectively. The CAP-CHP system has payback of between 2.8 years for the larger piggeries and 8.1 years for the smaller piggery sizes investigated. These short paybacks are very promising for piggeries of all sizes. It should be noted that the revenue streams for both systems are heavily influenced by government legislation however. Approximately 48-51% of the revenue was assumed to come from ACCUs and LGCs. These revenue streams are subject to a high degree of uncertainty within the timeframe of the analysis (10 years).

The engineered digestion system with the CHP unit was feasible only at larger piggeries because of the large investment costs. The system has a payback period ranging from just over 12 years at the 10 000 SPU piggery size to 4.7 years for the largest piggeries. The payback period is longer than the CAPs due to the larger investment costs associated with this system. However, an engineered digestion system typically has a lifetime of between 20 and 50 years. This means that the plant infrastructure does not need to be replaced after ten years making the long term (20+ year) feasibility of these facilities more attractive. It is not clear what additional maintenance expenses would arise from the CAP system in this time In addition to this, engineered digesters are highly controlled, with constant production of methane gas. Therefore, pig producers at the larger end of the scale should not disregard this system because it is not as economically favourable as the CAP systems reviewed. The added benefits of ease of control, longer life and constant methane gas production may outweigh the higher costs over the first 10 years.

The feasibility of the CAP system with a boiler could be increased if there was higher energy demand at the facility (such as where a feed mill was located on site) or where there was another way to utilise heat at the piggery to generate income. This option should be considered by larger pig producers. Similarly, the economics of installing combined heat and power would improve if there was another economically viable use for heat beyond what the piggery is able to utilise.

Consideration must be taken when interpreting these results. All piggeries are different and it is advised that an individual economic feasibility carried out before any project is undertaken.

This study shows that the pork industry has many opportunities for reducing GHG emissions, whilst also increasing the turnover of individual farmers. The use of CAPs and capture/utilisation of biogas as a GHG mitigation opportunity is especially interesting for pig producers as it is now a recognised abatement methodology under the Carbon Farming Initiative (CFI). This methodology allows for the generation of additional revenue for piggery owners through the sale of carbon credits. Technologies which have not been previously considered for methodology development under the Carbon Farming Initiative (CFI), such as trafficable sedimentation basins, screens and short HRT systems can be used to significantly reduce emissions from piggeries. There is a clear opportunity for these to be included under the CFI. This report shows that pork producers can profit while reducing their negative impact on the environment. This is an obvious benefit to the industry as a whole and the development of CFI methodologies should be seriously considered in order to promote these opportunities.

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Appendix A – Manure Excretion Model

Piggery GHG and Nutrient Mass Balance

In order to determine the GHG emissions potential of each of the systems under review in this report, a mass balance approach has to be taken. This is applied to each of the VS, N, P and K flow rates into and out of each of the systems.

Methane Emissions Potential

The VS removal efficiencies, ultimate methane yield (B_o) and methane conversion factor (MCF) of each of the stage of the manure management system were found using the IPCC and DCCEE estimations, in conjunction with emission factors from the literature. In order to carry out the mass balance throughout each stage of the MMS it was decided to use both the IPCC and best science (literature) emission factor estimates.

Table 30 to Table 34 show the emission factors for every stage of the manure management system included in this study.

Table 30: VS mass balance, ultimate methane yield (Bo) and methane conversion factor (MCF) for piggery housing systems

Housing system	Best science emission and partition factors	Details of reference
Flushing piggery		
VS out to treatment	1.00	
Bo	0.45	DCCEE 2010
MCF	0.000	
Deep Litter		
VS out to treatment	0.968	
Bo	0.45	DCCEE 2010
MCF	0.033	DCCEE 2010
Range	0.015-0.05	DCCEE 2010
Short HRT system		
VS to land application	0.865	
B_o	0.45	DCCEE 2010
MCF	0.135	IPCC 2006
Range	0.03-0.3	IPCC 2006

Table 31: VS mass balance, ultimate methane yield (B_o) and methane conversion factor (MCF) for pre-treatment systems

Pre-treatments	Best science emission and partition factors	Details of reference
Rundown screen		
VS removal fraction	0.25	PIGBAL
VS to further treatment	0.75	
Trafficable sedimentation basin		
VS removal fraction	0.8	Kruger et al. 1995
VS to further treatment	0.2	
Screw press		
VS removal fraction	0.2	Tucker et al. 2010
VS to further treatment	0.8	

Table 32: VS mass balance, ultimate methane yield (B_o) and methane conversion factor (MCF) for effluent treatment systems

Effluent treatments	Best science emission and partition factors	Details of reference
Anaerobic pond		
VS out to secondary pond	0.1	
B_o	0.45	DCCEE 2010
MCF	0.9	DCCEE 2010
CAP		
VS out to secondary pond	0.35	
B_o	0.45	DCCEE 2010
MCF	0.65	(Craggs et al. 2008)
Secondary pond		
B_o	0.3	Wiedemann S.G. and McGahan, E.J. 2011
MCF	0.9	DCCEE 2010
Engineered system		
B_o	0.45	DCCEE 2010
MCF	1.00	

Table 33: VS mass balance, ultimate methane yield (B_o) and methane conversion factor (MCF) for stockpiling and composting

Stockpile	Best science emission and partition factors	Details of reference
B_o	0.45	DCCEE 2010
MCF	0.035	(IPCC 2006)
Range	0.02-0.05	
Composting (passive windrow)		
B_o	0.45	DCCEE 2010
MCF	0.010	(IPCC 2006)
Range	0.005-0.015	

Table 34: VS mass balance, ultimate methane yield (B_o) and methane conversion factor (MCF) for land application

Land Application	Best science emission and partition factors	Details of reference
Liquid Effluent Irrigation		
B_o	0.45	DCCEE 2010
MCF	0	Prapaspongsa et al. 2010
Solid application		
B_o	0.45	DCCEE 2010
MCF	0	Prapaspongsa et al. 2010

Nitrous Oxide and Ammonia Emissions Potential

The nitrous oxide and ammonia emissions potential of each of the stage of the manure management system were found using the IPCC and DCCEE estimations, in conjunction with emission factors from the literature. For carrying out the mass balance throughout each stage of the MMS it was decided to use both the IPCC and best science (literature) emission factor estimates. For indirect nitrous oxide emissions (which occur through the volatilisation of N as NH_3 and NO_x and subsequently the deposition of these gases on soil), an emission factor of 0.01 kg N_2O-N/kg NH_3-N volatilised ((IPCC 2006) and (DCCEE 2010)), was assumed for every stage of the system.

Table 35 to Table 39 show the emission factors for every stage of the manure management system included in this study.

Table 35: Nitrogen mass balance, ammonia emission factor (kg NH_3 per kg N), direct and indirect nitrous oxide emission factors (kg N_2O per kg N) for piggery housing systems

Housing System	Best science emission and partition factors	Details of reference
Flushing piggery		
Volatilised from housing as NH_3	0.080	FSA Consulting 2011
Range	0.00-0.12	FSA Consulting 2011
Volatilised from housing as N_2O	0.0	Cabaraux et al. 2009
Indirect N_2O from NH_3 deposition	0.001	
N to further treatment	0.920	
Deep Litter		
Gaseous N loss	0.170	FSA Consulting 2007
Volatilised from housing as NH_3	0.128	FSA Consulting 2007
Volatilised from housing as N_2O	0.043	
Indirect N_2O from NH_3 deposition	0.001	
N to further treatment	0.830	
Short HRT system		
Gaseous N loss	0.252	
Volatilised from housing as NH_3	0.250	IPCC 2006
Range	0.15-0.30	IPCC 2006
Volatilised from housing as N_2O	0.002	IPCC 2006
Range	0.002-0.004	IPCC 2006
Indirect N_2O from NH_3 deposition	0.003	

Table 36: Nitrogen mass balance for pre-treatment systems

Pre-treatments	Best science emission and partition factors	Details of reference
Rundown screen		
N removed	0.027	Watts et al. 2001
N to further treatment	0.973	
Trafficable sedimentation basin		
N removed	0.400	Watts et al. 2001
N to further treatment	0.600	
Screw press		
N removed	0.042	Watts et al. 2001
N to further treatment	0.958	

Table 37: Nitrogen mass balance, ammonia emission factor (kg NH_3 per kg N), direct and indirect nitrous oxide emission factors (kg N_2O per kg N) for effluent treatment systems

Effluent treatments	Best science emission and partition factors	Details of reference
Anaerobic pond		
N to sludge	0.23	PIGBAL
N lost from pond as GHG emissions	0.40	IPCC 2006
Volatilised from pond as N-NH_3 and N- NO_x	0.40	IPCC 2006
Range	0.25-0.75	IPCC 2006
Volatilised from pond as N_2O	0.00	IPCC 2006
Indirect N_2O from NH_3 deposition	0.00	
N Irrigated from pond	0.37	
CAP		
N to sludge	0.23	PIGBAL
N volatised from pond as GHG emissions	0	IPCC 2006
Volatilised from pond as N-NH_3 and N- NO_x	0	IPCC 2006
Volatilised from pond as N_2O	0.00	IPCC 2006
Indirect N_2O from NH_3 deposition	0.00	
Irrigated from pond	0.67	
Secondary pond		
N to sludge	0.23	PIGBAL
N lost from pond as GHG emissions	0.40	IPCC 2006
Volatilised from pond as N-NH_3 and N- NO_x	0.40	IPCC 2006
Range	0.25-0.75	IPCC 2006
Volatilised from pond as N_2O	0.00	IPCC 2006
Indirect N_2O from NH_3 deposition	0.00	
N Irrigated from pond	0.37	
Engineered system		
Volatilised from system as N-NH_3 and N- NO_x	0	IPCC 2006
Volatilised from system as N_2O	0.00	IPCC 2006
Indirect N_2O from NH_3 deposition	0.00	
Irrigated from digester	1.0	

Table 38: Nitrogen mass balance, ammonia emission factor (kg NH_3 per kg N), direct and indirect nitrous oxide emission factors (kg N_2O per kg N) for stockpiling and Composting

Stockpile	Best science emission and partition factors	Details of reference
N volatised from system	0.205	
Volatilised from stockpile as N-NH_3 and N- NO_x	0.200	FSA Consulting 2007
Volatilised from stockpile as N_2O	0.005	IPCC 2006
Range	0.005-0.01	IPCC 2006
Indirect N_2O from NH_3 deposition	0.002	
Composting (passive windrow)		
N volatised from system	0.210	
Volatilised from system as N-NH_3 and N- NO_x	0.200	FSA Consulting 2007
Volatilised from system as N_2O	0.010	IPCC 2006
Range	0.01-0.02	IPCC 2006
Indirect N_2O from NH_3 deposition	0.002	

Table 39: Nitrogen mass balance, ammonia emission factor (kg NH_3 per kg N), direct and indirect nitrous oxide emission factors (kg N_2O per kg N) for land application

Land Application	Best Science Emission and Partition Factors	Details of Reference
Liquid Effluent Irrigation		
Volatilised from system as N-NH_3 and N- NO_x	0.200	IPCC 2006
Range	0.05-0.5	IPCC 2006
Volatilised from system as N_2O	0.020	Chadwick et al. 2011
Range	0.007-0.06	Range of sources from Chadwick et al. 2011
Indirect N_2O from NH_3 deposition	0.002	
Solid application		
Volatilised from system as N-NH_3 and N- NO_x	0.220	Williams et al. 2002
Volatilised from system as N_2O	0.010	DCCEE 2010
Indirect N_2O from NH_3 deposition	0.002	

Appendix B – Regulatory and Voluntarily Drivers that Support Piggery Biogas Capture and Use

Large-scale Renewable Energy Target & Small-scale Renewable Energy Scheme

In 2001 the Australian Government established a Mandatory Renewable Energy Target (MRET) scheme to encourage the generation of renewable electricity and reduce greenhouse gas emissions. Initially the scheme placed a liability on wholesale purchases of electricity to contribute an additional 9500 gigawatt hours (GWh) of renewable energy per year by 2010. In 2007, the government committed to increasing this target to 20% of Australia's electricity supply (41 850 GWh) by 2020 (Clean Energy Regulator 2012a).

The scheme has been successful in increasing the number of installations of small scale renewable energy projects, and has also resulted in over $9 billion of investment in renewable energy power stations by the end of 2010 (Clean Energy Regulator 2012b). The scheme also sets up the framework for the supply and demand market of renewable energy certificates (REC).

On 1st January 2011, the MRET was split into the Large-scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES). This led to the following changes to the existing MRET:

- RECs created from 2001 until the end of 2010 were reclassified as Large-scale Generation Certificates (LGCs) and put in the Register of Large-Scale Generation Certificates.
- From the 1st January 2011 Renewable Energy Power Stations create LGCs.
- From the 1st January 2001 RECs created for Small Generation Units are labeled as Small-scale Technology Certificates (STCs) and put in the Register of Small-scale Technology Certificates.

What are Renewable Energy Certificates?

- RECs are an electronic form of currency initiated by the Renewable Energy Electricity Act (2000).
- Large-scale Generation Certificates (LGCs) are created in the online REC Registry by renewable energy power stations and are equivalent to 1 MWh of renewable energy produced above the station's baseline power consumption.
- Small-scale technology certificates (STCs) are created in the online REC registry for small generation units such as heat pumps, small-scale wind, hydro and solar system. The STCs must be created within 12 months of the system being installed. One STC is equal to 1 MWh of renewable electricity generated (up to 15 years of lifetime of project for wind, hydro or solar systems) or fossil fuelled electricity displaced (up to 10 years of lifetime of project for solar water heaters and heat pumps) by these small generation units.
- After being registered online the LGCs and STCs are then validated by the Office of the Clean Energy Regulator before they can be traded on the market between registered persons.
- The Large-scale Renewable Energy Target places a legal requirement on power producers (termed RET liable entities) to purchase a fixed number of LGCs each year. These RET liable entities must surrender the LGCs to the Clean Energy Regulator on an annual basis. The amount of LGCs surrendered is equal to the power producer's annual liability.
- The SRES makes it a legal obligation of RET liable entities to purchase an amount of STCs every year. The amount of STCs that are purchased is based on the Small-scale Technology Percentage (STP) which is updated annually. This STP is applied to the amount of grid

purchased electricity required by the RET liable entities in order to determine how many STCs they need.

- Eligible parties can sell and transfer LGCs and STCs in the REC Registry to liable parties for a negotiated priced.
- Eventually all LGCs and STCs are surrendered to demonstrate liability requirements against the Government's Large-scale Renewable Energy Target and the Small-scale Renewable Energy Scheme.

In order to determine the amount of electricity eligible for LGCs a formula has been developed by the Clean Energy Regulator (Clean Energy Regulator 2012c). This electricity is everything above the power station's existing renewable energy baseline.

TLEG is equal to the total amount of renewable electricity generated at the power station. FSL is equal to the total amount of ineligible fossil fuel sources used by the power station. AUX represents the electricity used by the renewable power station for its continued operation and maintenance. DLEG is the net renewable electricity generated which is exported to the grid. MLF is the marginal loss factor which is used to determine the losses of renewable electricity after transport to the grid. It will be different for each region in Australia. It should be noted that if all of the renewable electricity generated is used onsite then this factor will be 1.

Figure 14 and Figure 15 show the large-scale generation certificate and small-scale technology certificate markets.

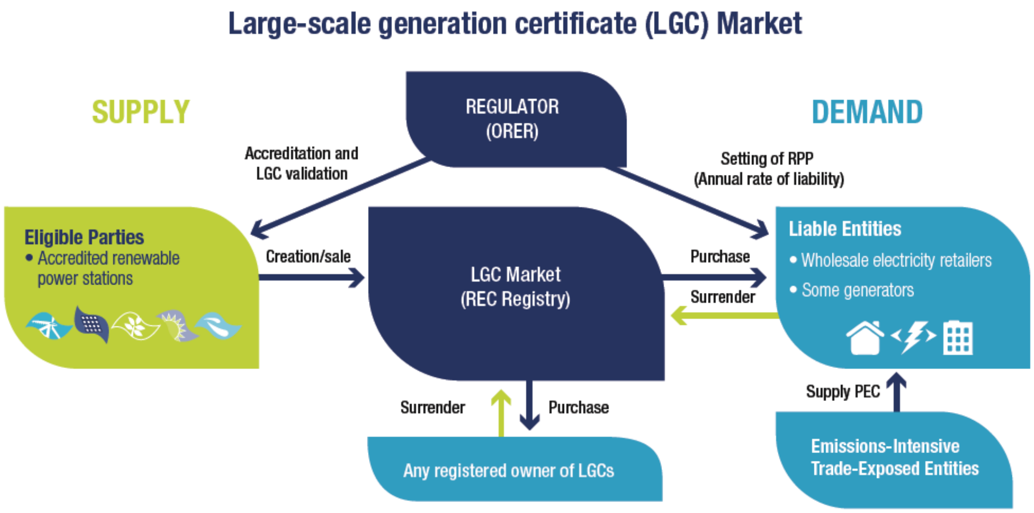

Figure 14: Diagram of the large-scale generation certificate (LGC) market – sourced from (ORER 2009)

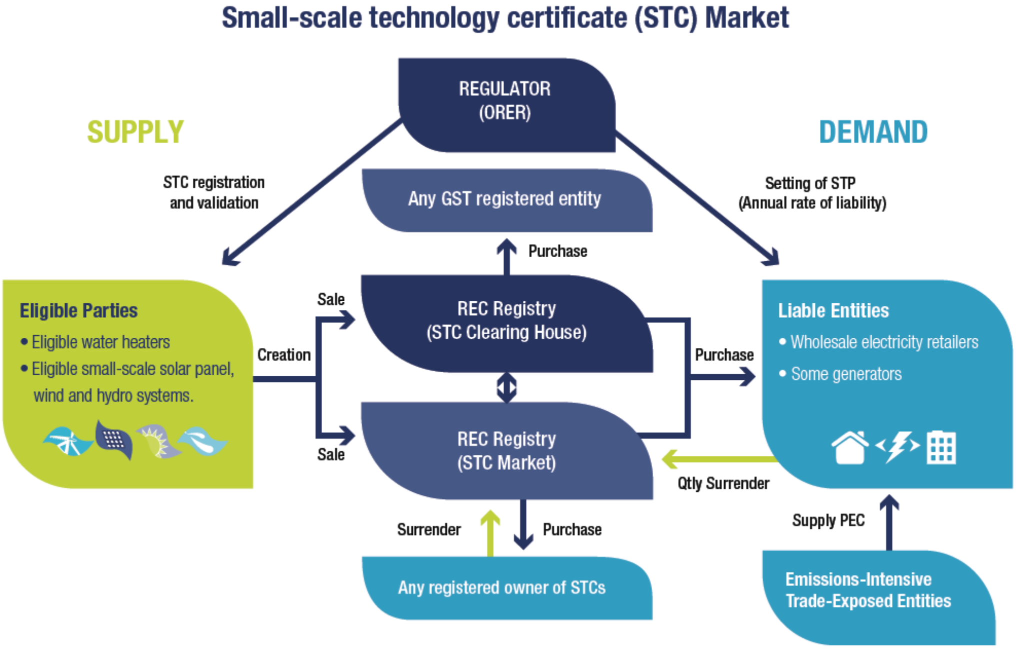

Figure 15: Diagram of the small-scale technology certificate (STC) market – sourced from (ORER 2009)

Eligible Suppliers LGCs

- Accredited renewable power stations – these power stations must generate electricity from approved sources such as wind, solar energy, agricultural waste or landfill gas.

Eligible Suppliers STCs

- Owners and agents of solar water heaters and small generation units.
- Small-scale renewable energy sources such as biogas, wind, hydro, solar and bagasse sourced from power stations.

Liable Buyers LGCs and STCs

- Wholesale electricity retailers and some generators who under the Renewable Energy Electricity Act (2000) must proportionately contribute towards the generation of additional renewable electricity.
- Liable parties are required to surrender the number of registered LGCs and STCs equal to their liability for previous calendar year.
- The Renewable Power Percentage (RPP) and the Small-scale Technology Percentage (STP), establish the annual rate of liability, and thus, determines the number of credits liable parties are required to surrender.

LGC and STC Market and Prices

The Renewable Energy Electricity Act (2000) allows for the electronic transfer of LGCs and STCs between REC Registry account holders. This process is market driven with price determined by demand. The Registry is not responsible for setting or regulating the price of LGCs (ORER 2009). The market price of the LGCs is dependent on supply and demand, and is fairly volatile, ranging from $10-$60 per LGC in the past. The spot price for LGCs was $37 per LGC for the 10th of October 2011 (Green Energy Trading 2011). The price of STCs also fluctuates quite considerably over a given period of time. For example the spot price of STCs varied between $37/MWh and $29/MWh between mid-January and 10th October 2011. However there is a Government guaranteed price of

$40 (excl. GST) per STC if the seller uses the STC Clearing House, which facilitates the exchange of Small-scale Technology Certificates (STCs) and is not available for LGCs.

Regulation
The Office of the Clean Energy Regulator assists the regulator by:

- Registering eligible parties.
- Accrediting eligible renewable power stations.
- Overseeing the validation and voluntary surrender of LGCs and STCs
- Imposing penalties for non-compliance with the provisions of the legislation.
- Undertaking audits of participants to ensure integrity of the measure.
- Maintain and update credit register.
- Provide industry and stakeholders with information about the measure (Clean Energy Regulator 2012a).

Carbon Farming Initiative
The Carbon Farming Initiative (CFI) is a voluntary scheme developed by the Australian Government which helps farmers, land owners and forest growers to earn additional income by reducing their greenhouse gas emissions such as methane and nitrous oxide through the adoption of emissions offsetting practices. The Government has dedicated approximately $45.6 million over a four year period to drive the successful implementation of the scheme (Clayton Utz 2011).

The CFI scheme becomes operational in December 2011 after legislation underpinning the scheme was passed by parliament on the 23rd of August 2011. On 15 September 2011 the Carbon Credits (Carbon Farming Initiative) 2011 (*CFI Act*) received royal assent.

Australian carbon credit units (ACCUs) will be issued for every tonne ($CO_{2\text{-equivalent}}$) of abatement generated by abatement activities. These units will then be sold to people and businesses wishing to offset their emissions. The Clean Energy Regulator will issue these units.

The scheme then enters an emissions trading phase (the flexible charge years). For the first three years, a intermediary carbon price ceiling and floor will control price volatility. Subsequently the price will be set only at auction (Lyster 2011). The CFI includes:

- Fast-tracked development of methodologies for carbon offset projects.
- Legislation to establish a carbon crediting mechanism.
- Information and tools to help farmers benefit from the carbon market.

Emission reduction activities under the CFI can include fertiliser management, manure management, reduced livestock emissions, savannah fire management and landfill gas flaring. Taking the pork industry as an example, for piggeries the carbon credit system is used to represent the abatement of greenhouse gases by reducing or avoiding emissions e.g. through the capture and utilisation of methane in a covered anaerobic pond (DCCEE 2011a).

To demonstrate additionality, there needs to be evidence that the emission reductions would not have occurred in the absence of the offset project; they must be additional to business as usual. To achieve this, a document called the Positive List was produced by the Australian Government. This document identifies activities that would be considered additional and eligible to participate in the scheme. This will help you determine whether your project is recognised as providing genuine environmental benefit. This is intended to provide greater assurance that particular projects will be approved and hence reduce overall transaction costs.

The Negative List provides for the exclusion of activities from the CFI if there is a risk that they will have an undesirable impact on the availability of water, the conservation of biodiversity, the local community, employment, and land access for agricultural production.

Offset projects established under the CFI need methodologies approved by the Government. These methodologies may be developed by private entities, industry and government bodies, and the abatement activity must be measurable and verifiable. A new methodology is submitted to the Domestic Offsets Integrity Committee (DOIC) for assessment. Applications for evaluation of proposed CFI methodologies must be prepared in agreement with the 'Interim Guidelines for Submitting Methodologies' by means of the template provided.

There are a number of steps involved in participating in an emissions offset program under the CFI. These include:

1) Planning the project – Determine what project is most suitable and check the Positive list to see if the project is eligible.
2) Determine if methodology exists for project – Check the list of currently approved CFI methodologies.
3) Application to become Recognised Offsets Entity – once the methodology stage is complete, the lead of the project must submit an application to become a recognised offsets entity to the Carbon Credits Administrator
4) Declaration of an Eligible Offsets Project – submit application to Carbon Credits Administrator so project is recognised as eligible, project can then generate ACCUs.
5) Reporting to administrator – Project proponent can chose how often to report, once it is between 12 months and five years.
6) Receiving credits – To receive ACCUs, the project lead is required to open an account in the Australian National Registry of Emissions Units and apply for a certificate of entitlement.

One factor that will affect adoption of the CFI is the carbon price mechanism. Once the future policy and regulatory framework around a carbon price becomes more distinct, interest in the CFI will without doubt increase. Even so, the CFI is a vital part of the general carbon market and the new carbon pricing mechanism.

The Department of Climate Change and Energy Efficiency (DCCEE 2011b) developed a methodology for the destruction of methane generated from manure in piggeries. This methodology includes trapping the biogas produced by the digestion of the piggery effluent in anaerobic lagoons and the combustion of the methane component of the gas.

For conventional piggeries, manure management involves the collection and storage of piggery manure in uncovered anaerobic ponds. The anaerobic conditions in the pond form methane and without any sort of abatement, this potent greenhouse gas is emitted to the atmosphere. The abatement procedure is as follows:

- Cover anaerobic lagoons to prevent release of biogas into the atmosphere.
- Install a biogas collection and combustion system
- Collect the biogas.
- Combust the methane component of the gas to convert it to CO_2 which is then emitted to the atmosphere.

This abatement activity converts the methane which has a global warming potential (GWP) of 21 to carbon dioxide which has a GWP of 1. The amount of methane generated is found using the PIGBAL model which calculates the total solids (TS), fixed solids (FS), volatile solids (VS), Nitrogen (N), Phosphorus (P), Potassium (K) and salt in the manure from a piggery where pigs are fed a diet of known composition. The methane yield is based on the amount of Volatile Solids (VS) in the effluent stream – this is termed the baseline condition, and the amount of CH_4 captured under project conditions is capped at this baseline level.

The abatement is calculated as the amount of methane captured and destroyed by the activity. The methane can be destroyed in three ways:

1. Flaring – open flare: devices where the residual gas is burned in open air with or without any auxiliary fuel assistance. Enclosed flare: devices where the residual gas is burned in a cylindrical or rectilinear enclosure that includes a burning system and a damper where air for the combustion reaction is admitted.
2. Methane destruction through a gas boiler.
3. Methane destruction for electricity generation.

The emissions from abatement activities can be measured at regular intervals, or a default value can be used. It is required that a report is submitted for the first reporting period (>12 months and <5 years) and ongoing reports for subsequent reporting periods.

To describe the abatement of methane in simple terms, the following equation is used (DCCEE 2011b):

Abatement = Greenhouse gas emissions $_{baseline}$ – Greenhouse gas emissions $_{project}$
= methane generated - methane not destroyed (removed)
= methane destroyed (removed)