OPTIONS FOR COST-EFFECTIVE AND EFFICIENT USE OF PIGGERY BIOGAS ENERGY

4C-114

Report prepared for the
Co-operative Research Centre for High Integrity Australian Pork

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August 2015

Executive Summary

Following recent increases in energy costs and to fulfil an industry commitment to reduce greenhouse gas (GHG) emissions, several Australian pork producers have recently installed on-farm anaerobic digestion systems. The biogas produced by these systems has typically been used to generate electrical and shed heating energy in combined heat and power (CHP) systems. While the mix of different energy requirements varies markedly between piggeries, some larger piggeries have reported producing biogas in excess of the volume required to satisfy on-site electrical power use, particularly if they are not operating on-site feed mills. Rather than flaring the unutilised biogas, or generating more electrical power for export to the grid (at relatively low rates of return), this review has examined the feasibility of adopting a range of alternative uses of biogas which could potentially improve on-farm energy use efficiency, in a cost effective manner.

A literature review was prepared providing background information on the status of biogas technology adoption in the Australian pork industry and outlining typical piggery biogas composition and properties, volatile solids (VS), biogas and methane production, seasonal variation and biogas energy estimates. Biogas use technologies identified in the literature review included: flares, boilers, internal combustion engines, electrical generators, micro-turbines, Stirling motors, organic Rankine cycle systems, fuel cells, cogeneration and trigeneration systems (providing cooling in addition to electrical energy and heat), vehicle fuel applications and biogas upgrading. The literature review suggested that these technologies could be used for biogas use applications such as odour mitigation, shed space heating, underfloor hot water circulation, radiators, radiant heaters, shed cooling, absorption chilling, drinking water chilling and snout cooling.

Five commercial piggery units having distinctly different pig capacities, herd compositions, and climatic conditions were selected for preparing biogas system Feasibility Studies. Site visits were carried out to gather relevant data relating to the pig herd, production and energy use at the five piggery units. These data were used to estimate typical dimensions and costs of constructing purpose-built covered anaerobic lagoons (CALs), and the biogas, methane and energy production potential, at each site. A range of biogas use options involving the generation and use of thermal and electric energy were investigated for each piggery and estimates of capital and operating costs and returns were provided in the Feasibility Studies.

The options resulting in the highest returns on investment (RoI) at each site ranged from the installation of a 50 kW_{th} boiler at a 2143 standard pig unit (SPU) breeder unit, to a 230 kW_e cogeneration unit at a 24,838 SPU combination finisher + farrow to finish unit. The other recommended piggery biogas use options employed a combination of hot water boilers and cogeneration units. The resulting overall RoIs ranged from 12 to 25%, indicating simplistic payback periods of four to eight years. These returns did not include the cost of constructing/installing the CALs and associated control equipment, or the estimated returns from the sale of Australian Carbon Credit Units (ACCUs).

It is anticipated that this research, which was carried out under Pork CRC Subprogram 4C – Carbon-Neutral Pork Production, will assist producers and industry service providers in planning and implementing biogas capture, treatment and use systems and in selecting a range of practical, cost-effective uses for the available biogas at Australian piggeries. The application of the options outlined in this report will improve the economic viability of biogas collection and use, while mitigating industry carbon emissions and reducing farm energy and hence production costs.

Table of Contents

1. Introduction

There has been considerable interest in the installation of biogas capture and use systems at Australian piggeries over recent years. The main drivers for this interest have been rapidly increasing on-farm energy costs, an industry commitment to reduce greenhouse gas (GHG) emissions (target: 1 kg CO_2-e per kg hot standard carcass weight [HSCW] of pork produced) and the introduction of the Australian Government's Carbon Farming Initiative (CFI) and subsequent Emissions Reduction Fund (ERF) which include provisions for producers to be paid for carbon credits earned by avoiding GHG emissions.

By late-2014, biogas from 9% of the Australian pig herd was being captured and combusted at 14 operational sites (Tait, 2014). These sites employed a mixture of digester technologies; however, unstirred CALs were the most common. There are currently (August 2015) seven piggery methane (CH4) combustion projects registered under the ERF. These projects have been issued with 101,212 Australian Carbon Credit Units (ACCUs) valued at $2,024,240 based on average ACCU value of $20.

It is anticipated that biogas will be captured and combusted from 15-20% of the national pig herd by 2017, increasing to 25-30% of the national herd by 2020. These projections are based on total pig numbers which include pigs accommodated in conventional sheds (approximately 65% of the total herd), in addition to free range pigs and pigs housed in deep litter systems (Tait, 2014).

The majority of the existing piggery biogas systems have adopted combined heat and power (CHP) systems which generate electricity for on-farm use and export to the grid (in some cases), in addition to hot water, which is used to heat farrowing and weaner sheds. While the mix of different energy requirements varies markedly between piggeries, some larger piggeries produce biogas in excess of the volume required to satisfy on-site electrical power use, particularly if they are not operating on-site feed mills. Rather than flaring the unutilised biogas, or generating more electrical power for export to the grid (at relatively low rates of return), this project has examined the feasibility of adopting a range of alternative, on-farm uses of biogas which could potentially improve overall on-farm energy use efficiency, while maximising economic returns.

2. Methodology

Literature review

Initially, a literature review was carried out to identify and evaluate a range of potential alternative uses for biogas which may be suitable for adoption by the Australian pork industry. This literature review also provided background information on the status of biogas technology adoption in the Australian pork industry and outlined typical piggery biogas composition and properties, volatile solids (VS), biogas and methane production, seasonal variation and biogas energy estimates. A range of biogas use technologies and applications were identified. This literature review (Skerman and Brown, 2014) has been included as Appendix 1 of this Final Report.

Feasibility studies

Site visits were carried out to the five commercial piggeries described below in Table 1, for the purpose of interviewing producers and gathering relevant data for preparing reports outlining the practical and economic feasibility of implementing a range of biogas use options and strategies.

Table 1 Details of piggeries A to E visited for the purpose of producing feasibility studies.

Piggery	Location	Production unit type	Sows	SPU[4]
A[1]	Northern Rivers NSW	Farrow to finish (4,000 growers off-site)	1300	8,352
B[1]	Upper Burnett Qld	Breeder	997	2,143
C[1]	Upper Burnett Qld	Farrow to finish	677	7,479
D[2]	Upper Burnett Qld	Grower + farrow to finish	0 + 1,200	10,176 + 14,662 = 24,838
E[3]	South-west slopes NSW	Breeder Grower	2,112 + 0	4,295 + 16,459 = 20,754

[1] existing piggeries not currently employing biogas capture and use technology.

[2] proposed farrow to finish unit to be established adjacent to an existing grower unit.

[3] existing breeder and grower units equipped with CALs and CHP systems.

[4] standard pig unit (SPU), 1 SPU produces VS equivalent to a 40 kg live-weight grower pig.

During the course of the site visits and subsequent communications, data relating to the piggery diets, herd characteristics, pig production and energy use were obtained from the piggery owners/managers. These data were entered into the PigBal model (Skerman et al., 2013) to estimate the piggery VS production. Separate spreadsheets, developed specifically for this project, were used to estimate biogas and methane production and to calculate suggested capacities and dimensions of CALs specifically designed to serve each of the five feasibility study piggeries.

Messrs Deke Faile and Liam Pech of Simons Green Energy analysed the data collected during the site visits and subsequent communications with the piggery owners/managers, before preparing preliminary Feasibility Studies for each of the five piggeries, in consultation with Mr Alan Skerman of the Department of Agriculture and Fisheries (DAF). These Feasibility Studies considered a range of biogas use strategies and provided itemised estimates of capital and operating costs, expected returns and returns on investment for each option.

As noted in Table 1, Piggery E incorporated existing breeder and grower units which were already equipped with CALs and CHP systems. A preliminary analysis of the data provided for Piggery E suggested that there was very limited capacity to improve the on-farm biogas energy use efficiency and rates of return resulting from the existing CALs and CHP systems. While the records of flared biogas indicated some potential for installing an additional biogas engine-generator unit, because the existing CHP systems already generate electrical power in excess of on-farm consumption, virtually all of the electricity generated by an additional unit would have to be exported to the grid at a relatively low feed-in tariff. Consequently, it was concluded that the resulting relatively low rate of return would not justify the additional capital expenditure. Accordingly, a detailed Feasibility Study was not prepared for Piggery E.

The Feasibility Study reports were discussed with the piggery owners/managers to ensure that the assumptions used in preparing the studies were accurate and that the findings and recommendations were realistic and practical.

The Feasibility Study reports (Faile, Pech and Skerman, 2015) are included as Appendix 2 of this Final Report.

3. Outcomes

The literature review (Appendix 1) provided background information on the status of biogas technology adoption in the Australian pork industry and outlined typical piggery biogas composition and properties, VS, biogas and methane production, seasonal variation and biogas energy estimates.

It is anticipated that biogas will be captured and combusted from 15-20% of the national pig herd by 2017, increasing to 25-30% of the national herd by 2020 (Tait, 2014).

Whilst site specific assessment of methane potential is recommended, a reasonably conservative estimate of annual CH_4 production at Australian piggeries is 19 m^3 CH_4 per SPU, assuming that the raw effluent is screened prior to discharge into a CAL. This provides 177 kWh (637 MJ) of primary energy per SPU annually.

Biogas use technologies identified in the literature review included: flares, boilers, internal combustion engines, electrical generators, micro-turbines, Stirling motors, organic Rankine cycle systems, fuel cells, cogeneration and trigeneration systems, vehicle fuel applications and biogas upgrading. The literature review suggests that these technologies could be used for biogas use applications such as odour mitigation, shed space heating, underfloor hot water circulation, radiators, radiant heaters, shed cooling, absorption chilling, drinking water chilling and snout cooling.

Table 2, below, provides a summary of the existing energy uses, estimates of biogas energy production and proposed biogas use options for piggeries A to E, as reported in the Feasibility Studies (Appendix 2).

Table 3, below, provides a summary of the estimated costs and returns for the recommended biogas use options for piggeries A to D, as reported in the Feasibility Studies. Figure 1 provides pie charts for each of the five piggeries A to D, showing the proportions of the estimated returns from the various sources associated with the proposed biogas use systems.

Table 2. Details of existing energy use, estimates of biogas energy production and proposed biogas use options for piggeries A to E.

Parameter	Units	Piggery A	Piggery B	Piggery C	Piggery D	Piggery E
Piggery Location		Northern Rivers NSW	Upper Burnett Qld	Upper Burnett Qld	Upper Burnett Qld	South-west slopes NSW
Production unit type		Farrow to finish[1]	Breeder	Farrow to finish	Grower + Farrow to finish	Breeder + Grower
Pigs	sows	1,300	997	677	1,200	2,112
	SPU	8,352	2,143	7,479	24,838	20,754
Recommended covered anaerobic lagoon (CAL) dimensions						
Capacity	m^3	10,158	2,551	8,904	29,571	
Cover area	m^2	4,041	1,424	3,612	8,343	
Estimated VS, biogas, methane, energy and GHG production						
VS	t VS/yr	689,040	177,000	617,018	2,049,000	2,282,940
Biogas	m^3 biogas/yr	316,958	81,450	283,828	942,710	1,050,152
Methane	m^3 CH_4/yr	206,023	52,961	184,488	612,524	682,599
Energy	kWh/yr	2,119,920	489,737	1,709,164	6,293,988	6,323,840
	GJ/yr	7,632	1,763	6,153	23,615	22,766
GHG emissions	kg CO_2-e/yr	2,935,086	740,000	2,628,000	8,577,500	9,724,579
Estimated boiler heat energy output						
Thermal	kWh/yr	1,695,936	391,790	1,367,331	5,035,190	5,059,072
Estimated cogeneration system (CHP) energy output						
Electric	kWh/yr	635,976	146,921	512,749	1,702,857	1,897,152
Thermal	kWh/yr	1,059,960	244,868	854,582	2,838,095	3,161,920
Existing electricity use						
Total	kWh/yr	445,000	352,000	176,500	730,000	830,000
Heat lamps	kWh/yr	120,000	120,000	86,400	150,000	
Feed mill	kWh/yr				182,500	
Proposed biogas energy use options						
CHP	kW$_e$	80	–	25	230	240
Boiler	kW$_{th}$	–	50	80	–	–
Estimated biogas energy use						
Thermal	kWh/yr	0	438,000	700,800	0	
On-site elec	kWh/yr	278,544	0	97,800	576,000	1,780,974
Export elec	kWh/yr	352,176	0	0	1,314,720	321,426

[1] 4,000 growers accommodated off-site.

kW$_e$ kilowatt electrical - measure of electrical power output.

kW$_{th}$ kilowatt thermal - measure of heating power output.

Table 3. Estimated costs and returns for the recommended biogas use options for piggeries A to D.

Parameter	Units	Piggery A	Piggery B	Piggery C	Piggery D
Covered anaerobic lagoon (CAL)					
Construction[1]	$	$313,000	$146,432	$281,000	$639,432
Operating[2]	$/yr	$26,285	$13,335	$22,985	$49,935
ACCU value[3]	$/yr	$28,884	$7,400	$25,830	$85,770
Thermal solutions					
Boiler cost[4]	$		$67,520	$71,520	
Boiler op[5]	$/yr		$2,100	$2,100	
Thermal int[6]	$	$270,936	$100,800	$93,888	$174,500
Total cost		$270,936	$168,320	$165,408	$174,500
Net return[7]	$/yr	$49,140	$20,400	$28,484	$53,375
RoI	%	18.1%	12.1%	17.2%	30.6%
Electricity generation solutions					
Installed cost[8]	$	$357,720	0	$157,400	$643,320
Operating cost[9]	$/yr	$36,800	0	$16,117	$90,674
On-site elec[10]	$/yr	$75,825	0	$25,113	$138,938
Export elec[11]	$/yr	$9,822	0	$0	$37,772
RECs[12]	$/yr	$22,422	0	$3,574	$64,464
Net return[13]	$/yr	$71,269	0	$12,570	$150,500
RoI	%	19.9%	—	8.0%	23.4%
Overall Project					
Installed cost	$/yr	$628,656	$168,320	$322,808	$817,820
Net return[14]	$/yr	$120,409	$20,400	$41,054	$203,829
RoI	$/yr	19.2%	12.1%	12.7%	24.9%

Notes:

[1] lagoon earthworks, supply and install cover, flare and control/monitoring system.

[2] lagoon cover replacement, sludge management, daily inspections and ERF auditing.

[3] Australian Carbon Credit Unit (ACCU) value based on $10/tonne of CO$_2$-e under ERF.

[4] boiler, biogas conditioning, installation and commissioning.

[5] boiler maintenance, chiller operation, general and scrubber maintenance.

[6] thermal integration: install piglet heating pads, chilled sow drinking water, shed space heating.

[7] production benefit value from chilled water, reduced electricity use for heat lamps, reduced LPG use for shed space heating.

[8] biogas chiller, ferric oxide scrubber, knock-out pot, plant room, cogeneration system, installation and commissioning.

[9] cogeneration system oil changes, engine overhauls, ferric oxide replacement, maintenance.

[10] on-site electricity use valued at $0.25/kWh.

[11] electricity exported to the grid valued at $0.025/kWh.

[12] Renewable Energy Certificate (REC) returns valued at $0.0395/kWh.

[13] on-site electricity returns + exported electricity returns + RECs - operating cost.

[14] does not include ACCUs.

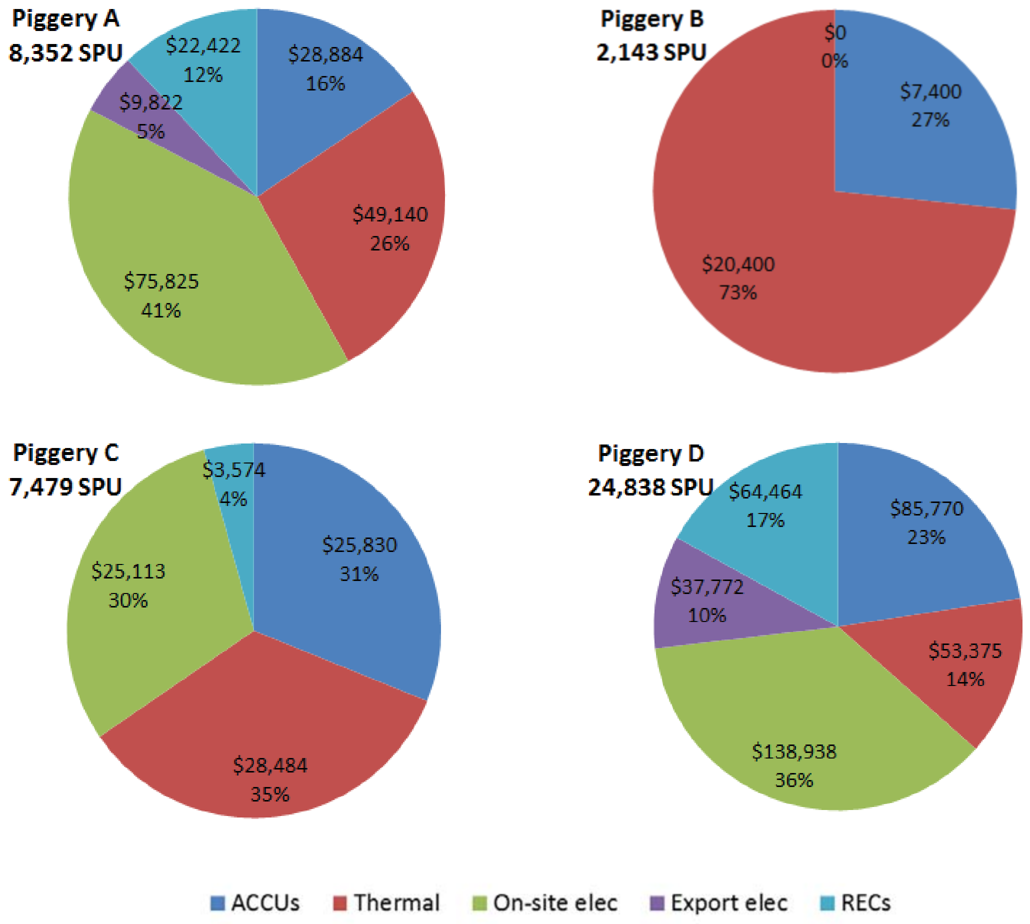

Figure 1. **Estimated returns from proposed biogas use systems.**

Viability of lagoon cover retro-fit option

The feasibility study for Piggery A suggested that retro-fitting a cover on an existing anaerobic lagoon would be more expensive than constructing a new 'fit-for-purpose' CAL. Purpose-built CALs are generally designed for higher VS loading rates than most existing uncovered anaerobic lagoons, resulting in lower storage volumes and surface areas.

Depending on the proposed sludge management strategy, purpose-built CALs are commonly equipped with sludge extraction pipes which allow regular removal of sludge without disrupting the lagoon operation. By comparison, many older uncovered anaerobic lagoons were designed to store accumulated sludge for extended periods up to 10 years, resulting in large total storage capacities.

Purpose-built CALs are generally designed to be relatively deep, to promote activity of anaerobic micro-organisms and mixing of the stored effluent, and relatively narrow, for ease of desludging. In combination, these factors generally mean that retro-fitting a cover onto an existing anaerobic lagoon is unlikely to be economically or practically viable.

In the case of Piggery A, the required cover area for the purpose-built lagoon (4,041 m^2) was less than half of the cover area required for the existing lagoon (10,585 m^2). The resulting estimated cost for earthworks and covering the purpose-built CAL was $248,000, compared with $335,000 to cover the existing lagoon.

Sale of ACCUs under the ERF

Capture and destruction of methane generated in an anaerobic digester or CAL can attract a financial benefit through the Australian Government's Emissions Reduction Fund (ERF) policy. Through a reverse auction, a new carbon abatement project can 'sell' ACCUs to the Australian Government. Under the current policy, ACCUs will only be generated for the initial seven years of a methane destruction project. At the first auction held in April 2015, the average price per tonne of carbon abatement was $13.95 (Clean Energy Regulator Website). The feasibility studies have assumed a price of $10/tonne CO_2-e for remaining auctions in 2015. Compulsory audit fees will offset the returns from the sale of ACCUs.

Thermal solutions

The feasibility studies suggested that the following options are likely to be economically viable at piggeries.

Chilled sow drinking water

Willis and Collman (2007) found that lactating sows provided with chilled drinking water during hot weather consumed significantly more water and feed compared to a control group, while the weaning weights and weight gains of piglets were also significantly improved. It was estimated by the authors of this study that the increase in weaning weight from providing chilled drinking water had an economic benefit of $61/sow/year, including the cost of the additional feed. The feasibility studies estimated the cost of supplying and installing chilled drinking water systems (2 kW Summit Matsu electric chillers and water storage tanks) in lactating sow crates would be $98 per crate, resulting in a return on investment (RoI) of 62%.

The feasibility studies found that there was limited information available regarding 10 to 50 kW micro absorption chillers which would be suitable for using heat energy to chill water for on-farm use. Consequently, it was concluded that the installation of electric chillers would be the most cost-effective option for this application. Providing electric chillers are powered using excess electricity generated on-site from biogas, this option represents an effective use of a renewable energy resource. However, it should be noted that this assumption may not be valid in cases where there is insufficient on-site electricity generated from biogas to satisfy all on-site demands and in cases where the electric chiller electricity consumption reduces export to the grid.

Sow cooling

Wagenberg et al. (2006) found that providing cooling for lactating sows via Chilled Water (CHW) pipework under the pens had a positive impact on reducing sow body temperatures. The cool-sow system was found to remove, on average, 107 W of heat per pen, of which approximately 58 W was directly removed from the sow's body. The sow cooling also had a positive effect on sow feed intake, resulting in higher (20 g/d) piglet growth rates compared to the control group. In the feasibility studies, it was assumed that the benefit of the cool-sow system may be $42.50/sow/year. It should be noted that this study was conducted under Dutch conditions. The cost of integrating the Cool-Sow System was estimated at $515 per farrowing crate, including an 18 kW Matsu electric chiller, water storage tank and installation. While the above estimates suggest that this option produced only a modest RoI of 8%, animal welfare considerations may elevate the priority for implementing this option, particularly in warm climates.

While the combined effects of installing both the chilled drinking water and cool-sow system are unknown, in this study, it has been assumed that the benefits are additive. If this proves to be an incorrect assumption, the chilled drinking water option provides a considerably higher RoI at a lower capital cost, and would therefore be a more attractive option.

Shed space heating

Shed heating may be provided by circulating hot water, from a biogas-fired boiler or cogeneration system, through Reventa Deltapipes and/or Twinpipes to provide shed space heating. Capital expenditure, including installation costs, is estimated to be $240/kW (0.3 kW per metre), including thermal integration with the heat source(s) as required. In many piggeries, this space heating will offset the cost of operating existing heating systems burning LPG.

RoIs of 49% and 42% were estimated for installing 30 kW and 100 kW of Delta pipe at Piggeries C and D, respectively, based on the displacement of LPG space heating in piggery sheds.

Piglet nest heating

Electrically powered 100 W infrared heat lamps are commonly installed in farrowing pens for zone heating piglets. Use of these heat lamps could be offset by installing an under-floor hydronic piglet heating system. In this type of system, hot water from a biogas boiler or cogeneration system is circulated through heating pads installed in the floor of each farrowing pen. While some piggeries have installed concrete heating pads fabricated on-farm (Skerman and Collman, 2012), the Reventa Thermo Plus piglet nest heating system is an example of a commercially marketed product specifically manufactured for this purpose. The feasibility studies estimated the cost of installing Thermo-Plus heating pads to be $504 per farrowing crate, including flow and return pipework, but not including the heat source.

In the Piggery D Feasibility Study, it was assumed that 250 x 100 W heat lamps would operate for 6000 hours/year (approximately 70% of the time) consuming 600 kWh/year per heat lamp or 150,000 kWh of electricity for the whole piggery. Assuming that the proposed Reventa Thermo Plus piglet nest heating system reduces heat lamp usage by 75%, this represents an annual electricity cost saving of $28,125, based on an electricity price of $0.25/kWh, and an RoI of 22%. Similar RoIs were predicted for piggeries A and C.

Hot water boiler

Installing a biogas-fired boiler is likely to be the lowest cost Waste-to-Energy solution for many piggeries. Hot water from the boiler may be used to supply hydronic piglet heating pads to offset heat lamp electricity consumption. The boiler may also supply hot water to delta or twin pipes to offset LPG use for shed space heating, during the winter months.

The feasibility study for Piggery B suggested that a hot water boiler was the best biogas use option for this 997 sow breeder unit, giving an estimated RoI of 12%, based on supplying hot water to the piglet heating pads. Breeder units commonly produce less manure and hence less biogas than grower units, while having a high energy requirement for piglet zone heating.

Boilers will not provide a renewable source of electricity for operating drinking water chillers, fans or other site requirements. However, they can offset a substantial portion of the site's electricity consumption for heat lamp piglet nest heating and most, or all, of the site's LPG space heating requirements.

Depending on the materials used in the boiler construction, biogas boilers may tolerate higher concentrations of H_2S in the biogas fuel, compared to most biogas engines used for electrical power generation or in CHP systems. Chilling the biogas to 4°C is generally recommended to condense the moisture which can then be removed in a knock-out pot, to reduce the risk of excessive corrosion.

Combined heat and power (CHP) options

A number of biogas CHP options, as outlined below, were considered in the feasibility studies.

Micro cogeneration or CHP units produce less than 50 kW of electrical power. Yanmar 25 kW biogas-driven micro cogeneration units can be installed in a modular configuration running up to eight units in parallel. These units are able to load-follow the site's electricity demand, to match site needs below 25 kW; however, operation at low loads decreases the overall electrical efficiency relative to the full load operating efficiency of 32%. In addition to electricity generation, according to the manufacturer's performance data, these units produce 40.6 kW of recoverable thermal energy, resulting in an overall efficiency of 84%.

One of these units was recommended, along with an 80 kW hot water boiler, as the best option for the 677 sow, farrow-to-finish Piggery C. The capital cost for supplying a single Yanmar 25 kW biogas cogeneration unit was estimated at $75,000, increasing to an installed cost of $191,120, with the addition of a biogas scrubber, knock-out pot, plant room, installation and commissioning costs.

Annual operating costs were estimated at $16,117 for maintenance, overhauls and scrubber operation. Annual returns were estimated at $28,706 for on-site electricity use and RECs, resulting in a RoI of 7% (not including thermal energy utilisation costs and offsets). It was estimated that the Yanmar 25 kW unit could produce 90% of the on-site electricity requirement at Piggery C, operating for approximately 7,100 hours/year (81% of the time).

The feasibility study for Piggery A suggested that the most cost-effective waste-to-energy option involved installing an Ener-G 80 kW cogeneration system. This was the largest cogeneration system possible at Piggery A, based on the estimated methane production from a purpose-built CAL and near-continuous operation. The Ener-G 80 kW cogeneration system is unable to produce electricity below 50% of rated capacity (40 kW) and operates optimally no lower than 75% of rated capacity (60 kW). This performance characteristic is typical of most cogeneration systems running on either natural gas or biogas.

After accounting for the reduction in electricity demand to supply the electric heat lamps (following the installation of the proposed Thermo-Plus piglet nest heating) the new site electricity demand at Piggery A was estimated to be less than 60 W most of the time. Without the capability of exporting electricity to the grid, the 80 kW cogeneration system could only operate 10% of the time. Consequently, to effectively utilise most of the methane produced on-site, the Ener-G 80 kW cogeneration system must be configured to export electricity to the grid.

The capital cost for supplying a single Ener-G 80 kW cogeneration system was estimated at $201,600, increasing to an installed cost of $357,720, with the addition of a biogas scrubber, knock-out pot, plant room, installation and commissioning costs. Annual operating costs were estimated at $36,800 for maintenance, overhauls and scrubber operation. Annual returns were estimated at $108,070 for on-site electricity use, export of electricity to the grid and RECs, resulting in a RoI of 20% (not including thermal energy utilisation costs and offsets).

The Ener-G 80 kW system with thermal integration is expected to produce almost enough electricity to satisfy the total site electricity demand at Piggery A. The system will also export electricity to the grid while producing enough thermal energy for the recommended thermal integration solutions. The total project RoI is estimated at 19.1% (including the thermal solutions but not including the CAL construction costs or ERF subsidy).

In comparison to installing a smaller 50 kW cogeneration system, the additional revenue resulting from installing an 80 kW system and exporting excess electricity to the grid (including RECs) allows the system to satisfy more on-site electricity demand. The larger system also has a lower installation cost per kW. These attributes result in a higher estimated RoI compared to the smaller 50 kW system. Returns from the exported electricity, at the relatively low rate of $0.03/kWh, are expected to offset the increased maintenance and ferric oxide replacement in the scrubber, without increasing the RoI. Should utility company incentives and prevailing commercial terms and conditions improve in the future, the 80 kW system may result in an increased RoI.

The feasibility study for Piggery D concluded that the most cost-effective waste-to-energy option for adoption at piggery D was the installation of an Ener-G 230 kW cogeneration system. This was the largest cogeneration system possible at Piggery D, based on the estimated methane production from a new, purpose-built CAL and near-continuous operation. Similarly to the Ener-G 80 kW cogeneration system, the Ener-G 230 kW system is unable to produce electricity below 50% of rated capacity and operates optimally no lower than 75% of rated capacity. As previously noted, this is typical of most cogeneration systems running on either natural gas or biogas.

After accounting for the reduction in electricity demand from the electric heat lamps (following installation of the proposed Thermo-Plus piglet nest heating) the new site electricity demand is not expected to exceed 200 kW, with the possible exception of a few hours per year. For the 230 kW system to operate at optimal efficiency, it must export significant amounts of generated electricity to the grid.

In comparison to the 125 kW cogeneration option, the capital expenditure required to utilise most of the methane potential at the expanded piggery increases overall; however, the fixed costs associated with the installation decrease. Cogeneration system capital costs also decrease per kW, due to an 'economies of scale' effect.

The capital cost for supplying a single Ener-G 230 kW cogeneration system was estimated at $421,200, increasing to an installed cost of $643,320, with the addition of a biogas scrubber, knock-out pot, plant room, installation and commissioning costs. Annual operating costs were estimated at $90,674 for maintenance, overhauls and scrubber operation. Annual returns were estimated at $241,128 for on-site electricity use, export of electricity to the grid and RECs, resulting in a RoI of 25% (not including thermal energy utilisation costs and offsets).

The Ener-G 230 kW system with thermal integration is expected to produce almost all of the electricity required to satisfy the site electricity demand. The proposed system will also export electricity to the grid while producing sufficient thermal energy for the recommended thermal integration solutions. The total project RoI is estimated at 25% (not including the CAL construction costs or ERF subsidy).

The resulting overall RoIs for the various combinations of thermal and electrical energy generation and use options ranged from 12 to 25%, indicating simplistic payback periods of four to eight years. These returns did not include the cost of constructing/installing the CALs and associated control equipment or the estimated returns from the sale of ACCUs.

Export of electrical power to the grid

While this option has been briefly addressed under some of the cogeneration options outlined above, the following points should be noted:

While direct returns from supplying power to the grid are relatively low at $0.025/kWh, the installation of a higher output cogeneration system may have the advantage of allowing a higher percentage of the total on-farm electrical power consumption to be offset from biogas-derived energy while increasing the thermal energy output and decreasing the cost per kW(e) generated. However, it should be noted that the ability to export electrical energy to the grid is very dependent on a range of factors such as the location of the piggery, electrical network infrastructure, the policies and regulations of the local electricity supply company, prevailing market forces and government policies. Proponents considering projects that involve export of electricity to the grid should commence discussions with the relevant local electricity supply company, at the earliest opportunity during the project planning phase.

4. Application of Research

The research findings from this project are expected to assist pork producers and industry service providers in planning biogas capture and use systems, and in selecting a range of practical, cost-effective uses for the available biogas. The application of the options outlined in this report will mitigate the economic risks associated with implementing biogas use systems, resulting in reduced farm energy and production costs, while lowering individual farm and industry-wide greenhouse gas emissions.

5. Conclusions

Piggery biogas production is generally estimated from the mass of VS in the effluent stream entering an anaerobic digester or CAL. The mass of VS (and hence biogas production) is primarily influenced by factors such as the numbers and classes of pigs accommodated in the piggery, diet, feed wastage, effluent management system, and the performance of any pre-treatment devices used to remove a portion of the solids from the effluent stream, prior to discharge into the anaerobic digester or CAL. Whilst site specific assessment of methane potential is recommended, a reasonably conservative estimate of annual CH_4 production from CALs at Australian piggeries is 19 m^3 CH_4 per SPU, assuming that the raw effluent is screened prior to discharge into the CAL. It is estimated that this CH_4 volume can provide 177 kWh (637 MJ) of primary energy per SPU annually, which may be converted to approximately 142 kWh of thermal energy in a hot water boiler (80% efficiency), or 53 kWh (191 MJ) of electrical energy (30% efficiency) and 88 kWh (318 MJ) of thermal energy (50% efficiency) per SPU annually in a cogeneration system.

To maximise the benefits from the growing adoption of biogas capture, treatment and use systems in the Australian pork industry, it will be increasingly important for producers to access a range of robust, practical, cost-effective technologies and appliances which can be tailored to match on-farm energy production and use, and to enable economically beneficial export of any excess energy. Because all farms have distinctly different energy use profiles which vary seasonally along with biogas production, some flexibility in the mix of biogas use technologies and appliances may be required to maximise energy use efficiency.

While several larger piggery operators have recently adopted biogas capture and use systems, if the industry is going to meet its greenhouse gas emission target of 1 kg CO_2-e per kg HSCW, it is likely that biogas capture and use systems will need to be adopted at numerous smaller piggeries, down to approximately 4000 SPU capacity. This will require access to smaller-scale biogas use appliances such as flares, hot water boilers and cogeneration units, which are relatively simple to operate, robust, practical and cost effective.

It is anticipated that hot water boilers and cogeneration (CHP) systems (generating electricity for onsite use or export to the grid, and hot water for farrowing and weaner shed heating) will continue to be the main biogas use options used at many piggeries. While trigeneration systems (providing cooling in addition to electrical energy and heat), could provide potentially useful cooling energy at some piggeries, currently there appears to be a lack of suitable cost-effective absorption chillers, within the required energy range, available on the Australian market. This situation may change as the market for relatively small-scale absorption chillers expands. The Feasibility Studies also suggested that absorption chillers are unlikely to be suitable for large-scale space cooling applications due to the large volumes of air movement in piggery sheds.

This project has highlighted several alternative use options for energy derived from biogas which have not been previously implemented by the Australian pork industry. These options include chilling sow drinking water, sow cooling and tallow tank heating, in addition to current options such as piglet nest and shed space heating.

The options identified in the Feasibility Studies resulting in the highest RoI at each of the five piggery sites ranged from the installation of a 50 kW_{th} boiler at a 2143 SPU breeder unit, to a 230 kW_e cogeneration unit at a 24,838 SPU combination finisher + farrow to finish unit. The other recommended piggery biogas use options employed a combination of hot water boilers and cogeneration units. The resulting overall RoIs ranged from 12 to 25%, indicating simplistic payback periods of four to eight years. These returns did not include the cost of constructing/installing the CALs and associated control equipment or the estimated returns from the sale of ACCUs.

Some of the recommended options involved installing higher output cogeneration systems supplying power to the grid at relatively low feed-in tariffs. However, these systems had the advantage of allowing a higher percentage of the total on-farm electrical power consumption to be offset from biogas-derived energy, while increasing the thermal energy output and decreasing the cost per kW(e) generated. Proponents considering projects that involve export of electricity to the grid should commence discussions with the relevant local electricity supply company, at the earliest opportunity during the project planning phase.

The use of biogas as a fuel for pig transporting trucks and tractors for on-farm use does not appear to be financially viable at the present time, given the technical and operational demands associated with biogas upgrading and compressing the biomethane for on-board storage purposes. Nevertheless, this option may be appropriate for adoption at some large piggeries where excess biogas is available after meeting other on-farm energy needs. Alternatively, price rises for vehicular fossil fuels may make this option more attractive in the future.

Unlike Europe, there appears to be limited scope in Australia for supplying biomethane (upgraded biogas) into centralised natural gas grids. The cost and level of technology required for upgrading biogas produced by individual piggeries to the required standard is likely to be prohibitive. As most Australian piggeries are situated in relatively remote locations, often considerable distances away from major population centres and energy-intensive industries, centralised treatment and use of biomethane derived from piggery biogas does not appear to be currently feasible.

It is anticipated that this research will assist producers and industry service providers in planning and implementing biogas capture, treatment and use systems and in selecting a range of practical, cost-effective uses for the available biogas at Australian piggeries. The application of the options outlined in this report will improve the economic viability of biogas collection and use, while mitigating industry carbon emissions and reducing farm energy and hence production costs.

6. Limitations/Risks

The values of ACCUs, renewable energy certificates (RECs) and returns from the export of electricity to the grid are all subject to a range of potentially variable market forces and government policy decisions. Consequently, it is difficult to predict long term returns from these sources. The Feasibility Studies assumed relatively conservative values for these returns, based on recent historical values. Producers should seek current values for these market-driven returns prior to finalising site-specific feasibility studies for proposed biogas use projects.

7. Recommendations

It is recommended that the outcomes of this study should be made readily available to producers and industry service providers by: publishing a detailed report on the Pork CRC website, providing more concise articles for inclusion in industry publications, and/or by delivering presentations at relevant industry forums.

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Appendices

Appendix 1: Literature Review

The following Literature Review (Skerman and Brown, 2014), entitled ‘A review of cost-effective options for efficient use of biogas energy from Australian piggeries’ was prepared by Messrs Alan Skerman and Grant Brown of DAF, Toowoomba, Queensland, and submitted to the Pork CRC in December 2014.

Department of Agriculture, Fisheries and Forestry

Pork CRC Project ID: 4C-114
Options for cost-effective and efficient use of piggery biogas energy

A review of cost-effective options for efficient use of biogas energy from Australian piggeries

December 2014

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Pork CRC

Pork CRC

Australian Government
Department of Industry and Science

Business
Cooperative Research
Centres Programme

Queensland
Government

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Contents

Table of tables

Table of figures

Glossary

GHG	Greenhouse gas
HSCW	Hot standard carcass weight
CFI	Carbon Farming Initiative
CAL	Covered anaerobic lagoon
CHP	Combined heat and power
CH_4	Methane
CO_2	Carbon dioxide
H_2S	Hydrogen sulphide
H_2O	Water
SO_2	Sulphur dioxide
VS	Volatile solids
TS	Total solids
SPU	Standard pig unit
Bo	Ultimate methane yield
BMP	Biochemical methane potential
GC	Gas chromatograph
HHV	Higher heating value
LLV	Lower heating value
AM2MA	Australian methane to markets in agriculture
HWS	Hot water system
IC engine	Internal combustion engine
ORC engine	Organic Rankine Cycle engine
PEM fuel cell	Proton exchange membrane fuel cell
CNG	Compressed natural gas
LNG	Liquefied natural gas

Background

There has been considerable interest in the installation of biogas capture and use systems at Australian piggeries in recent years. The main drivers for this interest have been rapidly increasing on-farm energy costs, an industry commitment to reduce greenhouse gas (GHG) emissions (target: 1 kg CO_2-eq per kg hot standard carcass weight [HSCW] of pork produced) and the introduction of the Federal Government's Carbon Farming Initiative (CFI) which included provisions for producers to be paid for carbon credits earned by avoiding GHG emissions.

By mid-2014, biogas from 7-8% of the Australian pig herd was being captured and combusted at 14 operational sites. These sites employed a mixture of digester technologies; however, unstirred covered anaerobic lagoons (CALs) were the most common. There are currently six registered piggery methane (CH_4) combustion projects under the CFI. These projects have been issued with 27,382 CFI carbon credits worth $600,000 at $22/carbon credit.

It is anticipated that biogas will be captured and combusted from 15-20% of the national pig herd by 2017, increasing to 25-30% of the national herd by 2020. These projections are based on total pig numbers which include pigs accommodated in conventional sheds (approximately 65% of total herd), in addition to free range pigs and pigs housed in deep litter systems (Tait, 2014).

The majority of the existing piggery biogas systems have adopted combined heat and power (CHP) systems which generate electricity for on-farm use and export to the grid, in addition to hot water which is used to heat farrowing and weaner sheds. While the mix of different energy requirements varies markedly between piggeries, some larger piggeries produce biogas in excess of the volume required to satisfy on-site electrical power use, particularly if they are not operating on-site feed mills. Rather than flaring the unutilised biogas, or generating more electrical power for export to the grid (at relatively low rates of return), this project will examine the feasibility of adopting a range of alternative, on-farm uses of biogas which could potentially improve overall on-farm energy use efficiency, while maximising economic returns.

To date, no Australian piggeries are currently using biogas energy for shed cooling. This project will examine whether this option is economically viable, particularly during summer when biogas production rates are higher and heating requirements are lower. The feasibility of using biogas as a transport fuel will also be examined, particularly in relation to pig transporting trucks and tractors for on-farm use.

Unlike Europe, there appears to be limited scope in Australia for supplying biomethane (upgraded biogas) into centralised natural gas grids. The cost and level of technology required for upgrading biogas produced by individual piggeries to the required standard is likely to be prohibitive. As most Australian piggeries are situated in relatively remote locations, often considerable distances away from major population centres and energy-intensive industries, centralised treatment and use of piggery biogas does not appear to be feasible. Consequently, this project will focus on on-farm biogas use options.

Biogas composition and properties

Biogas is the mixture of gases produced when bio-degradable organic matter is digested by micro-organisms under anaerobic conditions (i.e. in the absence of oxygen). In the Australian pork industry, effluent discharged from conventional flushed sheds may be digested in either a CAL or an engineered digester. The resulting biogas typically consists of 60–70% CH_4, 30–40% carbon dioxide (CO_2), 200–3,000 ppm hydrogen sulphide (H_2S) (0.02% to 0.30%), and traces of ammonia, hydrogen, nitrogen, and carbon monoxide (Davidson *et al.* 2013).

Due to the hot humid environment inside digesters, raw biogas is generally saturated with water vapour. At a temperature of 35°C, one cubic metre of biogas will contain 40 g of water (4% vol) (Van Haren and Fleming, 2005). The condensate resulting from cooling the raw biogas should be collected in traps for removal from the gas train, prior to use.

Typical piggery biogas properties are outlined in Table 1.

Table 1. Typical piggery biogas properties (German Agricultural Occupational Health and Safety Agency, 2008).

Heating value (kWh/m³)	6
Density (kg/m³)	1.2
Density ratio to air	0.9
Ignition temperature(°C)	700
Explosion range (% vol.) in air	6–12
Theoretical air requirement (m³/m³) to form flammable mixtures	5.7
Methane (CH_4) %	60–70
Carbon dioxide (CO_2) %	30–40
Hydrogen sulphide (H_2S) % by volume	0.02–0.30

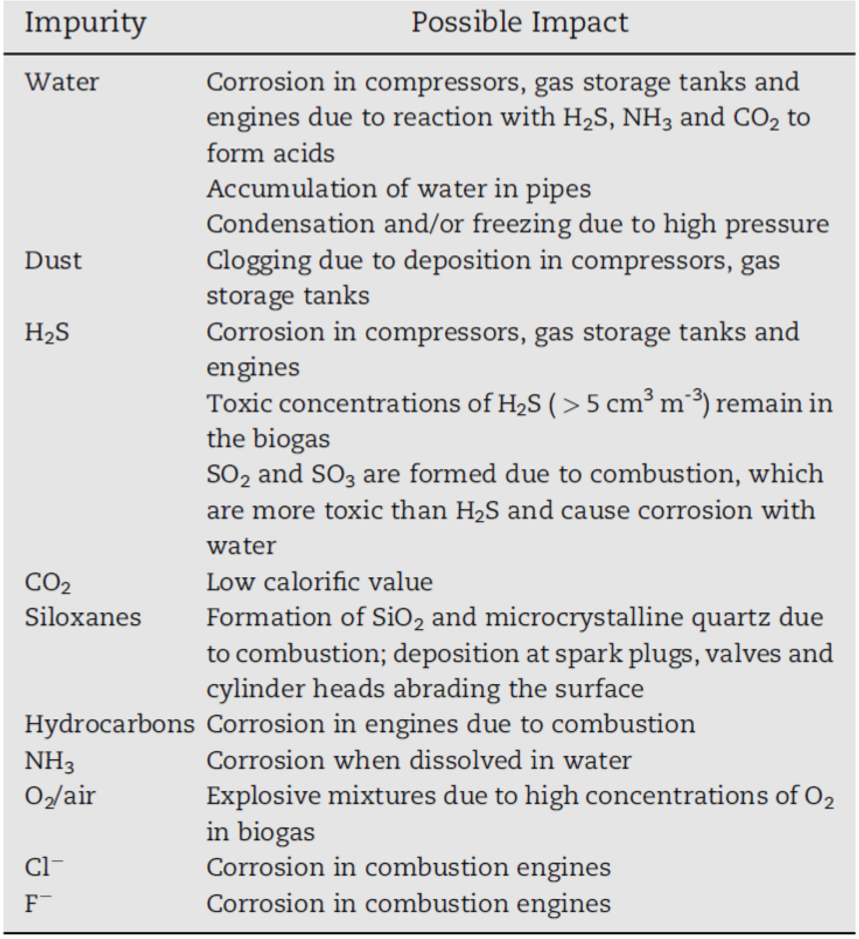
The potential adverse impacts associated with the various contaminants present in raw biogas are outlined in Table 2 (Ryckebosch *et al*., 2011).

Whilst piggery biogas may be used in its raw form in a number of applications, levels of H_2S, CO_2 and H_2O may limit several other use options. Table 3 outlines the required biogas qualities for four major uses of abattoir biogas.

Raw biogas, however, can be treated to produce a quality suitable for the intended use while minimising adverse impacts such as those listed in Table 2. Ultimately, biogas can be refined or ‘upgraded’ into biomethane, typically containing 95-97% CH_4 and 1-3% CO_2, which can be used as an alternative for natural gas (Ryckebosch *et al*., 2011).

Ryckebosch *et al*. (2011) provides explanations of the various biogas upgrading technologies.

Table 2. Potential adverse impacts associated with the various contaminants present in raw biogas (Ryckebosch *et al*., 2011).



Impurity	Possible Impact
Water	Corrosion in compressors, gas storage tanks and engines due to reaction with H_2S, NH_3 and CO_2 to form acids Accumulation of water in pipes Condensation and/or freezing due to high pressure
Dust	Clogging due to deposition in compressors, gas storage tanks
H_2S	Corrosion in compressors, gas storage tanks and engines Toxic concentrations of H_2S ($> 5\ cm^3\ m^{-3}$) remain in the biogas SO_2 and SO_3 are formed due to combustion, which are more toxic than H_2S and cause corrosion with water
CO_2	Low calorific value
Siloxanes	Formation of SiO_2 and microcrystalline quartz due to combustion; deposition at spark plugs, valves and cylinder heads abrading the surface
Hydrocarbons	Corrosion in engines due to combustion
NH_3	Corrosion when dissolved in water
O_2/air	Explosive mixtures due to high concentrations of O_2 in biogas
Cl^-	Corrosion in combustion engines
F^-	Corrosion in combustion engines

Table 3. Summary of biogas quality requirements (AMPC and MLA, 2013)

Biogas component	**Flare**	**Boiler**	**Reciprocating gas engine**	**Microturbine**
Methane (CH_4)	>50%	>50%	>60%	>55%
Hydrogen sulphide (H_2S)	Not specified	Not specified	<250 ppm	<5,000 ppm
Water (H_2O)	Free water removal	Free water removal	<80% relative humidity	<55% relative humidity
Ammonia (NH_3)	Not specified	Not specified	<25 ppm	<200 ppm
Chlorine (CL_2)	Not specified	Not specified	<40 ppm	250 ppm
Flourine (F_2)	Not specified	Not specified	<40 ppm	1,500 ppm
Siloxanes	Not specified	Not specified	<2 ppm	<0.005 ppm
Dust	Not specified	Not specified	50mg/10kWh	20 ppm
Particle size	Not specified	Not specified	<3µm	<10 µm

Piggery biogas production

Volatile solids production

Piggery biogas production is generally estimated from the mass of volatile solids (VS) in the effluent stream entering an anaerobic digester or CAL. The mass of VS is primarily influenced by factors such as the numbers of pigs of various classes accommodated in the piggery, diet, feed wastage, effluent management system, and the use of pre-treatment devices to remove a portion of the solids from the effluent stream, prior to discharge into the anaerobic digester or CAL.

Tucker *et al.* (2010) provided predicted VS outputs in the manure and waste feed typically produced by various classes of pigs, based on PigBal modelling (Casey *et al.*, 2000). In Australia, piggery capacities are commonly described in terms of standard pig units (SPUs) where one SPU produces 90 kg VS/pig/year, which is the mass of VS typically contained in the manure and waste feed produced annually by an average sized grower pig (40 kg live weight). A range of SPU multipliers is provided for other classes of pigs. Consequently, the SPU concept is useful for estimating VS production from piggeries which typically house pigs of varying classes, spanning a range of ages and live weights. The SPU multipliers and VS outputs suggested by Tucker, *et al.* (2010) are provided in Table 4 for a range of typical pig classes.

Table 4. Standard pig unit (SPU) multipliers and VS outputs for a range of pig classes (Tucker, *et al.*, 2014).

Pig class	Live weight range (kg)	Age range (weeks)	SPU multiplier (SPU/pig)	VS output (kg VS/pig/yr)
Gilts	100 – 160	24 – 30	1.8	162
Boars	100 – 300	24 – 128	1.6	151
Gestating sows	160 – 230	–	1.6	151
Lactating sows	160 – 230	–	2.5	215
Suckers	1.4	0 - 4	0.1	11.0
Weaner pigs	8.0	4 – 10	0.5	47
Grower pigs	25.0	10 – 16	1.0	90
Finisher pigs	55.0	16 – 24	1.6	149
Heavy finisher pigs	100.0	24 – 30	1.8	–

As shown in Figure 1, Skerman *et al.* (2013) used the data presented in Table 4 to develop a polynomial regression equation for estimating SPU multipliers from grower pig live weights. This figure also provides estimated VS outputs, based on the standard VS output value of 90 kg VS/SPU/year.

As noted previously, feed wastage and diet can significantly influence piggery VS production. McGahan *et al.* (2010) used the PigBal model to demonstrate that varying the standard feed wastage allowance for a grower pig (10%) by ±5% resulted in VS production variations in the order of ±30%. Furthermore, in the PigBal model validation trials, Skerman *et al.* (2013b and 2015) found that a barley diet produced significantly higher masses of manure VS compared to diets primarily comprised of other common grains.

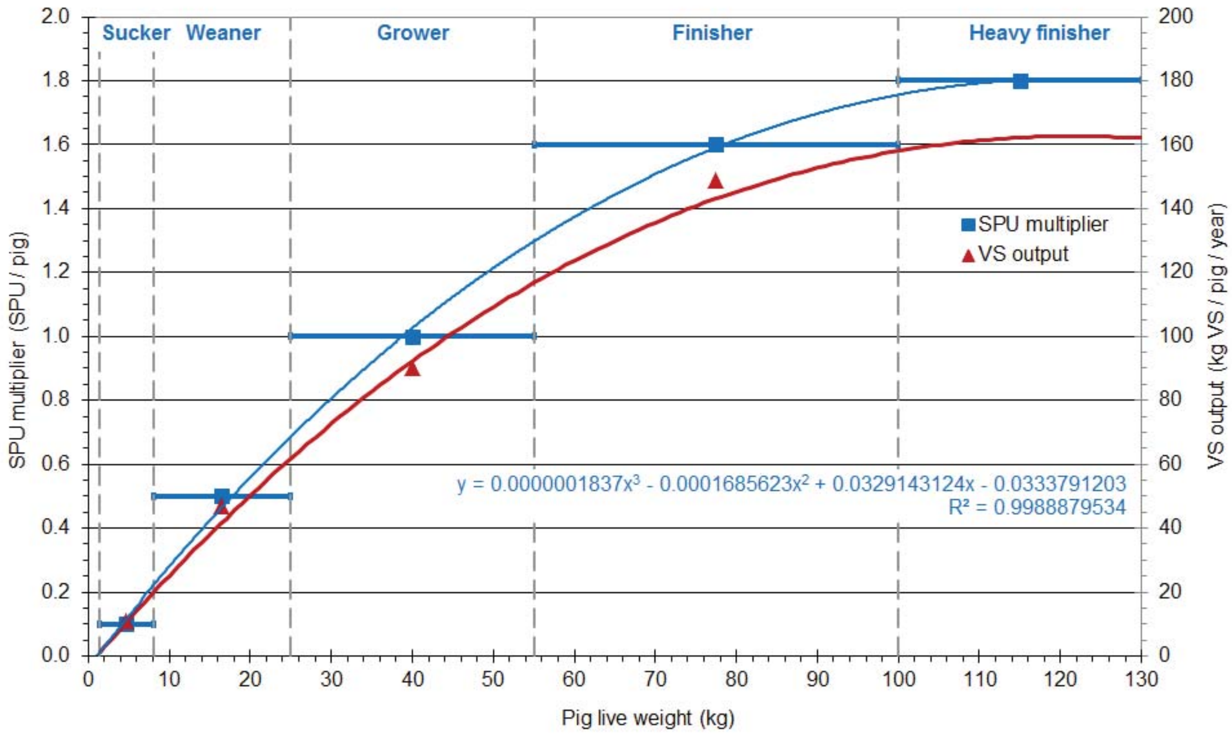


Figure 1. SPU multiplier and VS output values for a range of grower pig live weights, based on a polynomial regression equation developed by Skerman *et al*. (2013b and 2015).

Further modelling using the updated PigBal 4 model (Skerman *et al*., 2013c) suggests that the standard VS production value of 90 kg VS/SPU/year is relatively conservative and that values up to 120 kg VS/SPU/year could be realistic at some piggeries, depending on diet, feed wastage, feed consumption and production factors.

McGahan *et al*. (2013) suggest that the type of effluent management system employed at a piggery may affect the biogas potential as some organic matter (VS) is degraded in a pull plug system prior to exiting the sheds. This may lead to a loss of biogas potential compared to an identical piggery with a direct flush system, where fresh manure is regularly flushed into a CAL.

Various forms of pre-treatment or solids separation devices have been employed in the Australian pig industry for decades. The most common form of pre-treatment is the stationary run-down screen. A stationary screen should remove 20% of the total solids (TS) under optimal operating conditions (FSA, 2002). Assuming a VS/TS ratio of 75%, the corresponding VS removal rate is 25%, as suggested in the recently updated PigBal 4 model (Skerman *et al.*, 2013c).

Birchall (2010) found that higher biogas yields were recorded when a stationary run-down screen was bypassed resulting in untreated effluent being discharged into a CAL at a Victorian piggery. Because the coarse solids contained in raw shed effluent may result in ongoing operational issues such as crusting on the pond surface and increased rates of sludge deposition, some industry service providers recommend effluent pre-treatment, prior to discharge into a CAL. In the case of engineered digesters, some form of effluent pre-treatment would generally be required to meet the more limited range of influent solids concentrations.

VS conversion to biogas

As summarised by McGahan *et al.* (2010), ultimate CH_4 yield (Bo) values, ranging from 0.24 to 0.52 m^3 CH_4/kg VS, have been recorded in the literature. Based on laboratory biochemical methane potential (BMP) analyses, Skerman *et al.* (2013b) reported Bo values ranging from 0.36 to 0.41 m^3 CH_4/kg VS for the four typical grower pig diets used in the PigBal validation trials. These results did not include any contribution from waste feed which would inevitably result in increased Bo values in commercial piggeries. Tait *et al.* (2014) noted that while BMP analyses are simple and cost-effective, they provide a reliable but conservative estimation of biogas production which may result in the overdesign of a facility.

Craggs *et al.* (2008) measured a CH_4 emission rate of 0.28 m^3 CH_4/kg VS added from a piggery anaerobic pond in New Zealand (NZ). The Australian NGGI (DCCEE, 2011) and Federal register of legislative instruments (2012) methodologies have adopted a default Bo value of 0.45 m^3 CH_4/kg VS.

Skerman (2013a) recorded an average CH_4 concentration of 67% over a 15 month monitoring period at a south-east Queensland piggery, using a portable gas analyser. This value is slightly higher than the 63% average CH_4 concentration reported by Birchall (2010) for a Victorian piggery, based on gas chromatography (GC) analyses of bagged samples. The GC analysis results indicated considerable concentrations of residual gases which were not identified, suggesting that the actual CH_4 concentration may have been higher. In summary, 65% appears to be a reasonably conservative piggery biogas CH_4 concentration.

A value of 0.43 m^3 biogas/kg VS added has been suggested as a reasonably conservative biogas production rate for use in feasibility studies for CALs used by the Australian pig industry (S. Tait, pers comm.). Based on a biogas CH_4 concentration of 65%, this equates to a CH_4 yield of 0.28 m^3 CH_4/kg VS added.

Typical methane production estimates

Based on the values suggested in previous sections, Table 5 summarises typical VS, biogas and CH_4 production estimates for CALs at Australian piggeries. These values could be used for preliminary planning purposes; however, more rigorous analyses are recommended for detailed design and economic feasibility assessments.

Table 5. Typical VS, biogas and CH_4 production estimates for CALs at Australian piggeries.

Parameter	Units	Conservative	Possible
VS production	kg VS/SPU/yr	90	110
Static rundown screen VS removal	%	25	25
Remaining VS after screening	kg VS/SPU/yr	67.5	82.5
Biogas production	m^3 biogas/kg VS added	0.43	0.46
Biogas methane content	%	65	65
Methane production	m^3 CH_4/kg VS added	0.28	0.30
Methane production (no screen)	m^3 CH_4/SPU/yr	25	33
Methane production (w/screen)	m^3 CH_4/SPU/yr	19	25

Seasonal variation in biogas production

The activity of the microorganisms responsible for the anaerobic digestion of piggery effluent is influenced by temperature. Consequently, biogas production in unheated CALs generally decreases in winter and increases in summer.

At Bears Lagoon piggery near Ballarat in Victoria, Birchall (2010) measured approximately ±20% variation from the mean CH_4 production values during summer and winter. Skerman *et al.* (2011) measured similar variations at Grantham (SE Qld) based on limited data, while Craggs *et al.* (2008) measured a variation of approximately ±50% from the mean CH_4 production values in NZ. Krich *et al.* (2005) suggested variations of +20% and -30% from the mean biogas production for a Californian dairy, based on modelling. There is also some anecdotal evidence based on observations at existing CALs that biogas production may respond to daily or weekly temperature variations, in addition to longer term seasonal variations.

For biogas system planning purposes, it is suggested that a sinusoidal variation around the mean CH_4 production rate could be adopted, assuming maximum and minimum CH_4 production dates in mid-January and mid-July, respectively. An example of this approach for a 1000 sow (10,000 SPU) farrow to finish piggery is provided in Figure 2, based on conservative and possible CH_4 production scenarios, both with and without solids separation, assuming ±20% variation around the mean CH_4 production rate.

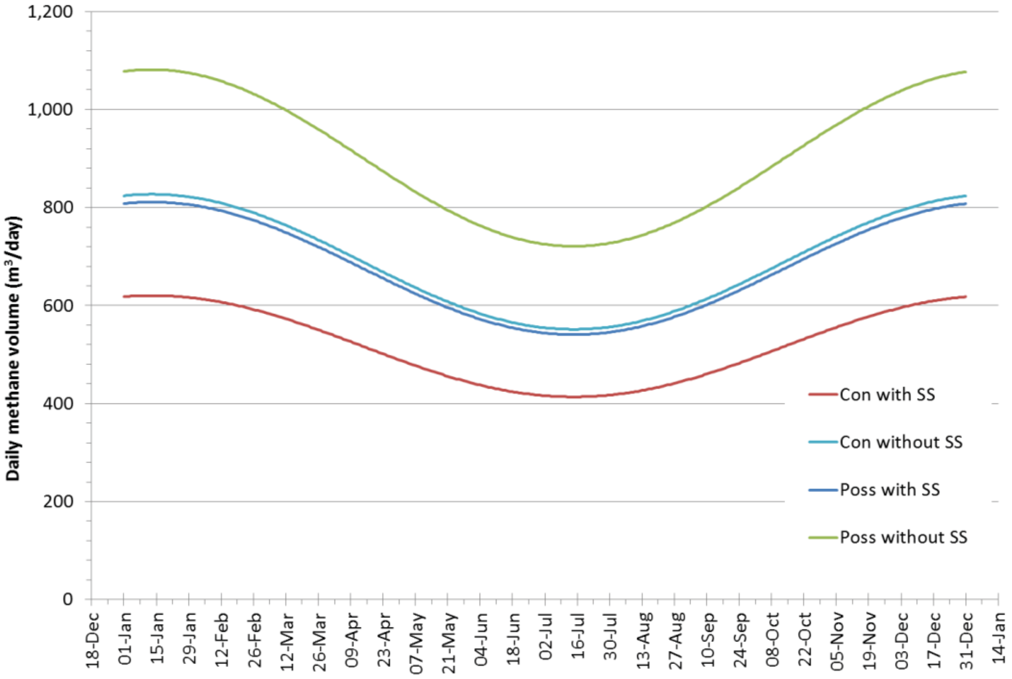


Figure 2 Estimated seasonal variation in CH_4 production for a 1000 sow (10,000 SPU) farrow to finish piggery with a ±20% variation around the mean CH_4 production values. Conservative and possible estimates are provided, with and without solids separation (SS).

Piggery biogas energy

When hydrocarbon fuels, such as CH_4, are burned, water is produced, along with other combustion products. High combustion temperatures result in the water forming steam which stores some of the energy released during combustion as the latent heat of vaporisation. The higher heating value (HHV) of a fuel includes the latent heat stored in the vaporised water. In some applications (e.g. condensing boilers), it may be possible to condense this vapour back to its liquid state to recover a proportion of this energy. However, in the case of engines, high exhaust temperatures prevent the water vapour condensing, and hence the steam and associated stored energy escape with the exhaust gases.

The lower heating value (LHV) is the amount of heat available from a fuel after the latent heat of vaporisation is deducted from the HHV. This is the energy available when the fuel is burned in an engine. Gas engines efficiencies are typically quoted based on LHV values for the gas. The LHV of a fuel determines the required fuel flow rate into the engine to produce a specific output power. The lower and higher heating values of CH_4 are outlined in Table 6 below:

Table 6. Lower and higher heating values of CH_4.

	MJ/kg CH_4	MJ/Nm^3 CH_4	kWh/Nm^3 CH_4
Lower heating value (LHV)	50.0	35.8	9.97
Higher heating value (HHV)	55.5	39.6	11.0

Standard conditions: 0°C = 273.15°K, 101,325 Pa

For the purpose of estimating the energy produced by Australian piggery biogas systems, it is generally appropriate to use the LHV. The values provided in Table 6 for standard conditions (0°C and 101,325 Pa) are reduced to 9.3 kWh/m^3 CH_4 (33.4 MJ/m^3 CH_4) at a temperature of 20°C. This is similar to the gross thermal energy value of 9.4 kWh/m^3 CH_4 adopted by NIWA (2008) in their NZ piggery biogas information sheet.

Based on these values and the CH_4 production figures outlined in Table 5, the estimated gross thermal energy produced per SPU is likely to range from 233 to 307 kWh/SPU/yr for piggeries where no pre-treatment is used, to 177 to 233 kWh/SPU/yr where pre-treatment devices are installed. These values are summarised in Table 7.

Table 7. Typical gross thermal energy values for CALs at Australian piggeries.

Parameter	**Units**	**Conservative**	**Possible**
Energy production (no screen)	kWh/SPU/yr	233	307
Energy production (with screen)	kWh/SPU/yr	177	233

Biogas use technologies

This section outlines a number of potential technologies which may be suitable for the effective on-farm use of the biogas energy produced at Australian piggeries. However, it should be noted that the viability of these technologies will vary from farm to farm. McGahan *et al.* (2013) suggest that the following major factors influence the feasibility of installing a biogas utilisation system on a particular farm:

- size of piggery (number of SPU)
- type of piggery (breeder or grower with more potential biogas generated at grower units in comparison to breeder and weaner units)
- effluent management system (pull plug or flushing – some organic matter is degraded in a pull plug system prior to exiting the sheds, leading to a loss of biogas potential compared to an identical piggery with direct flush system)
- feed ration
- site layout (whether or not the piggery is a multi-site operation)
- energy demands and whether there is a feed mill on site
- energy cost
- type of electricity supply (3-phase power gives the potential to sell excess electricity generated from biogas capture back to the grid)
- location (different states have different legislative requirements)
- Government incentives.

Flaring

Piggery biogas systems will generally require the installation of a flare for safely burning excess biogas, or as an emergency measure for use when other biogas burning appliances such as engines or boilers require maintenance. However, the use of a flare as the sole biogas destruction method may be appropriate at small piggeries which do not generate sufficient biogas for economically viable electrical power generation, and where the primary objectives are GHG and/or odour emission reduction. Based on analyses of data collected from Australian piggeries under the Pork CRC Bioenergy Support Program, Tait (pers. comm.) has suggested that the minimum sized piggery likely to be economically viable for the installation of a CHP system may be 500 to 600 sows (farrow to finish) which is equivalent to approximately 5000 to 6000 SPU.

Using life cycle assessment analyses, Wiedemann and McGahan (2011) demonstrated that the installation of a CAP and flare system at a conventional piggery lowered GHG emissions by 46%.

GHD (2008) produced a publication outlining Australian biogas flaring standards funded by the Australian Methane to Markets in Agriculture (AM2MA) program. This publication describes the various types of flares (open, enclosed and hybrid), flaring systems, safety standards and regulations applying in each Australian state.

Van Haren and Fleming (2000) state that the rich gas mixture, lack of insulation, and poor mixing often lead to an incomplete burn as well as considerable radiant heat loss in open flares which are usually constructed several metres off the ground to protect both workers and supply pipes from the radiated heat. By comparison, enclosed flares are usually ground-based structures with the burner enclosed in a cylinder lined with refractory material. The insulation and control of air mixture contribute to a more uniform burn as well as lower emissions.

Tait (2014) suggested that safety flares should have capacities at least 1.2 to 1.6 times the maximum expected CAP or digester biogas production rate to ensure that the stored biogas can be evacuated within a reasonable time period.

Boilers

On-farm boilers are likely to be used primarily for heating water circulated through under-floor heating pads and zone heating elements used to heat creep areas in farrowing sheds and weaner accommodation (hydronic heating), and/or for heating air blown through radiators/heat exchangers used for space heating in piggery sheds. As these applications generally require water heated to a maximum temperature of 90°C, biogas-fired boilers used in piggeries are not generally required to produce steam. One exception may be in large piggeries where steam is used for pelletising feed.

Darby and Borg (2004) state that boilers are generally classified according to the following categories:

- type of fuel - gas, oil or solid fuel
- physical structure - sectional or tube type, ‘wet’ or ‘dry’ based
- heat exchanger material - copper, steel, cast iron or combination alloy
- type of heat exchanger, condensing or non-condensing.

A number of boilers developed specifically for the combustion of biogas are available commercially. Alternatively, it may be possible to modify ‘off-the-shelf’ boilers designed to burn natural gas. The conversion should be approved under the relevant state legislation which generally requires the work to be carried out by an appropriately authorised gas fitter.

Biogas burnt in boilers does not necessarily need to be upgraded; however, the levels of H_2S should not exceed 1000 ppm (Wellinger and Lindberg, 2005). At higher H_2S concentrations, the formation of sulphuric acid is likely to result in serious corrosion. Alternatively, boilers burning untreated biogas may use components fabricated using corrosion resistant materials. Wellinger and Lindberg (2005) also recommend removing the water vapour from the biogas. Birchall *et al.* (2008) suggest that boilers containing a copper heat exchanger or fittings are likely to suffer from corrosion, unless the biogas is scrubbed to reduce H_2S concentrations. Frequent starting and stopping of the boiler may intensify this problem.

Skerman (2013a) reported on the installation of a Rheem Model 631265 NO heavy-duty hot water system (HWS) at a south-east Queensland piggery in April 2012. This HWS was originally designed to burn natural gas, before being converted by an authorised gas fitter to burn biogas for the purpose of heating water which is circulated through underfloor heating pads in the farrowing sheds. This conversion involved adjusting the burner pressure at the inlet regulator, drilling out the main jet from 4.8 to 6.0 mm diameter, and making minor adjustments to the mixture (interrupter) screw on the throat of the burner. The HWS experienced some initial, intermittent operating problems resulting from the gas control valve initiating system shut-down after unsuccessful attempts to restart. This issue may have been caused by excessive heat build-up near the gas control valve due to partial blockage of the flue and baffles by sulphurous deposits. These deposits appear to have resulted from burning untreated biogas having an average H_2S concentration of 2200 ppm. The HSW also experienced severe corrosion of the flue, baffles and casing.

Boiler thermal efficiency is typically 80% to 90% (Van Haren and Fleming, 2005). As pure CH_4 has an approximate LHV of 10 kWh/m^3 and piggery biogas contains around 65% CH_4 on average, 100 m^3 of biogas would contain around 650 kWh of energy. Based on a boiler thermal efficiency of 80%, this quantity of gas would yield around 520 kWh of heat.

Condensing boilers have higher thermal efficiencies than conventional boilers, utilising heat from exhaust gases that would normally be released into the atmosphere through the flue. They are fitted with at least one heat exchanger to cool the flue gases, condensing the water vapour released into the flue gas when the CH_4 is burnt. The latent heat of vaporisation extracted from the flue gases is returned to the heating system. This increases the boiler efficiency to at least 90% (up to 98%, Viessmann, 2012), meaning that at least 90% of the energy in the fuel is converted into useful heat.

The heated water can be utilised in a number of applications as outlined in Figure 3, below. These applications are discussed in more detail in subsequent sections.

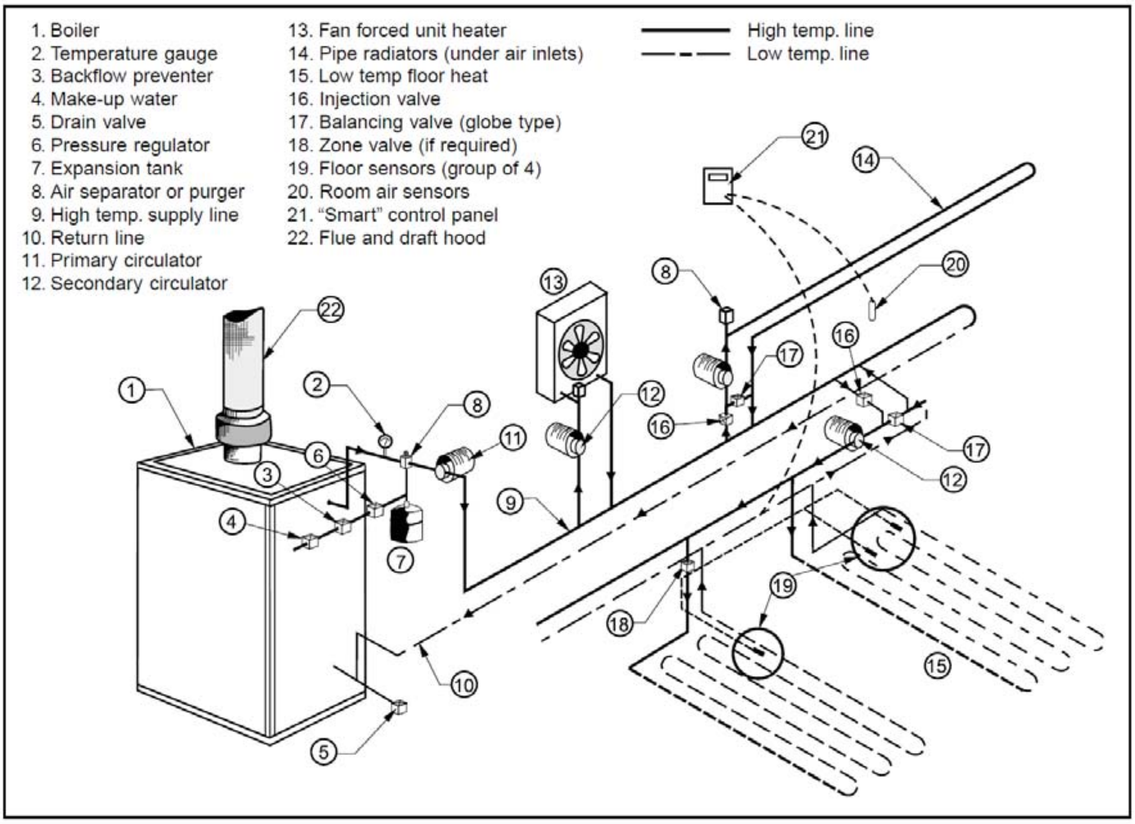


Figure 3. Schematic drawing of a typical hot water heating system (Darby and Borg, 2004).

Electricity generation

Biogas may be burnt in an internal combustion (IC) engine (compression or spark ignition) or a gas micro-turbine to power a generator used to generate electricity for on-farm use or export to the grid. In addition to generating electricity, the engine may be fitted with a heat recovery system, as described in sections 5.4 and 5.5, to provide cogeneration and trigeneration capability.

Internal combustion engines

IC engines are described as either spark ignition (Otto-cycle) or compression ignition (Diesel-cycle), depending on the method used for igniting the fuel. Spark ignition engines use a spark plug to ignite a pre-mixed air fuel mixture introduced into the cylinder. Compression ignition engines compress the air introduced into the cylinder to a high pressure, raising its temperature to the auto-ignition temperature of the fuel, which is injected at high pressure.

Several companies manufacture four-stroke spark-ignition (Otto cycle) engines specifically designed to operate burning either natural gas or biogas. Figure 4 shows one of three

Cummins HGN14 biogas engines driving 80 kW generators installed at Blantyre Farms piggery located near Young, NSW.

Figure 4. Cummins HGN14 biogas engine driving 80 kW generator installed at Blantyre Farms piggery located near Young, NSW.

Petrol engines can also be modified to operate on biogas by replacing the carburettor with a biogas-air mixer. The compression ratio can be increased and the spark timing advanced to partially compensate for the loss in power resulting from the decrease in volumetric efficiency and flame speed compared to petrol engines (Van Haren and Fleming, 2005).

Compression ignition engines are also available for dual-fuel operation, using a small amount of diesel (10%–20% of the amount needed for diesel operation alone) mixed with the biogas before combustion. In dual fuel operation mode, biogas is mixed with air prior to entering the combustion chamber. At the end of compression stroke, a pilot amount of diesel fuel is injected to ignite the mixture (Tippayawong *et al.,* 2010). One advantage of this type of engine is that it can run on anywhere from 0% to 85% biogas (Van Haren and Fleming, 2005) and can therefore be switched back to conventional diesel operation, if necessary.

Sulphur dioxide (SO_2), formed from combustion of relatively high levels of H_2S in the piggery biogas, can produce highly corrosive sulphurous and sulphuric acid by reacting with condensed water which forms when combustion exhaust gases are cooled below their dew point. The lubricating oil used in gas reciprocating engines may also require more frequent changing as it becomes contaminated with sulphur, lowering the pH and adversely affecting its lubrication qualities. Consequently, reciprocating gas engines typically require a biogas H_2S concentration less than 200 ppm to avoid excessive corrosion and lubrication issues (AMPC and MLA, 2013).

Caterpillar (2013) states that proper treatment of the biogas to remove contaminants will lead to extended engine overhaul intervals, longer spark plug life, extended oil change intervals, better component life and lower overall maintenance costs.

Biogas micro-turbines

In biogas micro-turbines, air is pressed into a combustion chamber at high pressure and mixed with biogas. The air-biogas mixture is burned resulting in a temperature increase and expansion of the gas mixture. The hot gases are then released through a turbine, which is connected to an electricity generator, typically having an electric capacity below 200 kWe. They also employ a heat exchanger on the exhaust which is used to pre-heat the inlet air before mixing with the biogas, improving the efficiency of operation (Van Haren and Fleming, 2005).

Biogas must be compressed to approximately 585 kPa for use in a micro-turbine (Wiltsee and Emerson, 2004). Micro-turbine shaft speeds can be as high as 96,000 rpm while electrical efficiencies from 25 to 30% can be achieved. The cost of biogas micro-turbines is relatively high and research and development work is aiming to reduce costs for future models (Seadi *et al.*, 2008).

Williams and Gould-Wells (2004) reported on a 30 kW (nominal) micro-turbine running on biogas from a CAL at California Polytechnic State University (400 cows intensively housed). This generator produced 15 to 25 kW at 20% to 25% efficiency with NOx emissions of 3 ppm. Micro-turbines generally produce lower NOx emissions in comparison to IC engines (Birchall, 2008).

The Capstone website states that micro-turbines can operate with gases having a wide range of energy contents, automatically adjust to changing energy densities over time, and can accept high levels of contaminants such as H_2S (5000 – 70,000 ppm). This may avoid the need for H_2S scrubbing altogether, with associated benefits in capital and maintenance costs.

Micro-turbines have a smaller number of moving parts than IC engines resulting in a lighter maintenance schedule (Van Haren and Fleming, 2005).

Stirling motors

The Stirling motor is an external combustion engine, based on the principle that temperature changes of gases result in volume changes. The pistons are moved by gas expansion caused by heat injection from the external energy source. The external heat can be provided from various sources such as a biogas burner. Due to the external combustion, biogas with lower CH_4 content and high levels of H_2S may be used without treatment (Seadi *et al.,* 2008).

The GasBox system, as shown in Figure 5, was developed by the Swedish company, Cleanergy. It is an example of how a Stirling engine has been used in a CHP application. The manufacturers claim that the GasBox system has an electrical power output of 2 – 9 kW and a thermal output of 8 – 26 kW, at an overall efficiency of 95%. It is also compatible with biogas produced from a wide range of substrates, from manure to food waste and plant residues, and will operate with land-fill biogas having a CH_4 concentration as low as 18%. Furthermore, the biogas does not require any upgrading prior to use (Cleanergy website, 2014).

Figure 5. The GasBox Stirling engine powered CHP system produced by Cleanergy. (Cleanergy website, 2014)

Organic Rankine Cycle Systems

Organic Rankine Cycle (ORC) systems utilise waste heat such as gas engine exhausts to produce additional electrical power. Installing an ORC to convert waste heat into electricity enables a better use of the primary energy.

The ORC is similar to a Steam Rankine Cycle in that it is based on the vaporisation of a high pressure liquid which is in turn expanded to a lower pressure thus releasing mechanical work. The cycle is closed by condensing the low pressure vapour and pumping it back to the high pressure. Therefore, the ORC involves the same components as a conventional steam power plant (a boiler, a work-producing expansion device, a condenser and a pump). However, the working fluid is an organic compound characterised by a lower ebullition temperature than water and allowing power generation from low heat source temperatures (Quoilin *et al.,* 2013).

The Clarke Energy website (2014) outlines how the GE Clean Cycle 125^{TM} utilises ORC technology to convert energy, in the form of waste heat, into useful electricity. It is claimed that this system, at full capacity, adds 125kW of electrical power output to a heat-generating application without consuming additional fuel. Operating at full load, one Clean Cycle™ system generates approximately 1 million kWh of electricity per year that would have otherwise been generated on the grid. This avoids more than 350 metric tonnes of CO_2 per year, equivalent to the annual CO_2 emissions of approximately 200 cars.

Fuel cells

Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy, without combustion. They consist of an electrolyte layer in contact with a porous anode and cathode on both sides. In a typical fuel cell, the gaseous biogas fuel is fed continuously to the anode (negative electrode) while an oxidant (oxygen from air) is fed continuously to the cathode (positive electrode). An electrochemical reaction takes place at the electrodes, producing an electric current (Seadi *et al*., 2008).

Fuel cells require pre-treatment of the biogas to purge H_2S to a concentration less than 0.5 to 1.0 ppm, and other harmful contaminants (Van Haren and Fleming, 2005).

Several types of fuel cells have been developed progressively over recent decades. Van Haren and Fleming (2005) reported that a Proton Exchange Membrane (PEM) fuel cell was the first fuel cell to generate electricity from agricultural biogas. The 5 kW unit was operated intermittently by researchers from the University of Minnesota on a dairy farm (Anon, 2005).

The FuelCell Energy website (2014) states that their 1.4 MW DFC1500 unit has an electrical efficiency of 47%, giving it higher efficiency than other distributed generation plants of similar size, and with virtually no pollutants. When configured for CHP operation, total thermal efficiency can approach 90%, depending on the application.

Generators

The renewable energy hub website (2014) describes the two main categories of generators as self-controlled (synchronous) and grid-controlled (asynchronous). Self-controlled generators are used when there is no connection to the grid. Alternatively they can operate in parallel with the mains or, in the event of supply interruption, without it (Birchall, 2008). Grid-controlled generators operate in parallel with the mains supply, deriving phase, frequency and voltage from it, and cannot stand alone. If the grid loses power they shut down so they are not suitable for stand-by (backup) power generation.

In stand-alone applications, local electrical contractors may install interlocks to prevent export of electricity to the distribution grid. This work does not generally require supplier approval as interlocks are commonly installed for backup generators (Birchall, 2008).

If an on-site CHP unit is to be run in parallel with the existing power supply system (grid synchronous), or will be configured to export electricity to the grid, contact with the local distribution network is recommended early in the planning phase of the on-farm biogas projects. The complexity and effort involved in providing the required electrical protection and safety systems, for connecting distributed generators to the local grid, varies between Australian states (Davidson *et al*., 2013).

Electrical efficiencies

Electrical efficiencies of IC engines (coupled with generators) vary (Van Haren and Fleming, 2005). Wellinger and Lindberg (2005) observed that some studies reported efficiencies as high as 29% for spark ignition engines and 31% for dual fuel engines, while the US EPA assumes a range of 18 to 25%, depending on engine design and load factor (AgSTAR, 2004).

Converted petrol engines offer efficiencies of 18% to 28%, but gas engines and compression (converted diesel) engines offer efficiencies up to 42%. In general, the small spark-ignition engines (converted petrol engines) cover the range from 10 to 60 kW, dual fuel engines from 40 to 200 kW, and gas engines from 150 to 500 kW (up to 3 MW is possible). An additional 40% of the biogas energy can be captured from engine jacket water and exhaust gases by a heat recovery system (Birchall, 2008).

Tait (2013) notes that returns on grid export of electricity are currently marginal because payments for power exported to the grid are significantly less than the rates paid for grid power usage. Consequently, producers generally favour on-farm power use in preference to grid export.

Heubeck and Craggs (2010) assume a 30% electrical power generation efficiency in feasibility studies carried out for biogas-powered, IC engine-driven CHP units in NZ piggeries.

Cogeneration

In addition to generating electricity as described in the previous section, cogeneration or CHP systems use heat exchangers to recover otherwise waste heat from the engine cooling and exhaust systems. The recovered energy is in the form of hot water at temperatures typically ranging from 70 to 80˚C. This hot water can be used for a range of productive uses, thereby further offsetting on-farm energy costs.

Tait (2013) suggests that a CHP system installed at a typical 500 sow conventional farrow-to-finish piggery can produce 840 kWh/day of electricity and 880 kWh/day of heat. This may exceed the daily energy consumption of the piggery resulting in opportunities for exporting electricity to the grid.

NIWA (2008) and Heubeck and Craggs (2010) assume a 30% electrical conversion efficiency and 50% thermal efficiency from CHP systems in piggery biogas feasibility studies.

The Evo Energy Technologies website (2014) claims their 2G Filius CHP systems, ranging from 50kWe to 150kWe provide electrical efficiencies from 35 to 38% and thermal efficiencies from 46 to 50%.

Similarly, the ENER-G website (2014) claims that their biogas CHP systems, ranging from 80 to 200 kWe provide electrical efficiencies from 32 to 39% and thermal efficiencies from 46 to 53%.

YANMAR also manufacture a range of micro-CHP systems suitable for biogas, ranging from 5 to 25 kWe electrical outputs. The 25 kWe unit is claimed to provide electrical and thermal efficiencies of 33.5% and 51.5%, respectively (Simons Green Energy, 2014a).

Trigeneration

In addition to the heat and power produced in cogeneration or CHP systems, trigeneration systems use a portion of the heat from the cooling water and/or flue gas produced by the engine (or turbine) driving the electrical generator, to produce cooling energy, using an absorption chilling process, as outlined schematically Figure 6, below.

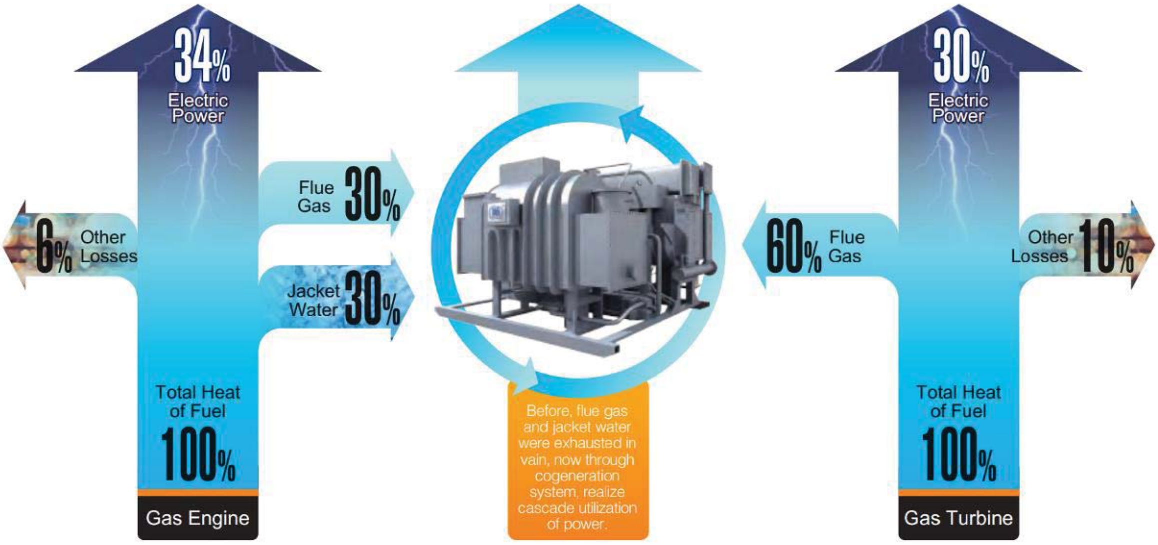


Figure 6. Trigeneration system schematic drawing showing heating, cooling and electrical energy potential from biogas (Simons Green Energy, 2014b).

Most trigeneration systems have the added benefit of being able to vary the amount of each output produced (Bruno *et al.*, 2009). This means that during winter, the amount of heat being produced could be increased while decreasing the amount of cooling, and vice versa for summer. The ability to use the unit for cooling that may give trigeneration a significant advantage over cogeneration for some Australian piggeries. Normally a proportion of the heat produced in a cogeneration system would be wasted in summer, but with the addition of the absorption chiller, that energy could be used in cooling applications.

Vehicle fuel

Raw biogas, produced from the anaerobic digestion process, must be upgraded to natural gas quality in order to be used in vehicles that are designed to use natural gas. This means that CO_2, H_2S, ammonia, particles and water (and sometimes other trace compounds) have to be removed so that the resulting gas has a CH_4 content of about 95-98% by volume (NSCA, 2006). The cost of upgrading biogas to biomethane depends on the size of the plant. Economics calculations show that the upgrading of biogas to biomethane can be profitable when at least 500 Nm^3 raw gas per hour can be used (Thrän *et al.,* 2014). This volume of biogas production would be expected from a piggery having a capacity of approximately 150,000 SPU (15,000 sows farrow to finish) which is clearly larger than any existing, single piggery units currently operating in Australia.

Biomethane was first used to fuel trucks during and after World War II in a number of European cities. It was relaunched as an automotive fuel in the early 1990s in Switzerland and Sweden and its use has now spread all over the world, predominantly in Europe and the USA. By the end of 2013, biomethane was available as an automotive fuel in 13 European countries (Green Gas Grids). Policies such as tax reductions on clean vehicles and renewable fuel quota systems are important for promoting this form of use (Thrän *et al.,* 2014).

In some European countries, vehicle manufacturers offer a range of light and heavy-duty vehicles that are suitable for operation using either natural gas or biomethane. The light-duty vehicles are generally fitted with spark-ignition engines suitable for ‘bi-fuel’ operation, allowing the vehicle to be run on either petrol or gas, as circumstances require. However, in some cases the vehicle may be designed to run solely on either natural gas or biomethane, being optimised for operation on a single fuel (NSCA, 2006).

Heavy-duty vehicles may be fitted with spark ignition dedicated gas engines or compression ignition dual-fuel engines which use diesel for pilot ignition purposes. High rates of substitution of compressed natural gas (CNG) or biomethane for diesel, sometimes up to 90%, have been claimed; however, an average of 70% is representative of fleet operation (NSCA, 2006). These vehicles can operate with the low emission benefits of natural gas whilst retaining the inherent power, efficiency and long life of compression ignition engines.

The biomethane gas fuel is stored on the vehicle in either compressed or liquefied form. CNG is the most common form of fuel storage on vehicles. This involves storing the gas at high pressure (200 bar = 20 MPa) in tanks. The energy density of CNG is approximately 25% of the value for diesel fuel. Consequently, for the same sized fuel storage tanks, the operating range of CNG powered vehicles is approximately one quarter of that of a comparable diesel powered vehicle. Alternatively, the fuel storage volume could be increased, possibly at the expense of some vehicle carrying capacity.

Some vehicles store the gas in liquefied form, commonly known as liquefied natural gas (LNG), to increase their range. The gas is both cooled to a temperature below -160°C and compressed to become a liquid, which is again stored in high-pressure tanks on the vehicle. The energy density of LNG is approximately 60% of that for diesel. This method is more common in heavy vehicles as range and payload are more critical to the vehicle operation (NSCA, 2006).

According to the Natural Gas website (2014), there are numerous natural gas vehicles currently operating in Australia, including Isuzu CNG refuse collection vehicles in Adelaide and Melbourne and substantial bus fleets in Adelaide (220), Melbourne (20), Sydney (300), Perth (100) and Brisbane (150). The following companies manufacture and service CNG engines and/or vehicles which are supplied with factory warranties: MAN, Iveco, Mercedes, Volvo, Cummins, Caterpillar, Isuzu, Mitsubishi, Toyota, Hino, Nissan, Honda and Mazda.

Implementation of biogas as a vehicle fuel has been successful in many overseas countries. Kelleher Environmental (2013) recently published a report on the use of biogas as a vehicle fuel in Europe, with Sweden having over 2,300 passenger vehicles successfully running on biomethane.

Valtra (Finland) manufactures a dual-fuel tractor which can run on either natural gas or upgraded traffic-quality biogas, and on diesel. The majority, up to 83% of the power is generated by CH_4 from natural gas or upgraded biogas and a minor part by diesel fuel which is used to ignite the gas-air mixture according to the diesel process (Valtra website, 2014). Figure 7 is a schematic drawing of the dual-fuel system used in the Valtra biogas tractor.

As previously discussed, one of the problems facing biogas tractor designers is providing sufficient biomethane storage capacity. The Valtra T133 experimental tractor provides 170 L of biogas storage capacity at a pressure of 200 bar (20 MPa). This is sufficient for a modest three to five working hours. However, the tractor retains its 165 L diesel fuel tanks which could be used to extend the running time between refills.

Methane is said to have the lowest carbon content of any fuel, the exhaust emissions are odour-free and the particulate level is up to 99% lower than other tractor fuels. Compared with diesel fuel, biogas combustion produces 95% less nitrous oxide and 25% less CO_2. The production tractor is expected to interest local authorities as well as farmers with biogas production (Anon, 2012).

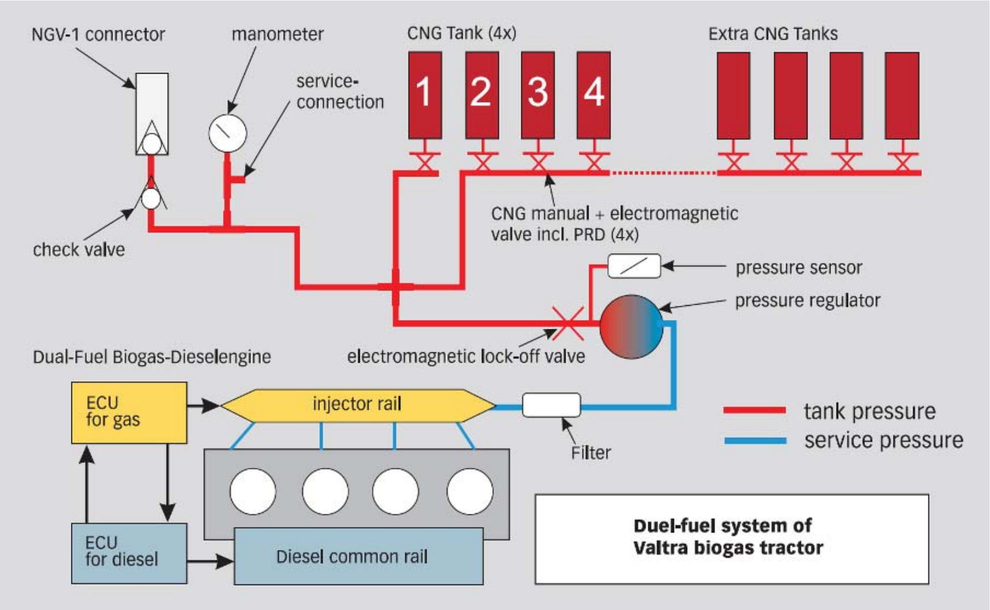


Figure 7. Schematic drawing of the dual-fuel system used in the Valtra biogas tractor (Valtra website, 2014).

Due to the close relationship with the natural gas market, energy units for biomethane are usually given in Nm^3 or kWh [1 Nm^3 of biomethane typically contains 10 kWh primary energy, equivalent to 36 MJ] (Thrän et al., 2014).

Clarke *et al*. (2007) carried out laboratory studies to measure the CH_4 yield and rate of digestion of reject bananas with a view to establishing a full-scale biogas plant in the banana growing region of North Queensland. Due to high consumer expectations on quality, approximately 30% of the 250,000 t of bananas grown annually in this region are rejected at the packing shed.

These initial tests showed that bananas are a very suitable feedstock for anaerobic digestion—yielding about 240 L of biogas per kilogram of dry bananas (equivalent to the energy content of 0.1 L of diesel fuel). The resulting biogas was of sufficient quality to be used directly as a substitute for diesel fuel in combustion engines, containing about 40% CH_4 and insignificant amounts of H_2S and other contaminants.

To use the biogas as transport fuel, the raw biogas was compressed to a pressure of 200 atm (20 MPa) and stored in a high-pressure tank on-board a diesel engine powered utility. The vehicle had been modified to operate on a combination of diesel and compressed biogas, employing the same technology used to operate vehicles on CNG. The biogas displaced about 30% of diesel fuel consumption required to operate the vehicle.

While replacement of diesel fuel in vehicles represents a high value application, the specialised skills required to maintain the compressors and other equipment are not generally available in the horticulture industry. As a result, for practical reasons, electricity generation was considered the most beneficial application for the banana-based biogas fuel (DERM, 2011).

It is envisaged that the main applications for using piggery biogas as vehicle fuel would be for farm machinery, such as tractors, and for trucks used to transport pigs between production units and to the abattoir. These applications may be economically feasible at piggeries where on-site energy usage is relatively low and there is excess biogas available after satisfying on-site electricity, heating and cooling needs. Depending on travel distances, vehicular storage of CNG may be limiting. Furthermore, the capital and ongoing operational costs involved in upgrading the raw biogas and converting existing vehicles may diminish the economic viability of this option.

Biogas upgrading

Biomethane is defined as CH_4 produced from biomass with properties close to natural gas. As noted in section 2 of this review, raw biogas must be treated (upgraded) to remove H_2S, CO_2 and other contaminants, to produce biomethane with a CH_4 content of at least 95%. It can then be used for any applications that natural gas is commonly used for, including injection into a centralised natural gas grid.

Thrän *et al.* (2014) recently produced a comprehensive report on the status and factors affecting market development and trade in biomethane, under IEA Bioenergy Tasks 40 and 37. Some of the content provided below has been reproduced from this publication.

Several European countries have well-developed natural gas infrastructure such as gas grids and road transport filling stations. Natural gas is commonly transported in the form of CNG or LNG using heavy-duty road and marine tankers. Nevertheless natural gas is a fossil-based fuel and some countries have initiated a transition from a fossil resource base towards renewable energy to address concerns regarding GHG emissions, energy security and conservation of finite resources. Biomethane is considered to be a fuel which could support this transition while achieving GHG emission reduction targets.

Because biomethane has virtually identical qualities to natural gas, it can be used as a substitute for transport fuels, to produce combined heat and power (CHP), heat alone or serve as feedstock for the chemical sector and it can be transported and stored in the existing facilities and infrastructure initially developed for natural gas.

Biogas upgrading to biomethane increases the energy density by separating CO_2 from CH_4. Furthermore, water, H_2S and other contaminants are removed, sometimes before the upgrading process, to avoid corrosion or other problems in downstream applications.

Unlike Europe, there appears to be limited scope in Australia for supplying biomethane into centralised natural gas grids. The cost and level of technology required for upgrading biogas produced by individual piggeries to the required standard is likely to be prohibitive. As most Australian piggeries are situated in relatively remote locations, often considerable distances away from major population centres and energy-intensive industries, centralised treatment and use of biomethane derived from piggery biogas does not appear to be currently feasible.

Biogas use applications

Figure 8 is a diagrammatic representation of the range of biogas use options with particular reference to large scale dairy operations in the US (Mears, 2001). The majority of these potential biogas uses are technically feasible for adoption by the Australian pig industry, as discussed in the following sections.

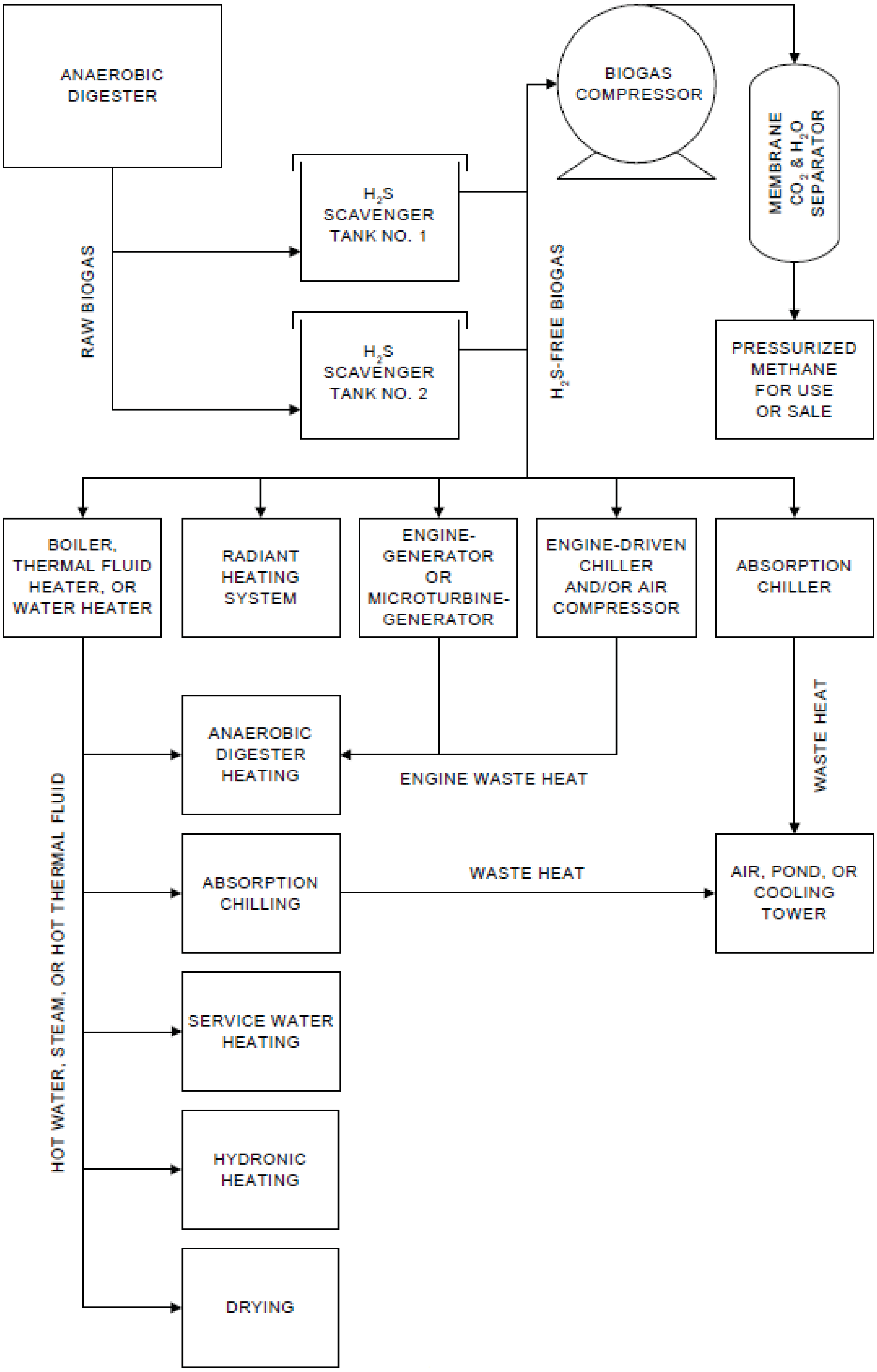


Figure 8. Range of biogas use options (Mears, 2001).

Odour mitigation

Biogas collection and use systems can significantly reduce piggery odour emissions. Smith *et al.* (1999) conclude that ponds are the major source of odours at typical Australian piggeries contributing about 75% of all emissions, while Camp Scott Furphy Pty Ltd (1993) concluded that 82% of odour emissions from a Scone (NSW) piggery resulted from the pond system.

Impermeable pond covers can reduce odour, H_2S, and ammonia emissions by 95% (Stenglein *et al*., 2011) while floating plastic covers reduced emissions of odour by 60 to 78% and H_2S by 90% (Nicolai *et al.*, 2002).

This suggests that the installation of an impermeable cover on an existing anaerobic pond, or the installation of a new CAL or digester at an existing piggery could substantially reduce overall odour emissions. This may assist producers operating piggeries in closely settled areas and/or in rural areas where urban or peri-urban encroachment have resulted in increased complaints regarding odour nuisance.

Flaring would be the simplest and least costly biogas use option in situations where odour mitigation is the primary objective for biogas collection.

Shed heating

Underfloor hot water circulation

Water heated using biogas-fired boilers or CHP systems is commonly circulated through heating pads installed in creep areas within individual farrowing pens to keep piglets warm. A number of companies manufacture plastic, ceramic and polymer concrete heating pads specifically designed for this purpose. An example of a plastic pad is provided in Figure 9.

Figure 9. Reventa “Thermo-Plus® ” porker nest heating pad.

Alternatively, Skerman and Collman (2012) described how a south-east Queensland pig producer installed custom-made heating pads using 15 mm diameter copper pipe ‘S’ bends which were fabricated on-farm and cast in concrete, as shown in Figure 10.

The concrete pads were formed by removing some of the plastic tiles and installing a plywood base. The copper pipe ‘S’ sections are joined (in series) using flexible polybutylene hot water pipe and fittings (Hepworth Hep2O). Hot water is circulated from an elevated hot water header tank through approximately 30 under-floor heating pads per circulation line.

The thermostat on the biogas-fired HWS was set at 60 - 65°C and the target heating pad temperature of 32 - 34°C was achieved by adjusting a valve on each recirculation line. During the system commissioning stage, the pad temperatures were monitored using an infrared thermometer.

A photograph of an operating heating pad in a farrowing pen is provided in Figure 11.

Figure 10. Typical copper pipe ‘S’ shaped section prior to pouring one of the concrete heating pads in the piggery farrowing sheds (Skerman and Collman, 2012).

Figure 11. Farrowing pen showing one of the custom-made concrete pads heated by circulating hot water through copper pipes cast into the pad (Skerman and Collman, 2012).

Figure 12 is an infrared photograph provided by Skerman (2013a) showing the temperatures on the surface of one of the farrowing shed under-floor heating pads. The outline of the ‘S’ shaped copper pipe which conveys the heated water through the concrete pad can easily be seen in this photograph.

Figure 13 is a schematic drawing of a typical Canadian under-floor heating system showing details of the plumbing and control features (Darby and Borg, 2004).

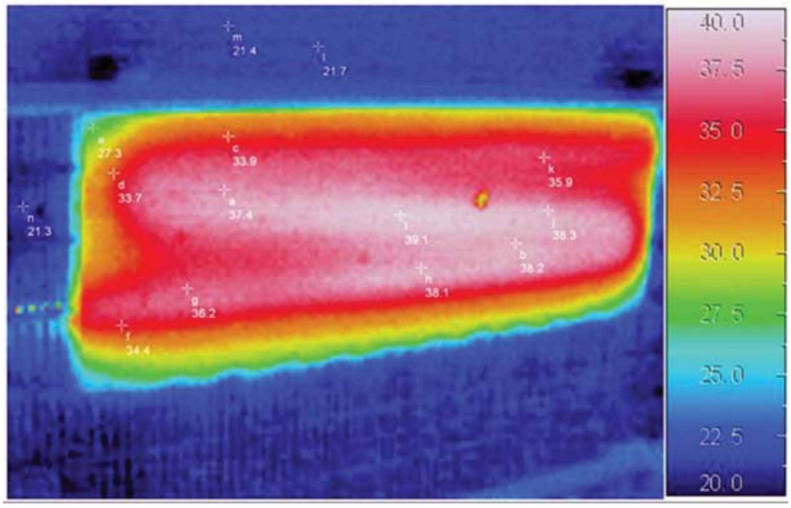


Figure 12. Infrared photograph of one of the farrowing shed heating pads showing the surface temperature variation (Skerman, 2013a).

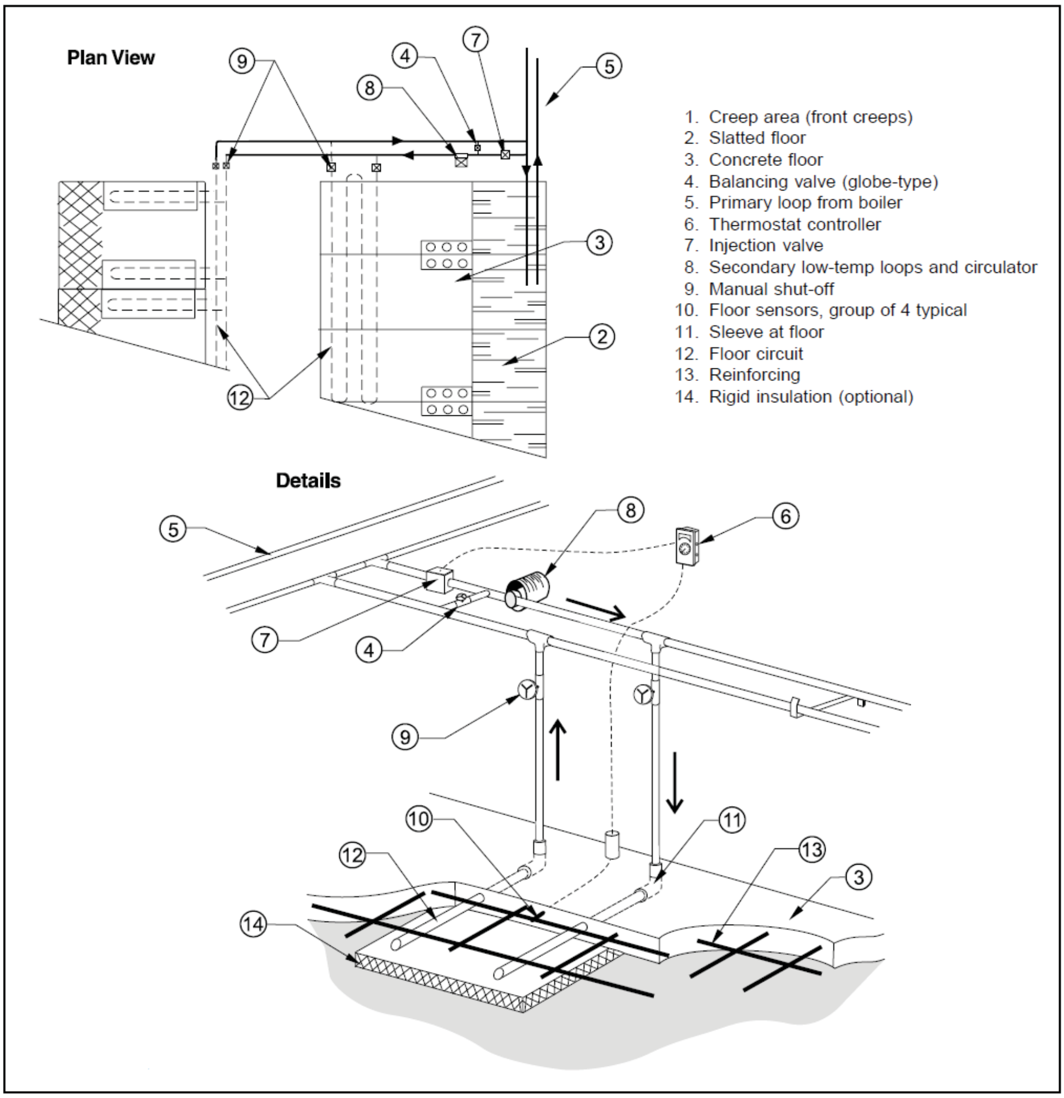


Figure 13. Piggery under-floor heating installation (Darby and Borg, 2004).

Radiators

Radiators transfer heat, from hot water, to a piggery room (Darby and Borg, 2004). Black steel pipe, finned-tube convectors, plate radiators, and fan-forced hot water unit heaters are the main types of radiators used world-wide in pig production housing. Figure 14 shows the various types of radiators and their applications.

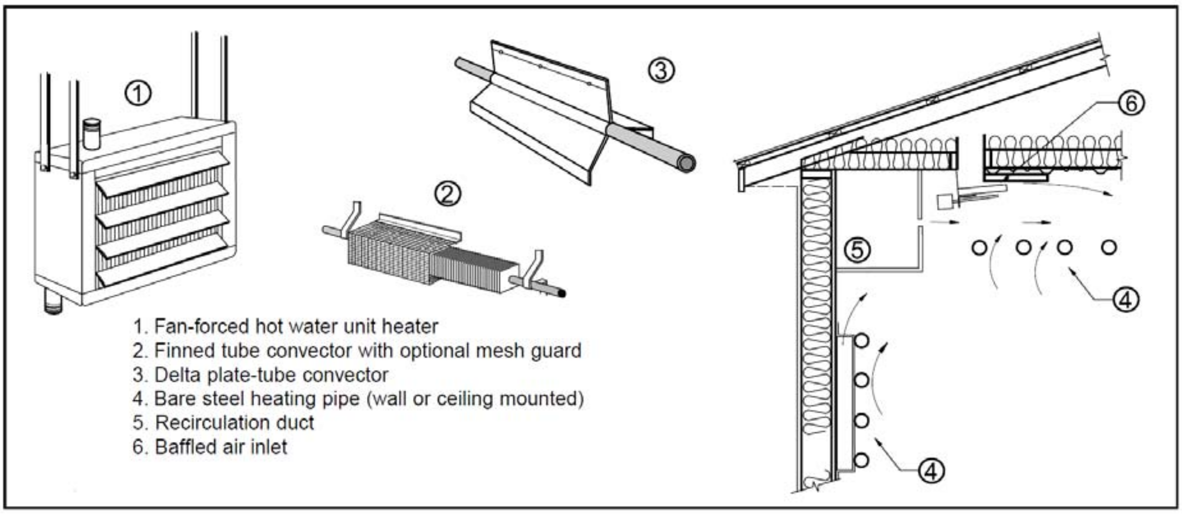


Figure 14. Various types of radiators used to heat piggery buildings (Darby and Borg, 2004).

The following descriptions of the various types of radiators were written by Darby and Borg (2004) based on Canadian climatic conditions. Some of these recommendations may not necessarily apply under Australian conditions.

Black steel pipe: Most commonly used in livestock buildings, it is easy to clean, least affected by dust, and not easily damaged. Bare pipe may be more costly and require more labour to install than finned-tube convectors because it is larger and more pipe is required. Galvanised pipe should not be used since the galvanising restricts heat transfer. Black steel pipe is usually mounted under air inlets or on wall brackets. Pipe radiators should be mounted at least one pipe diameter from the wall to permit free air circulation. Livestock rooms usually have from one to four loops of pipe.

Finned-tube convectors: These have four to five times the heat transfer capacity of bare pipe. Output varies with fin size and spacing, so consult manufacturer's design data. They are particularly suitable for small rooms or greenhouses where the length of bare pipe may be excessive. Where less heat is required, short sections of convector can be spaced along a wall. The main drawbacks to finned-tube systems are that they collect dust (reducing performance), require frequent cleaning and can easily be damaged. They are not recommended for dusty livestock buildings.

Plate-type radiators: These are a combination of fins and bare pipe by adding flat or triangular plate fins to the pipe. These offer the advantage of high output and ruggedness with less dust problems than fin-tubing.

Hot water unit heaters: These are excellent for small livestock rooms and similar areas where a concentrated heat source is desired. They can also be incorporated with ventilation ducts or other types of air circulation systems. In dusty buildings, these radiators should be inspected and cleaned regularly to maintain heating effectiveness.

Figure 15 shows two examples of commercial finned tube convectors. These products are manufactured by the German company, Reventa, from anodised aluminium in 4, 5 and 6 m lengths, resulting in relatively low weight and high heat conduction. The manufacturers claim a heat emission rate of up to 300 Watts per running metre. Figure 16 shows how these products are typically installed in piggery buildings.

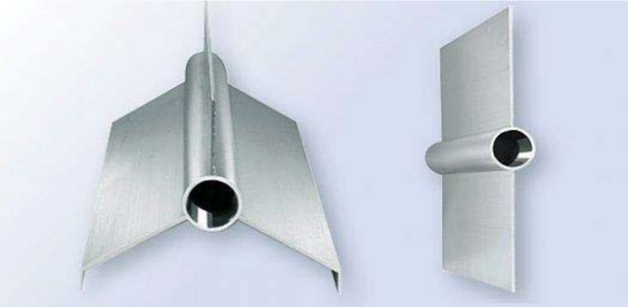


Figure 15. Reventa “Deltapipe” and “Twinpipe” finned tube convectors (Reventa website, 2014a).

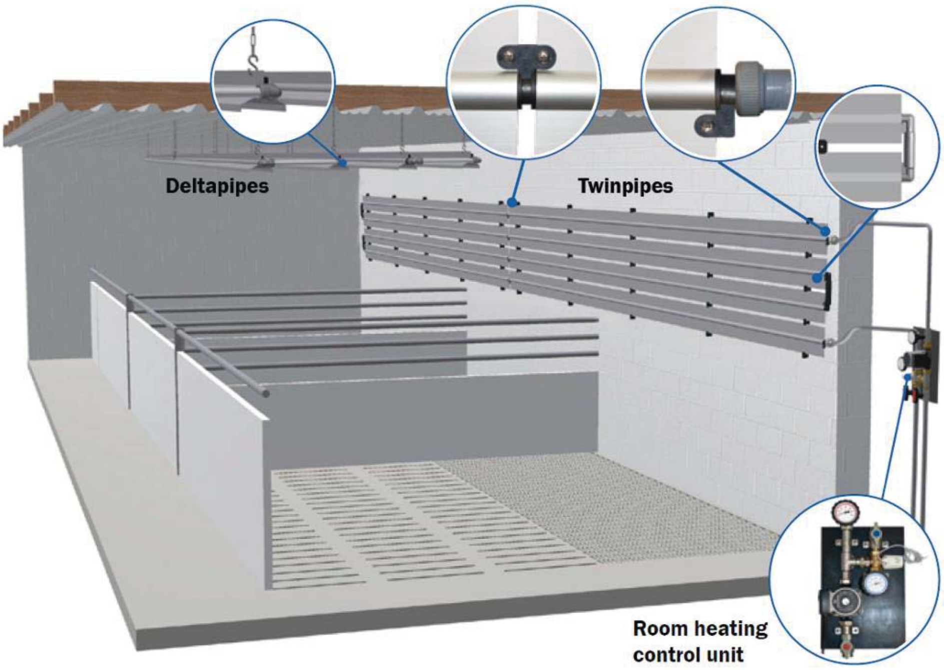


Figure 16. Typical installations of Reventa “Deltapipe” and “Twinpipe” finned tube convectors in a piggery building (Reventa website, 2014a).

Figure 17 shows several commercial examples of typical fan-forced, hot water to air heat exchangers used to heat piggery rooms. Reventa claim that their Heat-X ® heat exchangers are ideally suited for using the exhaust heat from biogas CHP plants. These units are available in many different configurations - vertical / horizontal / sucking (standard) / pressing as well as Heat-X ® compact.

Figure 18 shows an example of an area heat piglet cover (or hover) which may be installed to establish a warmer climate zone within a piggery building. The plate consists of an aluminium element, which is heated using hot water. The integrated insulation prevents heat emission via the top surface. The manufacturers claim that through the use of piglet covers, it is possible to reduce the temperature throughout the remainder of the shed and thereby save on overall energy costs.

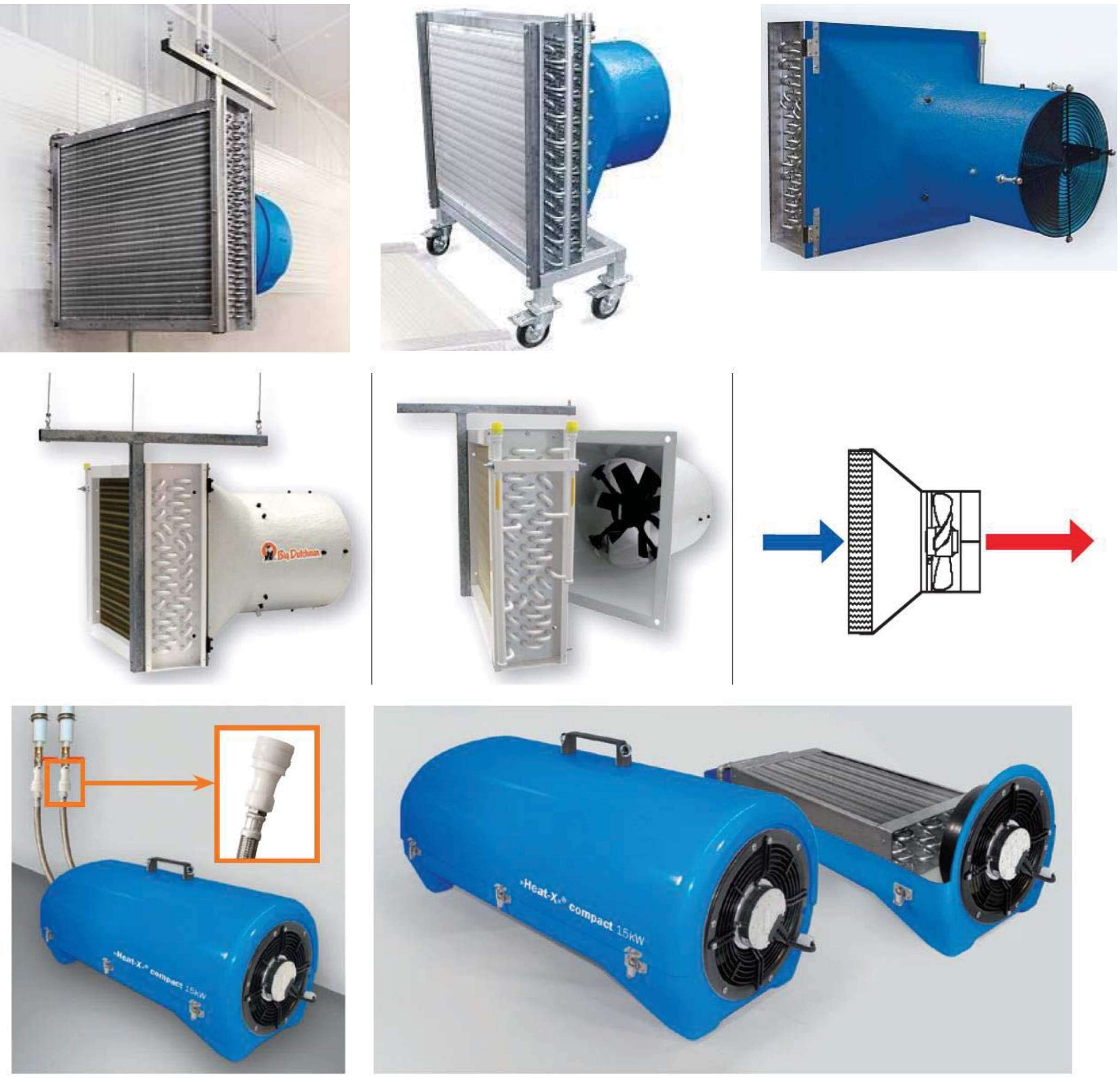


Figure 17. Commercial examples of fan-forced hot water to air heat exchangers used to heat piggery rooms (Reventa website, 2014b and Big Dutchman website, 2014).

Figure 18. Reventa area heat piglet cover (hover) is heated using hot water (Reventa website, 2014c)

Radiant heaters

Radiant heaters develop their infrared thermal radiation via a ceramic body that is heated to 600-800°C (red-hot) by the biogas flame. Approximately 95% of the biogas energy content is converted to heat resulting in thermal power outputs ranging from 1.5 to 10 kW for typical small heaters (Werner *et al*., 1989). Figure 19 shows a typical radiant heater which could be used in a piggery building.

Tube heaters are another type of radiant heater incorporating a fan burner which generates a long laminar flame. This flame heats alloy tubes to 650°C causing them to emit infrared radiation. Tube heaters are also referred to as 'dark heaters' because they do not glow brightly like luminous radiant heaters (Devex Systems website, 2014).

Most commercial radiant heaters are designed for operating on LPG and natural gas at supply pressures between 30 and 80 mbar (3 – 8 kPa). It may be possible to convert these units to operate satisfactorily using biogas by replacing the injector, provided an adequate supply pressure is maintained. As biogas fuelled radiant heaters may be susceptible to drafts, they should always be equipped with a safety pilot, and an air filter, if being used for long-term operation in dusty sheds (Werner *et al*., 1989).

Mears (2001) suggests that infrared heating systems offer the following advantages for space heating in piggery sheds:

- Radiant heat is not absorbed by the air, so it is highly efficient in areas that require frequent air changes or that have high infiltration rates.
- Radiant heating warms cold bodies directly without needing to heat up all of the air in the room or building. This rapid heat-up capability allows the heat to be off when the room or building is unoccupied, thus saving fuel.
- Radiant heating minimises heat losses through the roof and roof vents. The energy is directed radiantly down toward the area needing heat and the minimal air heating minimises stratification and the rise and escape of warm air.
- Radiant heating does not require forced air circulation in the room or building and thus minimises circulation of airborne particles.
- Radiant heating allows zone control. Different areas can be heated to different temperatures as required.
- Radiant heat is directional. Very specific areas can be heated without heating an entire room or building.

Care is required in managing the combustion by-products of radiant heaters which include CO_2, water vapour and possibly CO. Some radiant heaters may be fitted with a vent or flue to discharge the exhaust gases outside the piggery building. If the biogas has not been pre-treated to remove H_2S, the concentrations of SO_2 in the unflued exhaust gas may be harmful to livestock and workers in addition to promoting rapid corrosion of metallic fittings.

Figure 19. Typical radiant heater which could be used in a piggery building.

Shed cooling

Absorption chilling

The Carrier website (2015) provides the following explanation of absorption chiller operation:

"The refrigeration cycle for a conventional vapour compression chiller and an absorption chiller are similar in that both produce chilled water via the evaporation and condensation of a refrigerant at different pressures within the machine. However, a conventional chiller uses a mechanical means to compress and transport the refrigerant vapour to the condenser, while an absorption chiller depends on a thermo-chemical process involving lithium bromide and water to establish the pressure differential in lieu of mechanical compression. While most vapour compression chillers utilise electricity as its energy source to operate the machine, absorption chillers use heat, typically in the form of steam, hot water or through the direct combustion of natural gas."

Another good explanation of absorption chiller operation is provided by Mears (2001).

The Clarke Energy website (2014) notes that when water is used as the refrigerant and lithium bromide salt as the absorbent, chilled water in the temperature range 6-12°C may be generated. Alternatively, lower temperature chilling down to -60°C can be achieved when using ammonia as the refrigerant and water as the absorbent.

In the case of piggeries, the heat which drives the absorption chilling process may be provided by hot water from CHP engine cooling, waste heat from the CHP engine exhaust, or direct combustion of biogas. Because absorption chillers use waste heat as the driver for the process, they use significantly less electricity than conventional chillers.

The Simons Green Energy website (2014c) provides examples of a range of absorption chiller units which may be suitable for installation at some large piggeries, as part of trigeneration systems. As outlined in Figure 20, heat from the IC engine flue gas and jacket water can be used directly to operate these absorption chiller/heater units (Shuangulang IC Engine +Flue Gas/Hot Water Type, using Lithium Bromide absorbent) which can chill water to a minimum temperature of 5°C, having capacities ranging from 350 to 6000kW.

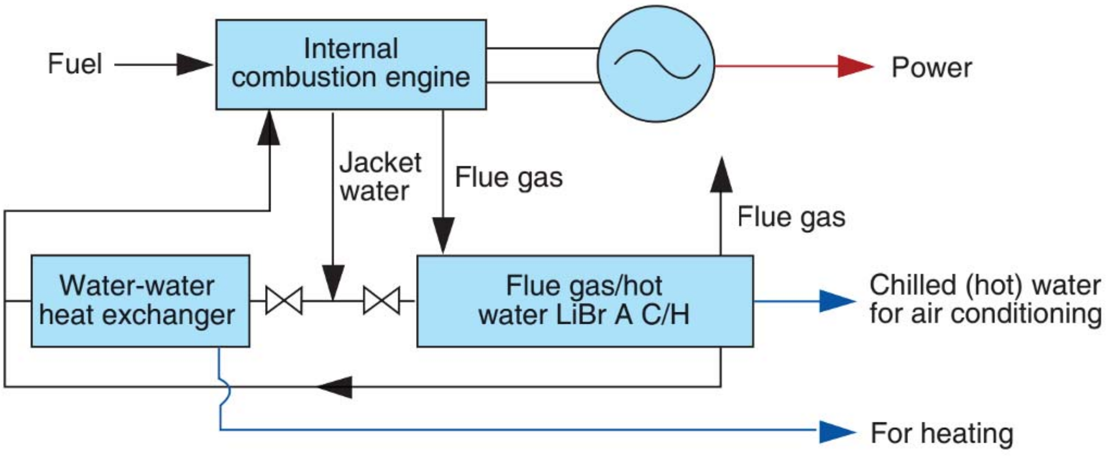


Figure 20. Schematic drawing of an IC engine +flue gas/hot water type Lithium Bromide absorption chiller/heater (Simons Green Energy website, 2014b).

McPhail and Rossington (2010) prepared a report on the use of abattoir waste heat for absorption refrigeration for Meat and Livestock Australia. They concluded that a packaged lithium bromide/water absorption chiller is the most appropriate option for use in abattoirs; however, as with other absorption refrigeration types, the resulting cooling energy is best suited to air conditioning applications. They also noted that the input heat could be sourced from the waste heat from a biogas-powered engine generator or by direct firing, using biogas.

In comparison to piggeries, abattoirs generally have a higher requirement for refrigeration. While lithium bromide/water absorption chillers may not achieve a low enough temperature for this application, they are likely to be more suitable for shed cooling applications in piggeries.

Drinking water chilling

A study conducted by Willis and Collman (2007) reported that cooled drinking water improved daily water intake, feed intake and body condition of lactating sows and the growth performance of their litters. The drinking water temperature preferred by lactating sows in the trials conducted at the University of Queensland Gatton Campus was about 20°C.

This study demonstrated the economic viability of using a milk vat to cool the drinking water resulting in an improvement of 0.7 kg in piglet weaning weight which equates to $61/sow/yr, applying the cooling over the three month summer period. Consequently, the use of an absorption chiller for this application appears to be a viable option for using excess biogas energy, particularly during the summer months.

It has also been reported in several studies (e.g. Gaughan, 1994) that drinking water temperature may have a significant effect on water intake and therefore on production efficiency of grower pigs. This option could provide further scope for increasing the economic and animal welfare benefits resulting from the use of biogas energy for drinking water chilling.

Snout cooling

Snout cooling is another management practice that could be considered as an option for using air cooled by an absorption chiller utilising biogas energy. Snout cooling can be used to alleviate seasonal heat stress, and improve feed intake (Stansbury *et al.*, 1987). However it does not appear to be as effective as drip cooling (McGlone *et al.*, 1988).

Conclusions

Piggery biogas production is generally estimated from the mass of VS in the effluent stream entering an anaerobic digester or CAL. The mass of VS (and hence biogas production) is primarily influenced by factors such as the numbers of pigs of various classes accommodated in the piggery, diet, feed wastage, effluent management system, and the use of pre-treatment devices to remove a portion of the solids from the effluent stream, prior to discharge into the anaerobic digester or CAL. Whilst site specific assessment of methane potential is recommended, a reasonably conservative estimate of annual CH_4 production at Australian piggeries is 25 m^3 CH_4 per SPU, or 19 m^3 CH_4 per SPU if the raw effluent is screened. This provides 233 kWh (839 MJ) or 177 kWh 637 (MJ), respectively, of primary energy per SPU annually.

To maximise the benefits from the increasing adoption of biogas capture, treatment and use systems in the Australian pork industry, it will be increasingly important for producers to access a range of practical, cost-effective technologies and appliances which can be tailored to match on-farm energy use, and/or enable economically beneficial export of excess energy.

Because all farms have distinctly different energy use profiles which vary seasonally along with biogas production, some flexibility in the mix of biogas use technologies and appliances is required to maximise energy use efficiency. However, capital and operating costs may require some rationalisation of biogas use technologies and appliances to maximise economic returns. For example, from an energy use perspective, it may be advantageous to utilise the cooling capabilities of a trigeneration system for using excess biogas during summer, when biogas production and cooling requirements are higher, while heating requirements are lower. However, the capital and operating cost of an adsorption cooler may make this option less profitable than simply flaring the excess biogas or generating more electricity for export into the grid over the summer period.

This review has highlighted several biogas use options which have not been previously trialled by the Australian pork industry. While it is anticipated that CHP systems (generating electricity for onsite use or export to the grid, and hot water for farrowing and weaner shed heating) will continue to provide an effective biogas use option at many piggeries, it is anticipated that the adoption of trigeneration systems may result in additional benefits at some piggeries. The inclusion of an adsorption cooling option may enable uses such as drinking water chilling and shed cooling to be included in the energy use mix.

The use of biogas as a fuel for pig transporting trucks and tractors for on-farm use does not appear to be particularly attractive at the present time, given the technical and operational demands associated with biogas upgrading and compressing the biomethane for on-board storage purposes. Nevertheless, this option may be appropriate for adoption at some large piggeries where excess biogas is available after meeting other on-farm energy needs. Alternatively, price rises for vehicular fossil fuels may make this option more attractive in the future.

Unlike Europe, there appears to be limited scope in Australia for supplying biomethane (upgraded biogas) into centralised natural gas grids. The cost and level of technology required for upgrading biogas produced by individual piggeries to the required standard is likely to be prohibitive. As most Australian piggeries are situated in relatively remote locations, often considerable distances away from major population centres and energy-intensive industries, centralised treatment and use of biomethane derived from piggery biogas does not appear to be currently feasible.

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Appendix 2: Feasibility Studies

The following Feasibility Studies (Faile, Pech and Skerman, 2015) were prepared for piggeries A to D by Messrs Deke Faile and Liam Pech of Simons Green Energy, Sydney, New South Wales, and Mr Alan Skerman, DAF, Toowoomba, Queensland, and submitted to the Pork CRC in June 2015.

Piggery A

A1. Site appreciation

Piggery A is located in the Northern Rivers region of New South Wales (NSW) which is characterised by the farm manager as a warm and humid climate for most of the year. This piggery is located in a relatively closely settled area and the neighbouring landholders show a keen interest in the activities of the piggery allowing for some complexities around any new farm operating procedures.

Piggery A is characterised as a farrow to finish unit accommodating 1,300 sows and 8,352 Standard Pig Units (SPU). Due to limitations with regard to the available land area on the farm and local government zoning considerations, approximately 4,000 grower pigs are housed at an off-site contract grower unit. These pigs are transported to the grower unit at eight weeks of age.

An aerial photo of the piggery is provided in Figure 1.

Figure 1. Aerial photo of piggery A (from Google Maps).

With the exception of 300 dry (gestating) sows and gilts, which are housed in a deep litter shed, all other pigs are housed in conventional flushed sheds with partial or fully slatted floors. A static run-down screen is used to remove solids from the raw effluent discharged from some of the piggery sheds into the effluent management system, which currently employs a primary anaerobic lagoon, a secondary lagoon and a tertiary effluent storage lagoon. Recycled effluent from the tertiary lagoon is used for irrigation onto land used for hay and pasture production. Recycled effluent is not used for flushing the piggery sheds.

The pig sheds are situated on top of a hill while the lagoons are located down the hill at a lower elevation. The piggery owners have taken advantage of the topography which is ideal for the gravity fed effluent system, with little or no effluent pumping required.

Depending on the season and energy density of the diet ingredients, approximately 80 to 100 t of feed are produced weekly by an on-site mill situated adjacent to the piggery. Tallow is a major diet ingredient and the on-site tallow tank requires heating to 60°C at all times, using LPG as the energy source. The mill, which is situated adjacent to the Electrical Main Switch Board (MSB) and electricity meter, is the highest electricity consuming activity on the site, followed by the mechanical ventilation fans and piglet heating lamps.

A1.1 Project objectives

Discussions with the piggery manager identified the following project objectives:

- reduce on-farm energy costs
- institute best practice for resource use and energy efficiency
- enhance lactating sow comfort and productivity.

A1.2 Sheds

The sows are housed in conventional farrowing and gestating sow sheds and a deep litter shed. Additional sheds are provided to house on-site weaner, grower and finisher pigs. Some of these sheds are naturally ventilated while others are mechanically ventilated with heating and cooling systems providing conditions suitable for the age of pigs housed in the various sheds.

A1.2.1 Farrowing sheds

There are a total of 240 farrowing crates in four farrowing sheds at Piggery A. One of the farrowing sheds is naturally ventilated while one is mechanically ventilated with evaporative cooling pads. The remaining farrowing sheds are mechanically ventilated with air inlet vents. For the comfort of the sows, the farrowing shed temperature is ideally maintained within the range from 18 to 22°C; however, this may increase to 25°C during summer.

Heating for the farrowing sheds is provided as follows:

- 1 x 100W infrared lamp operating continuously on electricity, installed in the creep areas of each farrowing crate to provide zone heating from 32°C for new-born piglets to 28°C at weaning (Figure 2). The heat lamp output is controlled thermostatically based on sensor readings in the creep areas of each shed. This results in relatively low heat output during summer. The creep areas at the Piggery A are not fitted with kennels or covers.

- Shed heating in the naturally ventilated farrowing shed is provided by diesel-fired, fan-forced space heaters and LPG fired radiant heaters on only the coldest nights.

Figure 2. Piglet nest heating.

Figure 3. Evaporative cooling pads.

Figure 4. Evaporative cooling fans.

A1.2.2 Gestating sow sheds

Additional sheds are provided for gestating (dry) sows. 300 gestating sows and gilts are housed in a deep litter shed where the manure is absorbed by straw and other fibrous bedding material. This shed does not contribute any manure to the effluent pond system. The remaining 714 gestating sows are housed in naturally ventilated conventional sheds.

A1.2.3 Weaner, grower and finisher sheds

The weaners are housed in cross-ventilated climate-controlled sheds while the growers and finishers are housed in naturally ventilated sheds. Some of these sheds are fitted with thermostatically controlled blinds.

Figure 5. Weaner shed with fans for evaporative cooling.

Figure 6. Naturally ventilated grower shed.

A1.3 Site energy consumption

The site consumes approximately 445,000 kWh of electricity per annum based on the 2014 National Metering Identifier (NMI) data provided by the utility. The greatest electricity consumption comes from the mill, followed by the sucker heating lamps and the fans used for evaporative cooling. It is assumed the sucker heating lamps in the farrowing sheds are active 5,000 hours per annum consuming approximately 120,000 kWh of electricity.

Figure 7, below, is a graphical representation of the piggery's electricity consumption for 2014. The site half-hourly electricity demand is represented in order, from the highest electricity consumption (175 kW), to lowest (40 kW). Figure 8 shows the hourly variation in electricity demand over the various seasons.

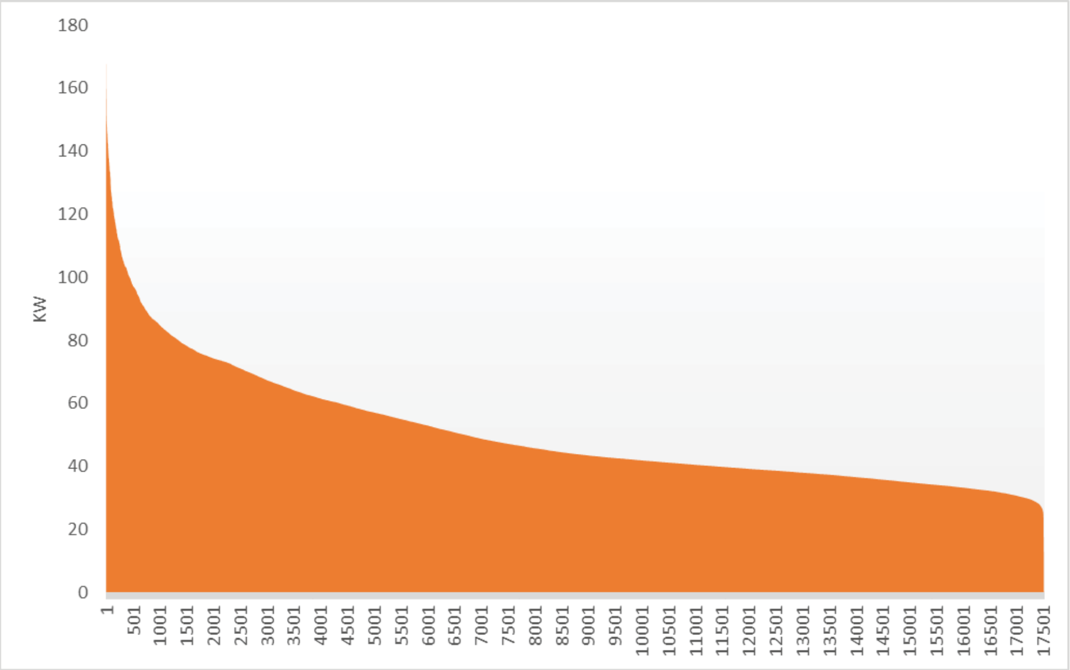

Figure 7. Piggery A electricity demand (half-hourly)

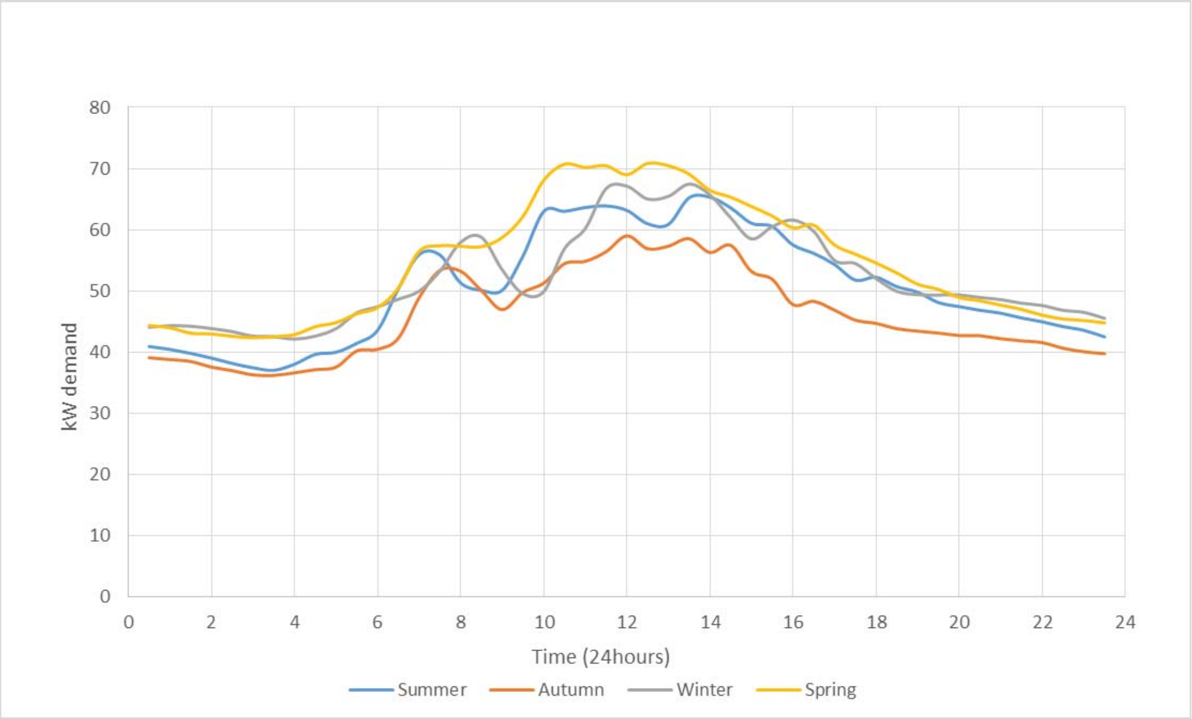

Figure 8. Seasonal variation in electricity demand

A1.4 Piggery biogas potential

Estimates for Piggery A methane production were produced based on the piggery shed effluent being discharged into a new Covered Anaerobic Lagoon (CAL) specifically designed and constructed to suit the current piggery operation. It was assumed that a solids separation device (such as the existing static rundown screen) will remove 25% of the volatile solids (VS) flushed from the sheds, prior to discharge into the CAL. The biogas, methane and energy potential estimated in Table 1, below, are considered 'possible'. Further details and the 'conservative' estimates are provided in Appendix I.

Table 1. 'Possible' piggery biogas potential estimates.

Description	Units	Hourly*	Annual
Sows	Quantity	1,300	1,300
Piggery operating capacity	SPU	8,352	8,352
Volatile Solids (VS)**	t	78.6	689,040
Biogas production rate	m^3 biogas	36.2	316,958
Methane collection	m^3 CH_4	23.5	206,023
Energy	kWh	242	2,119,920
Energy	GJ	0.87	7,632
CO_2-e	kg	335	2,935,086

A1.5 Existing lagoons

Piggery A currently has both a primary lagoon and secondary lagoon in operation. Both lagoons were visually inspected and feedback from the farm manager indicated the primary lagoon had been desludged within the last two years. It appeared that the existing primary lagoon was designed for a lower VS loading rate and longer retention time than required for a CAL. The approximate dimensions of the existing and proposed lagoons are provided in the next section.

Figure 9. Piggery primary and secondary lagoons

A2. Covered anaerobic lagoon (CAL)

Federal Government estimates in 2012 suggested 690 piggeries in Australia may be able to capture and destroy methane. Research also suggests that by 2017, methane emitted by 15-20% of the Australian pig herd will be captured and destroyed, increasing to 25-30% by 2020. (Tait, 2014). These estimates suggest CALs (or in some instances engineered digesters) will become a Business-as-Usual (BAU) scenario for many Australian piggeries. This section addresses the first stage in any Waste-to-Energy project, methane collection and destruction in a Covered Anaerobic Lagoon.

A2.1 Covering an existing primary lagoon

Piggery A has both a primary and secondary lagoon on-site, as noted in the previous section. This feasibility study has estimated the costs of covering the existing primary lagoon to then flare the methane. This activity could create Australian Carbon Credit Units (ACCUs) which attract payments from the Federal Government (or potentially a secondary market) for carbon abatement.

Covering an existing primary lagoon can potentially avoid earthworks costs associated with the construction of a new Fit-for-Purpose lagoon, as earthworks are expected to account for just under half the estimated construction cost of a CAL. Further consideration suggested that covering an existing lagoon for methane destruction had the following additional limitations:

- the size, shape and depth (including bottom contour) of the existing primary lagoon may not be suitable for optimal methane production
- depending on the cover design, retrofitting an existing lagoon with a cover may be more costly per m^2 than a new cover (Skerman & Collman, 2012).

A2.2 Existing lagoon and fit-for-purpose comparison

As outlined in Table 2, below, it was concluded that constructing a new Fit-for-Purpose CAL would be more cost effective than covering the existing primary lagoon at Piggery A. This is partly due to the existing primary lagoon having a much greater surface area than required for a CAL. Furthermore, the costs incurred to desludge the existing primary lagoon (estimated at $20,000) would need to be accounted for in the retro-fit option.

Table 2. Comparison of costs involved in retro-fitting a cover on the existing primary lagoon and installing a new 'fit-for-purpose' CAL.

Description	Existing Primary Lagoon	Fit-for-Purpose Lagoon
Length at full storage level (m)	115	110
Width at full storage level (m)	85	31
Surface Area (m^2)	9,775	3,348
Cover Area (m^2)	10,585	4,041
Estimated cost to Excavate and Cover	$335,000	$248,000

The costs outlined above do not take into account likely additional excavation costs to retro-fit an existing lagoon nor does it take into account risks associated with lagoon cover retro-fits.

In addition to lagoon and cover construction, all covered lagoons require a flare, safety and monitoring equipment. The table below outlines the total estimated costs for a CAL with associated methane destruction and safety apparatus.

Table 3. Fit-for-Purpose CAL costing estimates.

Activity	Description	Cost
Lagoon design and construction earthworks	10,158 m^3	$115,784
Supply and install lagoon cover	4,041 m^2	$132,219
Supply and install flare and control/monitoring system	Includes Development Application	$64,932
Total Cost		$313,000

A2.3 CAL operating costs and benefits

Capture and destruction of methane through the use of a CAL can attract a financial benefit through the Federal Government's Emissions Reduction Fund (ERF) policy. Through a reverse auction, a new carbon abatement project can 'sell' Australian Carbon Credit Units (ACCUs) to the Federal Government. ACCUs will only be generated for the initial seven years of a methane destruction project. The first auction has recently closed and the average price per tonne of carbon abatement was $13.95 (Clean Energy Website). For the purposes of this feasibility study a price of $10/tonne CO_2-e has been assumed for remaining auctions in 2015.

Table 4. Estimated benefits of Emission Reduction Fund (ERF) from capturing and destroying methane ('possible' scenario).

Activity	Description	Annual Benefit to Owner
Annual ERF participation and ACCU Creation	2,884 tonnes of CO_2-e destroyed	$28,884
Total Project Returns from ACCU creation	Initial seven years of Project	$201,880

A CAL also attracts additional operating costs relative to an uncovered lagoon. It is estimated an industry best practice lagoon cover (made from low-density polyethylene (LDPE) or polypropylene (PP)) will need replacement after 10 years in operation. Sludge management may be more labour intensive and costly due to the cover (relative to an uncovered lagoon). Two audits must be conducted where ACCUs are being created during the first seven years of the project.

Table 5. Estimates of CAL operating costs

Activity	Description	Annual Average Operating Expenditure
Lagoon Cover replacement	Replacement every 10 years	$13,000
Sludge Management	Periodic extraction	$10,000
Daily inspection	15 minutes visual inspection	$1,000
ERF Auditing	Twice in seven years	$2,285
Total Operating Expenditure	Annualised	$26,285

There are additional benefits associated with covering a lagoon including odour reduction. Covering a lagoon can decrease odour emission by up to 90% (Tucker et al., 2010). This odour reduction may have a positive effect on neighbours and may also allow a piggery future expansion plans.

A3. Waste-to-Energy project comparisons

In the Australian pork industry, Waste-to-Energy projects involve collecting the biogas produced from anaerobic digestion of the effluent discharged from piggery sheds. This effluent consists of manure, shed flushing and hosing water (which may include some recycled effluent), waste drinking water and spilled feed. Following collection of the biogas, the most cost effective Waste-to-Energy options may be selected after considering the following factors:

- amount of biogas and methane produced
- heating requirements of the site
- cooling requirements of the site
- electricity demand of the site.

Options currently being used by the Australian pork industry include:

- on-site electricity generation
- piglet nest heating.

Additional options considered in this study include:

- shed cooling
- chilled drinking water
- cool-sow system.

It is estimated that Piggery A would produce 23.5m^3 of CH_4 or 0.87 GJ per hour on average from a new CAL. This estimate has been used to appropriately size a range of Waste-to-Energy options at the piggery.

This methane potential is sufficient for the on-site thermal solutions discussed in Section 3.1 below, which are also applicable to the subsequent electricity generation solutions.

A3.1 Site thermal solutions

The manager of Piggery A considered sow cooling to be a high priority, piglet nest heating to be a medium priority and shed space cooling to be of low priority.

Heat from the combustion of methane, in either a hot water boiler or cogeneration system, may be used to provide on-farm heating requirements, including shed heating and piglet nest heating.

Utilising the heat from biogas combustion to produce cooling energy (e.g. absorption chilling) for on-farm use, was also investigated. The primary piggery cooling requirements identified in this study included chilling sow drinking water, sow cooling and piggery shed space cooling. These cooling energy uses peak during warmer months.

Mechanical air cooling of sheds was deemed to be difficult to achieve due to the large volume of air requiring cooling and the nature of the ventilation systems required to maintain shed air quality. Chilling lactating sow drinking water to 20°C was considered to be a more cost-effective use of the available energy generated from biogas.

Micro absorption chillers were investigated for converting biogas heat energy into chilled water for use in mechanical air cooling and producing chilled drinking water; however, pricing and technical information was difficult to obtain for micro absorption chillers in the required range (10 to 50 kW). Consequently, it was concluded that absorption chillers were not currently a viable option for on-farm utilisation of piggery biogas and that drinking water is most effectively chilled using an electric chiller. Electric chillers consume a minimal amount of energy (approximately 20 kWh per pig per annum), and can be installed at a relatively low capital cost, either through retro-fitting or new installation. Providing electric chillers are powered using excess electricity generated on-site from biogas, this option represents an effective use of a renewable energy resource. However, it should be noted that this assumption may not be valid in cases where there is insufficient on-site electricity generated from biogas to satisfy all on-site demands and in cases where the electric chiller electricity consumption reduces export to the grid.

Evaporative cooling may be less effective at Piggery A due to the consistently high levels of humidity.

Table 6 below outlines the costs associated with the thermal solutions recommended for Piggery A. These options are described in more detail in the following sections.

A3.1.1 Chilled drinking water

Willis and Collman (2007) found that sows provided with chilled drinking water during hot weather consumed 6.6 L more water and 0.252 kg more feed per day than a control group. In the same study the weaning weight of piglets was 0.7 kg higher amongst litters where sows were provided chilled drinking water. It was estimated by the authors of this study that the increase in weaning weight from providing chilled drinking water would have an economic benefit of $61/sow/year. This includes the cost of the additional feed.

Simon Green Energy (SGE) estimates the cost of integrating a chilled drinking water system in sow crates to be $98 per crate. This includes a 2 kW Summit Matsu electric chiller, water storage tank and installation. Due to the simplistic nature of this solution, it is assumed the cost to install is equivalent for a new build and a retro-fit.

A3.1.2 Sow cooling

Wagenberg *et al*. (2006) found that providing cooling for lactating sows via Chilled Water (CHW) pipework under the pens had a positive impact on reducing sow body temperatures. The cool-sow system was found to “remove, on average 107 Watts of heat per pen, of which approximately 58 Watts was directly removed from the sow’s body”. The sow cooling also had a positive correlative effect on sow feed intake. As the sows ate more during hot weather, their piglets also grew 20 grams per day faster than piglets in the control group. It is assumed the benefit of the cool-sow system may be $42.50/sow/year. It should be noted that this study was conducted under Dutch conditions.

SGE estimates the cost of integrating the cool-sow system to be $515 per farrowing crate, including an 18 kW Matsu electric chiller, water storage tank and installation. While the above estimates suggest that this option produces only a modest RoI of 8%, animal welfare considerations may elevate the priority for implementing this option in warm climates.

While the combined effects of installed both the chilled drinking water and cool-sow system are unknown, in this study, it has been assumed that the benefits are additive. If this proves to be an incorrect assumption, the chilled drinking water option provides a considerably higher RoI at a lower capital cost, and would therefore be a more attractive option.

A3.1.3 Piglet nest heating

Piggery A which is located in Northern NSW generally experiences warm, humid climatic conditions throughout much of the year. A single 100W infrared heat lamp has been installed in each farrowing crate for zone heating piglets. Use of these electric heat lamps could be offset by installing an under-floor hydronic piglet heating system. In this type of system, hot water from a biogas boiler or cogeneration system is circulated through under-floor heating pads installed in each farrowing pen. An example of this type of system is the Reventa Thermo Plus piglet nest heating system. SGE estimates the cost of installing Thermo-Plus heating pads to be $504 per farrowing crate. This cost includes flow and return pipework but does not include any heat source.

Figure 10. Reventa Thermo-Plus piglet nest heating.

The installation of piglet nest heating is expected to reduce electricity consumption from the heat lamps by 90%, assuming that the heat lamps may still be required on the coldest nights. Therefore, after installing the new piglet heating system, it is estimated that the electricity demand at Piggery A will be reduced by 108,000 kWh, from 445,000 kWh to 337,000 kWh.

Table 6. Costs and benefits of thermal solutions (cost per unit does not include tallow tank heating).

Activity	Description	Cost per unit	Total Cost	First year returns	Return on Investment
Piglet heating	240 farrowing crates	$504	$120,960	$24,300	20%
Sow chilled drinking water	240 farrowing crates	$98	$23,520	$14,640	62%
Cool-sow system	240 farrowing crates	$515	$123,000	$10,200	8%
Tallow tank heating	Heating to 60°C continuously	$2,856	$2,856	$3,154	110%
Total	Includes installation	$1,117*	$270,936	$49,140	18%

A3.2 Yanmar cogeneration systems

Yanmar 25 kW biogas driven micro combined heat and power (CHP) units could be installed modularly to increase total electrical and heat output on the piggery site. Options involving installing both 2 x 25 kW and 3 x 25 kW units are compared below. The Yanmar systems are able to load-follow site electricity demand but it is assumed these systems are not run below 10 kW output. There are some synergistic benefits associated with installing and operating multiple Yanmar CHP units. The installation, commissioning and maintenance costs, per kW installed, are lower for multiple units in comparison to a larger single unit.

A3.2.1 Capital expenditure

The estimated capital costs for the installation of Yanmar 50 and 75 kW CHP systems are outlined in Table 7.

Table 7. Estimated capital cost comparison for Yanmar 50 kW and 75 kW CHP systems.

Activity	Description	Capital Expenditure 2 x 25 kW	Capital Expenditure 3 x 25 kW
Biogas conditioning	Chiller, ferric oxide scrubber, knock out pot & plant room	$66,120	$66,120
Cogeneration System		$140,400	$207,600
Installation & commissioning	Mechanical & electrical integration to site	$79,200	$117,600
Total Cost ex GST		$285,720	$391,320

A3.2.2 Project cash-flows

The estimated operating costs for the Yanmar 50 and 75 kW CHP systems are outlined in Table 8.

Table 8. Estimated annual operating cost comparison for Yanmar 50 kW and 75 kW CHP systems, (including annualised overhaul costs)*.

Activity	Description	Annual operating cost 2 x 25 kW	Annual operating cost 3 x 25 kW
Cogeneration maintenance	Oil Change, consumables	$7,917	$9,412
Cogeneration overhauls*	Changing heads, boring cylinders, rebuilds	$10,557	$12,550
Biogas treatment system maintenance	General maintenance & ferric oxide replacement	$7,639	$8,137
Total Operating Expenditure (Opex)		$26,113	$30,100

Cogeneration maintenance and overhauls are calculated per kWh output. The smaller system produces less kWh per annum and hence the maintenance costs are almost half the larger system. However, the total amount energy produced per unit is actually less for the larger system and hence the annualised overhaul cost is quite similar to the smaller system.

Table 9. Estimated annual financial benefit for Yanmar 50 kW and 75 kW CHP systems.

Activity	Description	Annual Benefit 2 x 25 kW	Annual Benefit 3 x 25 kW
Electricity generation utilised on-site	$0.25/kWh	$65,980 (263,918 kWh annually)	$78,439 (313,754 kWh annually)
Renewable Energy Certificates	kWh*0.9*$0.0395	$9,382	$11,154
Total project returns		$75,362	$89,592

Figure 11 below shows the site’s baseline electricity demand (red dashed line), the estimated new demand for power after the installation of piglet nest heating, and the power generated by 2 x 25 kW Yanmar cogeneration units (green). The remaining electricity (orange) will be supplied and purchased from the gird.

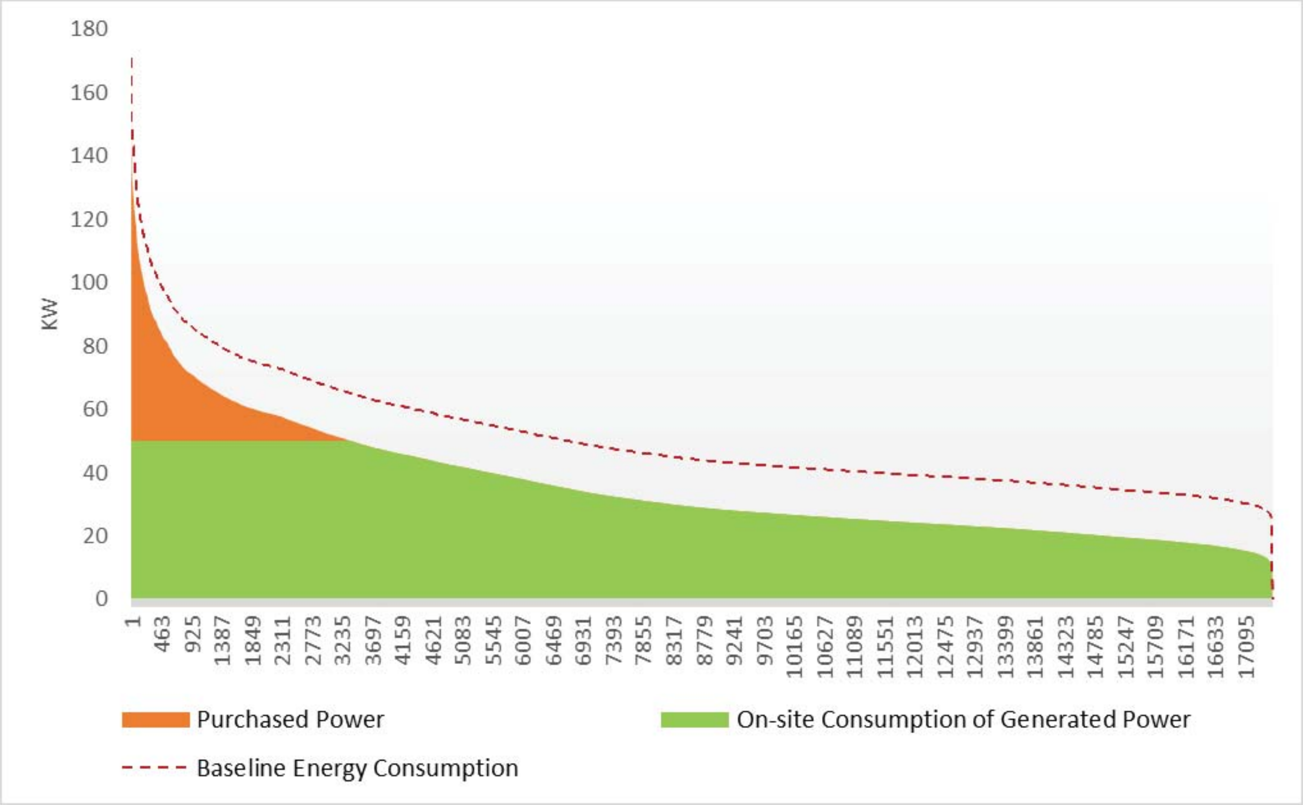

Figure 11. New electricity demand and on-site generation

Table 10. Comparison of cost, benefit and Return on Investment for Yanmar 50 kW and 75 kW CHP systems.

Activity	Capital Expenditure	Operating Expenditure	Benefit	Net Benefit	Return on Investment
Yanmar 2 x 25 kW incl biogas conditioning	$285,720	$26,113	$75,362	$49,248	17%
Yanmar 3 x 25 kW incl biogas conditioning	$391,320	$30,100	$89,592	$59,492	15%

The increased kWh of electricity supplied to the site from the third Yanmar 25 kW does not create enough added benefit to outweigh the cost of installing the additional unit. Therefore the smaller 50 kW system appears to be the optimal size for on-site electricity generation (for on-site use only). Please note that the figures above do not take into account thermal integration. The total project returns, including thermal integration will be discussed in the conclusion of this feasibility study.

A3.3 Ener-G 80 kW cogeneration system

The largest cogeneration system possible at Piggery A (based on the estimated methane production from a new CAL and near-continuous operation) is an 80 kW system. The Ener-G 80 kW cogeneration system is unable to produce electricity below 50% of nameplate capacity (40 kW) and operates optimally no lower than 75% of nameplate capacity (60 kW). This is typical of most cogeneration systems running on either natural gas or biogas.

After accounting for the reduction in electricity demand to supply the electric heat lamps (following the installation of the Thermo-Plus piglet nest heating) the new site electricity demand is estimated to be less than 60kW most of the time, as shown in Figure 12. Without the capability of electricity export to the grid, the 80 kW cogeneration system can only operate 10% of the time. Therefore, to effectively utilise all of the methane produced on-site, the Ener-G 80 kW cogeneration system must export electricity.

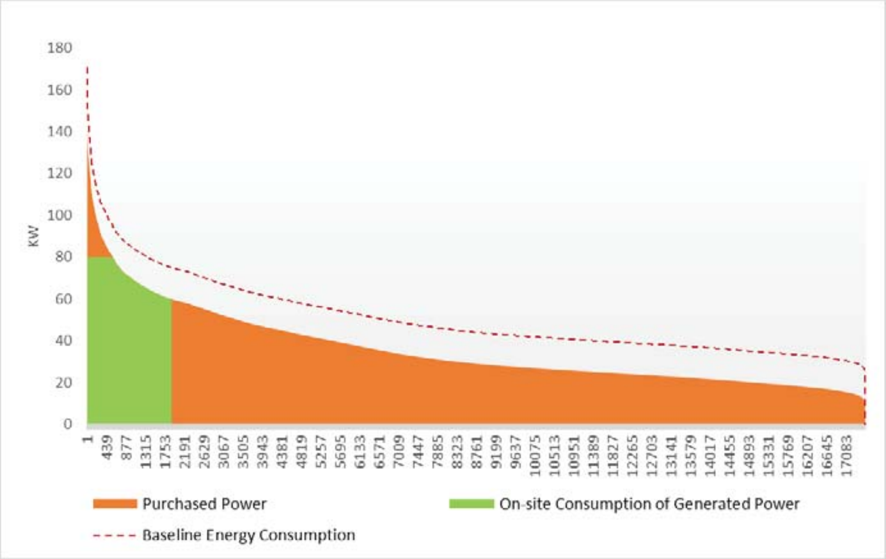

Figure 12. Estimate of Ener-G 80 kW CHP system operation with no electricity export.

A3.3.1 Capital costs

The estimated capital costs associated with installing the Ener-G 80 kW Cogeneration System are outlined in Table 11.

Table 11. Estimated capital costs for installing the Ener-G 80 kW Cogeneration system.

Activity	Description	Cost
Biogas Conditioning	Chiller, ferric oxide scrubber, knock-out pot & plant room	$66,120
Cogeneration System	80 kW generation capacity	$201,600
Installation & Commissioning	Mechanical & electrical integration to site	$90,000
Total Cost ex GST		$357,720

A3.3.2 Operating costs

The estimated annual operating costs for the Ener-G 80 kW Cogeneration system are outlined in Table 12.

Table 12. Estimated annual operating costs for the Ener-G 80 kW Cogeneration system

Activity	Description	Annual Cost to Owner
Cogeneration Maintenance	Oil change, consumables	$18,921
Cogeneration overhauls*	Changing heads, boring cylinders, rebuilds	$6,572
Biogas system Maintenance	General maintenance & ferric oxide replacement	$11,307
Total Operating Expenditure (Opex)		$36,800

A3.3.3 Project returns

Market research suggests the prevailing contracts for on-site electricity generation exported to the grid attracts relatively low returns per kWh. Retailers may pay a ‘pool price pass through’ where exported electricity is valued at the registered pool price for the half-hour exported (up to $0.30/kWh). Based on average spot prices in 2014 (adjusted for the most recent carbon policy), it seems likely that exported electricity may not receive more than $0.03/kWh on average.

The estimated annual project returns for the Ener-G 80 kW cogeneration system are outlined in Table 13.

Table 13. Estimated annual project returns for Ener-G 80 kW cogeneration system.

Activity	Description	Project returns
Electricity generation utilised on-site	278,544 kWh	$75,825
Exported electricity	352,176 kWh*$0.025	$9,822
Renewable Energy Certificates	630,720 kWh*0.9*0.0395	$22,422
Total project returns		$108,070

Figure 13, below, shows the site’s electricity baseline demand (red dashed line), the new demand for power (after the installation of piglet nest heating), electricity generated for on-site consumption (green area) and electricity exported and sold to the grid (blue area). The remaining electricity (orange) will be supplied and purchased from the gird.

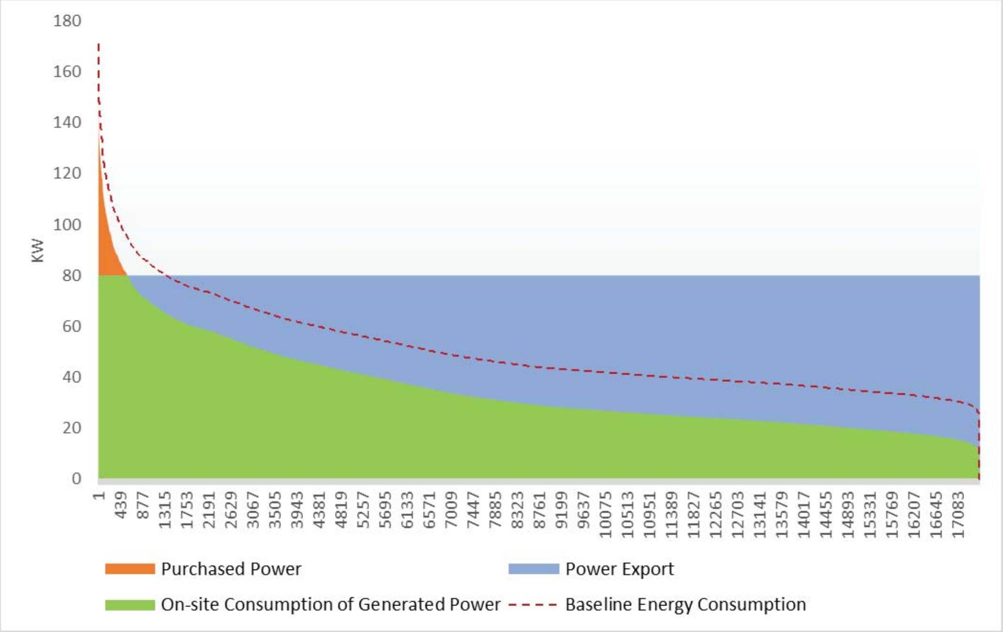

Figure 13. New site electricity demand and on-site generation

As outlined in Table 14, the Ener-G 80 kW system will satisfy most of the electricity demand on-site while exporting electricity to the grid. Due to the increased operating hours of both the cogeneration system and the biogas scrubber the operating costs will increase accordingly.

Table 14. Estimated costs, benefits and return on investment for Ener-G 80 kW cogeneration system.

Activity	Capital Expenditure	Operating Expenditure	Benefit	Net Benefit	Return on Investment
Ener-G 80 kW & biogas conditioning	$357,720	$36,800	$108,070	$71,270	20%

A3.4 Scenario comparison & conclusion

Table 15 provides a comparison of costs and returns associated with the 2 x 25 kW Yanmar and Ener-G 80 kW cogeneration system options. Please note, the cost of thermal integration and benefits of thermal utilisation are included in the table below.

Table 15. Comparison of costs and returns associated with the 2 x 25 kW Yanmar and Ener-G 80 kW cogeneration system options.

Item	2 x 25 kW Yanmar	80 kW Ener-G
Total capital expenditure cogeneration & thermal integration	$511,976	$583,976
Cost per kWe installed (cogeneration only)	$5,714	$4,472
Net project returns electricity generation & thermal offset	$105,885	$120,156
Return on Investment (RoI)	17.6%	19.1%

The Yanmar system (2 x 25 kW) with thermal integration produces enough electricity to satisfy 85% of total site electricity demand. The system does not export electricity but produces the required amount of heat to meet the site's thermal requirements. There is also sufficient electricity generation to supply chilled water cooling for the sows. The total project RoI is estimated at 17.6% (not including the CAL construction costs or ERF subsidy).

The Ener-G 80 kW system with thermal integration produces enough electricity to satisfy almost all of the total site electricity demand. The system also exports electricity to the grid and produces enough thermal energy for the thermal integration solutions. The total project RoI is estimated at 19.1% (not including the CAL construction costs or ERF subsidy).

The additional revenue resulting from installing the 80 kW cogeneration system and exporting electricity to the grid (including RECs) allows the system to satisfy more on-site electricity demand than the smaller 50 kW system. The larger system also has a lower cost per kW to install. These attributes of the larger system will provide a higher RoI than the smaller 50 kW system. The electricity exported at $0.03/kWh is estimated to offset the increased maintenance and ferric oxide replacement but is not likely to provide additional RoI. Should incentives and prevailing commercial terms and conditions change, the 80 kW system may have an increased RoI in the future.

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Appendix I Estimates of conservative and possible production of volatile solids, biogas, methane, thermal energy and equivalent CO_2 emissions.

Parameter	Units	Conservative	Possible
VS from sheds	kg VS/SPU/yr	90	110
	t VS/yr	752	919
VS removal in solids separator	%	25	25
VS to CAL	t VS/yr	564	689
Biogas production rate	m^3 biogas/kg VS added	0.43	0.46
Biogas production	m^3 biogas/yr	242,417	316,958
Biogas methane content	%	65	65
Methane (CH_4) production rate	m^3 CH_4/kg VS	0.28	0.30
Methane (CH_4) production	m^3 CH_4/yr	157,571	206,023
Methane lower heating value (LHV)	MJ/Nm^3 CH_4	33.35	33.35
Methane thermal energy	GJ/yr	5,255	6,871
	kW.hr/yr	1,459,793	1,908,670
CO_2 emissions	t CO_2-e/yr	2,245	2,935

Appendix II Assumptions used in calculating the required dimensions for a 'fit-for-purpose' CAL to service the Piggery A.

Parameter	**Units**	**Values**
Possible VS discharge to CAL	t VS/yr	689
Anaerobic pond activity ratio, k		0.92
Baseline VS loading rate	kg VS/m^3/day	0.4
Adjusted VS loading rate	kg VS/m^3/day	0.368
Treatment volume	m^3	5,126
Assumed VS/TS ratio		0.83
Estimated TS to pond	kg TS/day	2,273
Sludge accumulation rate	m^3/kg TS	0.00303
Desludging interval	years	2
Required sludge storage volume	m^3	5,031
Total storage volume	m^3	10,157
Total storage volume per SPU	m^3/SPU	1.22
Total storage depth	m	6
Batter - lengthwise, (1 vertical : Z horizontal)		2
Batter - breadthwise, (1 vertical : Z horizontal)		2
Freeboard - full storage level to crest	m	0.5
Length - at embankment crest	m	110.00
Breadth - at embankment crest	m	31.13
Length - at full storage level	m	108.00
Breadth - at full storage level	m	29.13
Length - at base	m	84.00
Breadth - at base	m	5.13
Cover additional anchorage allowance	m	2
Cover length	m	114.24
Cover breadth	m	35.37
Cover area - trenched into bank	m^2	4,041

Piggery B

B1. Site appreciation

Piggery B is located in the Upper Burnett region of Queensland. This region is characterised by the owner as a hot and dry climate with summer maximum daily temperatures commonly near or above 40°C and winter minimum temperatures commonly below 0°C. Air humidity is low throughout the year.

Piggery B is characterised as a breeder unit accommodating 997 sows and 2,143 standard pig units (SPU). Weaned piglets are transported to an off-site grower unit at an age of approximately 24 days. All pigs on the Piggery B are housed in conventional flushed sheds with partial or fully slatted floors. The property has a primary lagoon and a secondary effluent storage lagoon. Treated effluent from the secondary lagoon is used for shed flushing and applied to land growing a range of agricultural crops. This piggery also has on-site feed milling and storage facilities which are used to supply two additional piggery units operated by the piggery owners within the general vicinity of Piggery B. An aerial photograph of the piggery is provided in Figure 1.

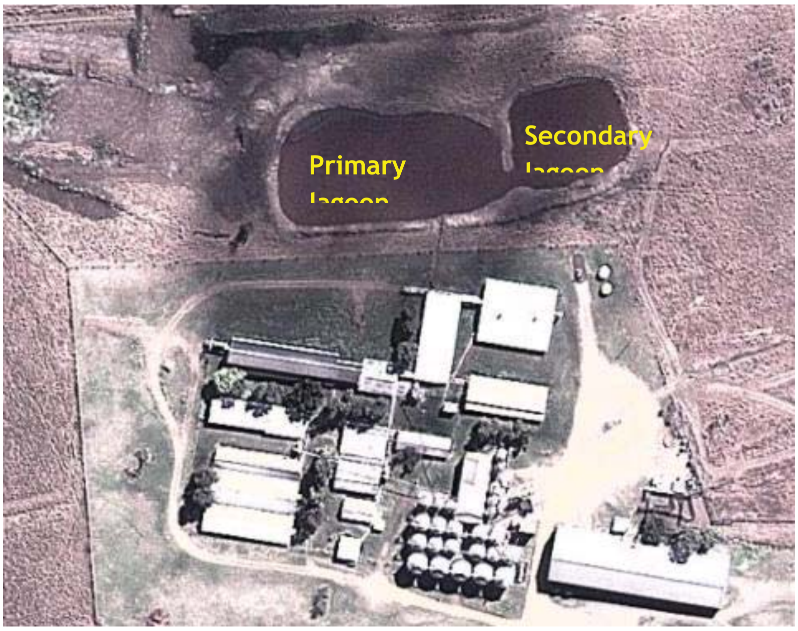

Figure 1. Aerial photograph of Piggery B (photo from Google Maps).

Site energy consumption includes electricity supplied for the operation of the feed mill, evaporative cooling fans and heat lamps for the piglets. LPG is also used for radiant heating in the sheds on the coldest nights.

B1.1 Project objectives

Discussions with the piggery manager identified the following project objectives:

- reduce on-farm energy costs
- institute best practice for resource use and energy efficiency
- cover lagoons to reduce odour emissions and improve the likelihood of obtaining an approval for the expansion of the piggery.

B1.2 Sheds

The sows are housed in conventional farrowing and gestating sow sheds. Heating and cooling systems provide conditions suitable for the age of pigs housed in these sheds. At 24 days of age the weaners are transported off-site to a grower farm and hence weaner and grower accommodation is not required at Piggery B.

B1.2.1 Farrowing sheds

There are a total of 200 farrowing crates in two farrowing sheds at Piggery B. The farrowing sheds are mechanically ventilated with evaporative cooling pads (Figures 4). For the comfort of the sows, the farrowing shed temperature is ideally maintained within the range from 18 to 20°C; however, this may increase to 25°C during summer.

Heating requirements for the farrowing sheds are as follows:

- 1 x 100W heat lamps operating continuously on electricity, installed in the creep areas of each farrowing crate. Heat lamps will provide zone heating from 32°C for new-born piglets to 28°C at weaning (see photo below).

- Shed space heating in the farrowing shed is provided by LPG-fired radiant heaters. These heaters are activated when shed ambient temperatures go below 18°C.

The heat lamps and radiant heaters are controlled thermostatically based on sensor readings in the creep areas and throughout the farrowing sheds, respectively. While there is significantly more energy consumption for heating during winter some heating is still required during summer, mostly in the creep areas. However, radiant shed space heating may be required on the coldest summer nights. The creep areas are covered at Piggery B, as shown in Figure 2.

It is estimated that the sucker heating lamps in the farrowing sheds are active 6,000 hours per annum (68% of the time) consuming approximately 120,000 kWh of electricity.


Figure 2. Piglet nest with creep cover.


Figure 3. Farrowing crates.


Figure 4. Farrowing shed evaporative cooling pads.

B1.2.2 Gestating sow sheds

The gestating sows are housed in naturally ventilated sheds which are equipped with fans to provide additional cooling during hot weather, as shown in Figure 5.


Figure 5. Naturally ventilated dry (gestating) sow shed with additional cooling fans.

B1.3 Site energy consumption

B1.3.1 Site electricity consumption

The site consumes approximately 352,000 kWh of electricity per annum based on the 2014 records provided by the utility company. The greatest electricity consumption comes from the mill, while fans (for evaporative cooling) and piglet heating equally contribute to the remaining site demand. It is assumed the sucker heating lamps in the farrowing sheds are active 6,000 hours per annum utilising 120,000 kWh.

Figure 6, below, is a graphical representation of the piggery electricity consumption for 2014 based on monthly utility bills provided by the owner.

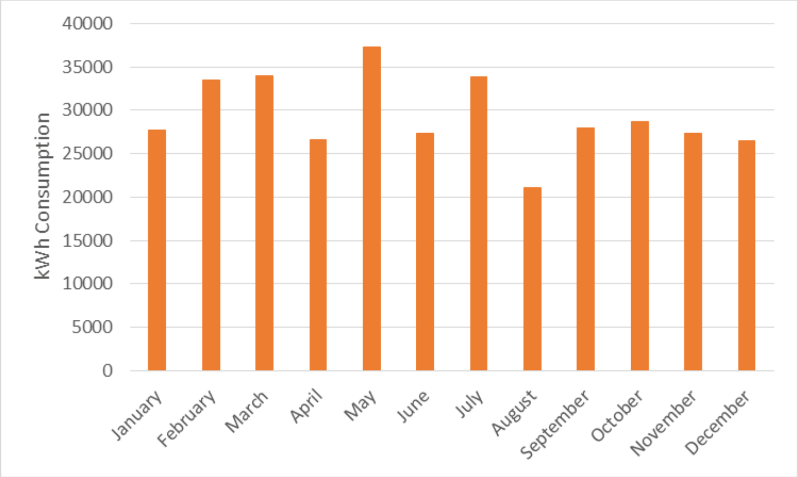

Figure 6. Monthly electricity consumption at Piggery B.

Figure 7 is a graphical representation showing the piggery's electricity consumption for 2014. The half-hourly consumption is represented in order of the highest (95 kW) to the lowest (13 kW) electricity consumption. This data has been extrapolated from three months of National Metering Identification (NMI) data provided by the utility company.

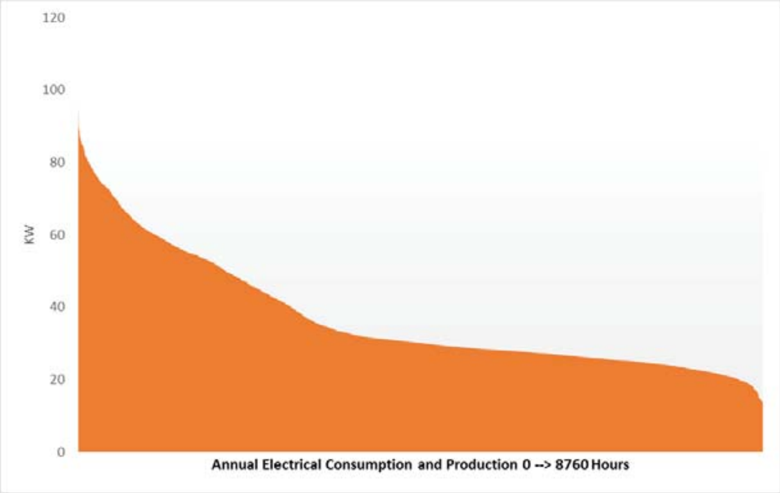

Figure 7. Site half-hourly electricity demand graph.

B1.3.2 Site LPG consumption

Piggery B consumes LPG to supply radiant heaters during winter when shed ambient temperatures are below 18°C. Utility bills indicated that approximately 200 litres of LPG is consumed annually for shed heating. Shed heating is required primarily overnight during winter.

B1.4 Piggery biogas potential

Estimates for Piggery B methane production have been provided based on the piggery shed effluent being discharged into a new Covered Anaerobic Lagoon (CAL) specifically designed and constructed to suit the current piggery operation. It has been assumed that a solids separation device (such as a static rundown screen) will remove 25% of the volatile solids (VS) flushed from the sheds, prior to discharge into the CAL. The biogas, methane and energy potential estimated in the table below are considered ‘possible’. Further details and ‘conservative’ estimates are provided in Appendix I.

Table 1. Piggery B biogas and methane potential.

Description	Units	Hourly*	Annual
Sows	Quantity	997	997
Piggery operating capacity	SPU	2,143	2,143
Volatile Solids (VS)	kg	20.2	177,000
Biogas production rate	m^3 biogas	9.3	81,450
Methane collection	m^3 CH$_4$	6.04	52,961
Energy	kWh	62	489,737
Energy	GJ	0.,22	1,763
CO$_2$-e	kg	84.5	740,000

*figures have not been seasonally adjusted

B1.5 Existing lagoons

Piggery B has both a primary and secondary lagoon in operation, as shown in Figures 9 and 10. Both lagoons were visually inspected and the farm manager indicated that the primary lagoon had been desludged within the last five years. It appeared that the existing primary lagoon was designed for a lower VS loading rate and longer retention time than required for a CAL. The approximate dimensions of the existing and proposed lagoons are provided in the next section.

Figure 8. Piggery B primary lagoon

Figure 9. Piggery B secondary lagoon

B2. Covered anaerobic lagoon (CAL)

Federal Government estimates in 2012 suggested 690 piggeries in Australia may be able to capture and destroy methane. Research also suggests that by 2017, methane generated by 15-20% of the Australian pig herd will be captured and destroyed, increasing to 25-30% by 2020. (Tait, 2014). These estimates suggest CALs (or in some instances engineered digesters) will become a Business-as-Usual (BAU) scenario for many Australian piggeries. This section addresses the first stage in any Waste-to-Energy project, methane collection and destruction in a CAL.

B2.1 Covering an existing primary lagoon

Piggery B has both a primary and secondary lagoon on-site, as noted in the previous section. This feasibility study has estimated the costs of covering the existing primary lagoon to then flare the methane. This activity could create Australian Carbon Credit Units (ACCUs) which attract payments from the Federal Government (or potentially a secondary market) for carbon abatement.

Covering an existing primary lagoon can potentially avoid earthworks costs associated with the construction of a new Fit-for-Purpose lagoon, as earthworks are expected to account for just under half the estimated construction cost of a CAL. Further consideration suggested that covering an existing lagoon for methane destruction had the following additional limitations:

- the size, shape and depth (including bottom contour) of the existing primary lagoon may not be suitable for optimal methane production
- depending on the cover design, retrofitting an existing lagoon with a cover may be more costly per m^2 than a new cover (Skerman & Collman, 2012).

B2.1.1 Existing and Fit-for-Purpose lagoon comparison

As outlined in Table 2, below, it was concluded that constructing a new Fit-for-Purpose CAL would be more cost effective than covering the existing primary lagoon at Piggery A. This is partly due to the existing primary lagoon having a much greater surface area than required for a CAL. Furthermore, the costs incurred to desludge the existing primary lagoon (estimated at $20,000) would need to be accounted for in the retro-fit option.

The costs outlined above do not take into account likely additional excavation costs to retro-fit an existing lagoon nor does it take into account risks associated with lagoon cover retro-fits.

In addition to lagoon and cover construction, all covered lagoons require a flare, safety and monitoring equipment. Table 3, below, outlines the total estimated costs for a CAL with associated methane destruction and safety apparatus.

Table 2. Comparison of costs involved in retro-fitting a cover on the existing primary lagoon and installing a new 'fit-for-purpose' CAL.

Description	Existing Primary Lagoon	Fit-for-Purpose
Length (m)	75	36
Width (m)	40	31
Surface Area	3,000	1,116
Cover Area	3,525	1,424
Estimated cost to Excavate and Cover	$136,114	$81,523

Table 3. Fit-for-Purpose CAL costing estimates

Activity	Description	Cost
Lagoon design & construction earthworks	2,551 m^3	$31,000
Supply and install lagoon cover	1,424 m^2	$50,500
Supply and install flare & control/monitoring System	Includes Development Application	$64,932
Total Cost		$146,432

B2.2 CAL Operating Costs and Benefits

Capture and destruction of methane through the use of a CAL can attract a financial benefit through the Federal Government's Emissions Reduction Fund (ERF) policy. Through a reverse auction, a new carbon abatement project can 'sell' Australian Carbon Credit Units (ACCUs) to the Federal Government. ACCUs will only be generated for the initial seven years of a methane destruction project. The first auction has recently closed and the average price for a tonne of carbon abatement is $13.95 (Clean Energy Website). For the purposes of this feasibility study a price of $10/tonne CO_2-e has been assumed for remaining auctions in 2015.

Table 4. Estimated benefits of Emission Reduction Fund (ERF) from capturing and destroying methane ('possible' scenario).

Activity	Description	Annual Benefit to Owner
Annual ERF participation & ACCU Creation	740 tonnes of CO_2-e destroyed	$7,400
Total Project Returns from ACCU creation	Initial seven years of Project	$51,800

A CAL also attracts additional operating costs relative to an uncovered lagoon. It is estimated an industry best practice lagoon cover (made from low-density polyethylene (LDPE) or polypropylene (PP)) will need replacement after 10 years in operation. Sludge management may be more labour intensive and costly due to the cover (relative to an uncovered lagoon). Two audits must also be conducted where ACCUs are being created during the first seven years of the project.

Table 5. Estimates for CAL operating costs

Activity	Description	Annual Average Operating Expenditure
Lagoon Cover replacement	Replacement every 10 years	$5,050
Sludge management	Excavation Every two Years	$5,000
Daily inspection	15 minutes visual inspection	$1,000
ERF Auditing	Twice in seven years	$2,285
Total Operating Expenditure	Annualised	$13,335

Based on the methane destruction potential at Piggery B, the CAL operating expenses outweigh the ERF potential benefits (at $10/t CO_2-e). However, if CALs are to become industry best practice, farm owners may wish to offset some of the operating expenses by entering the auction to create and sell ACCCUs.

There are also additional benefits associated with covering a lagoon including odour reduction. Covering a lagoon can decrease odour emission by up to 90% (Tucker *et al*., 2010). This odour reduction may have a positive effect on neighbours and may also allow a piggery to expand operations in the future.

B3. Waste-to-Energy project comparisons

In the Australian pork industry, Waste-to-Energy projects involve collecting the biogas produced from anaerobic digestion of the effluent discharged from piggery sheds. This effluent consists of manure, shed flushing and hosing water (which may include some recycled effluent), waste drinking water and spilled feed. Following collection of the biogas, the most cost effective Waste-to-Energy options may be selected after considering the following factors:

- amount of biogas and methane created
- heating requirements of the site
- cooling requirements of the site
- electricity demand of the site.

Options currently being used by the Australian pork industry include:

- on-site electricity generation
- piglet nest heating.

Additional options considered in this study include:

- shed Cooling
- chilled drinking water
- cool-sow system.

It is estimated that Piggery B could produce up to 6.06 m^3 per hour of CH_4 or 0.22 GJ of thermal energy every hour on average from a new CAL. This estimate has been used to appropriately size a range of Waste-to-Energy options at the piggery.

This methane potential is sufficient for the on-site thermal solutions discussed in Section 3.1 below, which are also applicable to the subsequent electricity generation solutions.

B3.1 Site thermal solution

B3.1.1 Hot water boiler

The possible methane production at Piggery B equates to approximately 60 kW of continuous thermal energy, on average. Consequently, there should be sufficient biogas energy to run a 50 kW hot water boiler, based on a boiler efficiency of 80%. Hot water from the boiler could be circulated through under-floor hydronic heating pads in the farrowing sheds (as described in the following section, to offset heat lamp electricity consumption.

B3.1.2 Piglet Nest Heating

A single 100W infrared heat lamp has been installed in each of the 200 farrowing crates for zone heating piglets. Use of these electric heat lamps could be offset by installing an under-floor hydronic piglet heating system. In this type of system, hot water from the proposed biogas boiler could be circulated through under-floor heating pads installed in each farrowing pen. An example of this type of system is the Reventa Thermo Plus piglet nest heating system, as shown in Figure 10. Simon Green Energy (SGE) estimates the cost of installing Thermo-Plus heating pads to be $504 per farrowing crate. This cost includes flow and return pipework but does not include the heat source.

Figure 10. Reventa Thermo-Plus piglet nest heating (Reventa website).

The installation of piglet nest heating is expected to reduce electricity consumption from the heat lamps by 75%, assuming the heat lamps may still be required on the coldest nights. Therefore, after installing the new piglet heating system, the electricity demand at Piggery C is expected to decrease by 90,000 kWh (120,000 kWh x .75) resulting in a new site total electricity demand of 262,000 kWh.

B3.1.3 Capital expenditure

Table 6 outlines the estimated capital costs for the installation of a biogas-fired hot water boiler and Thermo-Plus piglet nest heating system.

Table 6. Estimated capital costs for the installation of a biogas-fired hot water boiler and Thermo-Plus piglet nest heating system.

Activity	Description	Cost
Biogas Conditioning	Chiller, knock out pot & plant room	$33,720
Boiler System	50 kW Hot Water Capacity	$18,800
Thermo-Plus	200 sow stalls	$100,800
Installation & Commissioning	Mechanical & electrical integration to site	$15,000
Total Cost ex GST		$168,320

B3.1.4 Boiler Operating Costs

Table 7 outlines the estimated operating costs associated with the installation of a 50 kW biogas-fired hot water boiler.

Table 7. Estimated operating costs for the installation of a 50 kW biogas-fired hot water boiler.

Activity	Description	Annual Cost to Owner
Boiler Maintenance	Service, consumables	$1000
Biogas Chiller operation	Electricity usage	$100
Biogas system Maintenance	General maintenance	$1000
Total Operating Expenditure (Opex)		$2,100

B3.2 Waste-to-Energy scenario conclusion

The most viable Waste-to-Energy option for Piggery B appears to be the installation of a 50 kW biogas boiler to supply hot water for hydronic piglet nest heating.

Figure 11 outlines the expected reduction in electricity consumption following the installation of the proposed hydronic piglet nest heating system to offset heat lamp operation.

Table 8 outlines the estimated total cost, annual returns and return on investment for the proposed on-farm thermal energy utilisation option.

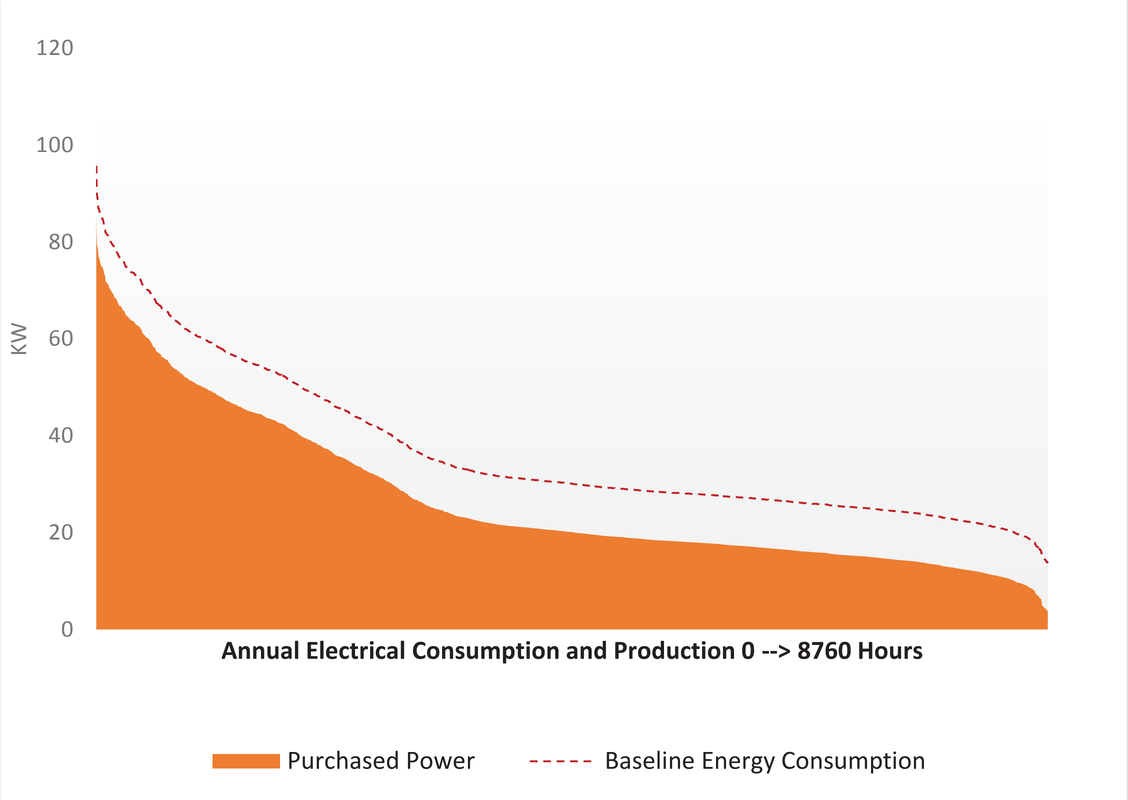

Figure 11. Graph showing the expected reduction in electricity consumption following the installation of the proposed hydronic piglet nest heating system to offset heat lamp operation.

Table 8. Estimated total cost, annual returns and return on investment for the proposed on-farm thermal energy utilisation option.

Activity	Description	Total Cost	Annual net returns	Return on Investment
Biogas boiler & piglet nest heating	200 lactating sow crate integration	$168,320	$20,400 (inc operating costs)	12%

References

Skerman, A. and Collman, G. (2012) Methane recovery and use at Grantham piggery, RIRDC Publication No 12/064, RIRDC Project No PRJ-005672, Rural Industries Research and Development Corporation, Barton, ACT. https://rirdc.infoservices.com.au/items/12-064

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Appendix I Estimates of conservative and possible production of volatile solids, biogas, methane, thermal energy and equivalent CO_2 emissions.

Parameter	Units	Conservative	Possible
VS discharge from sheds	kg VS/SPU/yr	90	110
	t VS/yr	193	236
VS removal in solids separator	%	25	25
VS discharge to CAL	t VS/yr	145	177
Biogas production rate	m^3 biogas/kg VS added	0.43	0.46
Biogas production	m^3 biogas/yr	62,201	81,327
Biogas methane content	%	65	65
Methane (CH_4) production rate	m^3 CH_4/kg VS	0.28	0.30
Methane (CH_4) production	m^3 CH_4/yr	40,430	52,862
Methane lower heating value (LHV)	MJ/Nm^3 CH_4	33.35	33.35
Methane thermal energy	GJ/yr	1,348	1,763
	kW.hr/yr	374,561	489,737
CO_2 emissions	t CO_2-e/yr	576	753

Appendix II Assumptions used in calculating the required dimensions for a ‘fit-for-purpose’ CAL to service the Piggery B.

Parameter	Units	
Possible VS discharge to CAL	t VS/yr	236
Anaerobic pond activity ratio, k		0.96
Baseline VS loading rate	kg VS/m^3/day	0.4
Adjusted VS loading rate	kg VS/m^3/day	0.384
Treatment volume	m^3	1,261
Assumed VS/TS ratio		0.83
Estimated TS to pond	kg TS/day	583
Sludge accumulation rate	m^3/kg TS	0.00303
Desludging interval	years	2
Required sludge storage volume	m^3	1,291
Total storage volume	m^3	2,551
Total storage volume per SPU	m^3/SPU	1.19
Total storage depth	m	6
Batter - lengthwise, (1 vertical : Z horizontal)		2
Batter - breadthwise, (1 vertical : Z horizontal)		2
Freeboard - full storage level to crest	m	0.5
Length - at embankment crest	m	36.00
Breadth - at embankment crest	m	31.15
Length - at full storage level	m	34.00
Breadth - at full storage level	m	29.15
Length - at base	m	10.00
Breadth - at base	m	5.15
Cover additional anchorage allowance	m	2
Cover length	m	40.24
Cover breadth	m	35.38
Cover area - trenched into bank	m^2	1,424

Piggery C

C1. Site Appreciation

Piggery C is located in the Upper Burnett region of Queensland. This region is characterised by the owner as a hot and dry climate with summer maximum daily temperatures commonly near or above 40°C and winter minimum temperatures commonly below 0°C. Air humidity is low throughout the year.

Piggery C is characterised as a farrow to finish unit with 677 sows and 7,479 Standard Pig Units (SPU). All pigs are housed in conventional flushed sheds with partially or fully slatted floors. The property has a primary lagoon and a secondary effluent storage lagoon. Treated effluent from the secondary lagoon is used for shed flushing and applied to land growing a range of agricultural crops. An aerial photograph of the piggery is provided in Figure 1.

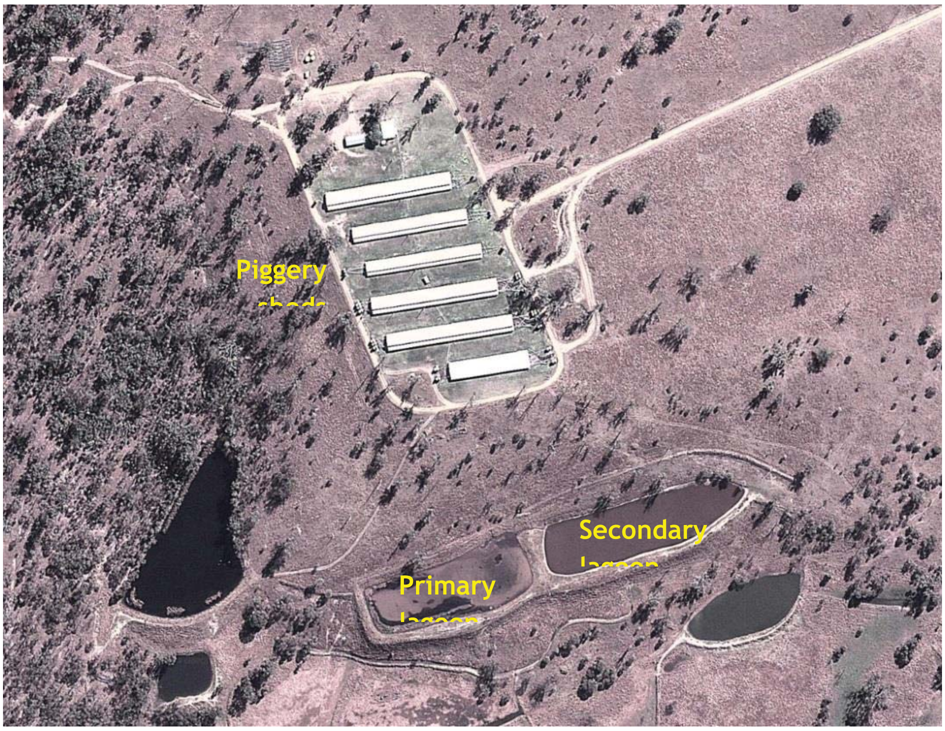

Figure 1. Aerial photograph of Piggery C (from Google Maps).

Site electricity consumption is primarily used to supply fans for evaporative cooling in sheds and heat lamps for piglet nest heating.

C1.1 Project Objectives

Discussions with the piggery manager identified the following project objectives:

- reduce on-farm energy costs
- institute best practice for resource use and energy efficiency
- cover lagoons to reduce odour emissions and improve the likelihood of obtaining an approval for the expansion of the piggery.

C1.2 Sheds

The sows are housed in conventional farrowing and gestating sow sheds. Additional sheds are provided to house weaner, grower and finisher pigs. Most of these sheds are naturally ventilated while others are mechanically ventilated with heating and cooling systems providing conditions suitable for the age of pigs housed in the various sheds.

C1.2.1 Farrowing Sheds

There are a total of 144 farrowing crates in two farrowing sheds at Piggery C. Based on the energy data received and assumptions it is assumed one of the farrowing sheds is naturally ventilated while the other is mechanically ventilated with evaporative cooling pads. For the comfort of the sows, the farrowing shed temperature is ideally maintained within the range from 18 to 20°C; however, this may increase to 25°C during summer.

Heating requirements for the farrowing sheds are as follows:

- 1 x 100W heat lamps operating continuously on electricity, installed in the creep areas of each farrowing crate. Heat lamps will provide zone heating from 32°C for new-born piglets to 28°C at weaning (see photo below).
- Shed space heating in the farrowing sheds is provided by diesel-fired, fan-forced space heaters and LPG fired radiant heaters on only the coldest nights.

The heat lamps and radiant heaters will be controlled thermostatically based on sensor readings in the creep areas and throughout the farrowing sheds, respectively. There will be significantly more energy consumption for heating in winter and much less in the summer. Heating is still required in summer, mostly in the creep areas.

Figure 2. Heat lamp installed in covered creep area.

C1.2.2 Gestating Sow, Weaner, Grower and Finisher Sheds

The remaining dry sows are housed in naturally ventilated and mechanically ventilated sheds. Weaner sheds and grower sheds are mechanically cooled with electrically driven fans and evaporative cooling pads. Weaner sheds are cross-ventilated while grower sheds utilise longitudinal tunnel ventilation (Figures 4 and 5).

Space heating in weaner sheds is provided by LPG fired radiant heaters when the ambient temperature is below 18°C.

Figure 3. Grower shed with longitudinal tunnel ventilation.

Figure 4. Weaner shed with cross-ventilation.

C1.3 Site Energy Consumption

The Piggery C site consumes approximately 176,500 kWh of electricity per annum based on 2014 electricity data provided by the utility. Higher electricity consumption during the summer months is due to increased fan use for evaporative cooling, as shown in Figure 5, below.

It is assumed the sucker heating lamps in the farrowing sheds are active 6,000 hours per annum (68% of time) consuming approximately 86,400 kWh of electricity. Figure 6 is a graphical representation of the half-hourly electricity consumption for 2014. The consumption data is arranged in order from the highest (44 kW) to the lowest (2kW) values.

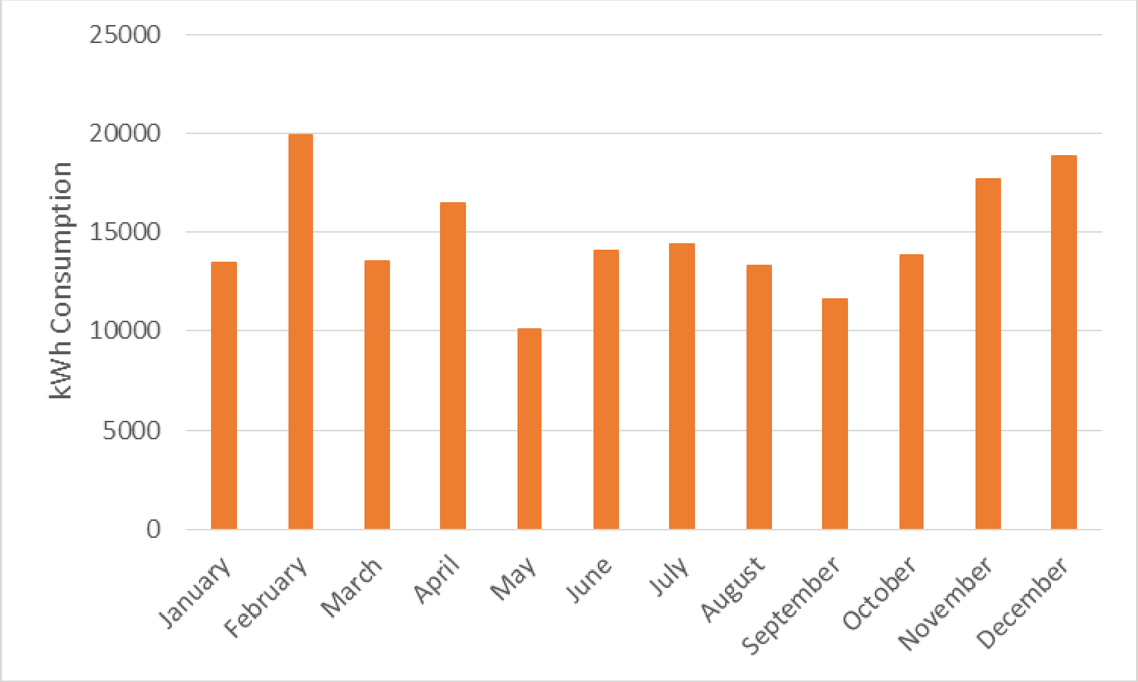

Figure 5. Monthly electricity consumption based on utility data.

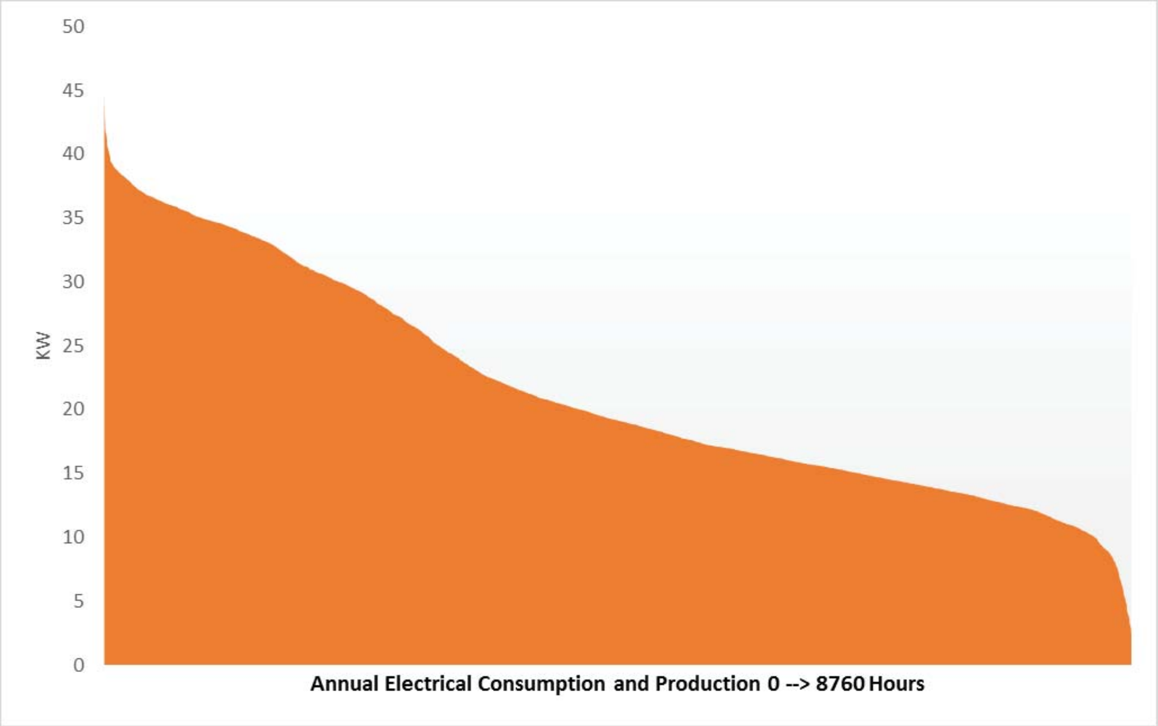

Figure 6. Piggery C electricity demand (half-hourly)

C1.4 Piggery biogas potential

Methane production estimates were produced based on the piggery shed effluent being discharged into a new Covered Anaerobic Lagoon (CAL) specifically designed and constructed (as outlined in Appendix II) to suit the current piggery operation. It has been assumed that a solids separation device (such as the existing static rundown screen) will remove 25% of the volatile solids (VS) flushed from the sheds, prior to discharge into the CAL. The biogas, methane and energy potential estimates provided in Table 1, below, are considered 'possible'. These estimates are based on analysis provided by Skerman (2015). Further details and 'conservative' estimates are provided in Appendix I.

Table 1. Piggery C biogas potential estimates (possible).

Description	Units	Hourly*	Annual
Sows	Quantity	677	677
Piggery operating capacity	SPU	7,479	7,479
Volatile Solids (VS)**	t	70.4	617,018
Biogas production rate	m^3 biogas	32.38	283,828
Methane collection	m^3 CH_4	21.1	184,488
Energy	kWh	195	1,709,164
Energy	GJ	0.70	6153
CO_2-e	kg	300	2,628,000

C1.5 Existing lagoons

Piggery C has both primary and secondary lagoons in operation, as shown in Figure 7. Both lagoons were visually inspected and feedback from the piggery owner indicated that the primary lagoon had been desludged within the last two years. It appeared that the existing primary lagoon was designed for a lower VS loading rate and longer retention time than required for a CAL. The approximate dimensions of the existing and proposed lagoons are provided in the following section.

Figure 7. Piggery C primary and secondary lagoons.

C2. Covered anaerobic lagoon (CAL)

Federal Government estimates in 2012 suggested 690 piggeries in Australia may be able to capture and destroy methane. Research also suggests that by 2017, methane generated by 15-20% of the Australian pig herd will be captured and destroyed, increasing to 25-30% by 2020. (Tait, 2014). These estimates suggest CALs (or in some instances engineered digesters) will become a Business-as-Usual (BAU) scenario for many Australian piggeries. This section addresses the first stage in any Waste-to-Energy project, methane collection and destruction in a CAL.

C2.1 Covering an existing primary lagoon

Piggery C has both primary and secondary lagoons on-site, as noted in the previous section. This feasibility study has estimated the costs of covering the existing primary lagoon to then flare the biogas. This activity could create Australian Carbon Credit Units (ACCUs) which attract payments from the Federal Government (or potentially a secondary market) for carbon abatement.

Covering an existing primary lagoon can potentially avoid earthwork costs associated with the construction of a new Fit-for-Purpose lagoon, as earthworks are expected to account for just under half the estimated construction cost of a CAL. Further consideration suggested that covering an existing lagoon for methane destruction had the following additional limitations:

- the size, shape and depth (including bottom contour) of the existing primary lagoon may not be suitable for optimal methane production
- depending on the cover design, retrofitting an existing lagoon with a cover may be more costly per m^2 than a new cover (Skerman & Collman, 2012).

C2.1.1 Existing and Fit-for-Purpose lagoon comparison

As outlined in Table 2, below, it was concluded that constructing a new Fit-for-Purpose CAL would be more cost effective than covering the existing primary lagoon at Piggery C. This is partly due to the existing primary lagoon having a much greater surface area than required for a CAL. Furthermore, the costs incurred to desludge the existing primary lagoon (estimated at $20,000) would need to be accounted for in the retro-fit option.

Table 2. Comparison of costs involved in retro-fitting a cover on the existing primary lagoon and installing a new 'fit-for-purpose' CAL.

Description	Existing Primary Lagoon	Fit-for-Purpose Lagoon
Length at full storage level (m)	150	96
Width at full storage level (m)	45	29
Surface Area (m^2)	6,750	2,784
Cover Area (m^2)	7,627	3,612
Estimated cost to excavate and cover	$262,000	$216,000

The costs outlined above do not take into account likely additional excavation costs to retro-fit an existing lagoon nor does it take into account risks associated with lagoon cover retro-fits.

In addition to lagoon and cover construction, all covered lagoons require a flare, safety and monitoring equipment. Table 3, below, outlines the total estimated costs for a CAL with associated methane destruction and safety apparatus.

Table 3. Fit-for-Purpose CAL capital costing estimates.

Activity	Description	Cost
Lagoon design & construction earthworks	8,904 m^3	$119,000
Supply and install lagoon cover	3,612 m^2	$97,000
Supply and install flare & control/monitoring system	Includes Development Application	$65,000
Total Cost		$281,000

C2.2 CAL operating costs & benefits

Capture and destruction of methane through the use of a CAL can attract a financial benefit through the Federal Government’s Emissions Reduction Fund (ERF) policy. Through a reverse auction, a new carbon abatement project can ‘sell’ Australian Carbon Credit Units (ACCUs) to the Federal Government. ACCUs will only be generated for the initial seven years of a methane destruction project. The first auction has recently closed and the average price per tonne of carbon abatement is $13.95 (Clean Energy Website). For the purposes of this feasibility study a price of $10/tonne of CO_2-e has been assumed for remaining auctions in 2015.

Table 4. Estimated benefits of Emission Reduction Fund (ERF) from capturing and destroying methane (‘possible’ scenario).

Activity	Description	Benefit of methane destruction
Annual ERF participation & ACCU Creation	2,583 tonnes of CO_2-e destroyed	$25,830
Total Project Returns from ACCU creation	Initial seven years of Project	$180,810

A CAL also attracts additional operating costs relative to an uncovered lagoon. It is estimated an industry best practice lagoon cover (made from low-density polyethylene (LDPE) or polypropylene (PP)) will need replacement after 10 years in operation. Sludge management may also be more labour intensive and costly due to the cover (relative to an uncovered lagoon). Two audits must also be conducted where ACCUs are being created during the first seven years of the project.

Table 5. CAL operating cost estimates for capturing and destroying methane.

Activity	Description	Annual Average Operating Expenditure
Lagoon Cover replacement	Replacement every 10 years	$9,700
Sludge management	Periodic extraction	$10,000
Daily inspection	15 minutes visual inspection	$1,000
ERF Auditing	Twice in seven years	$2,285
Total Operating Expenditure	Annualised	$22,985

There are additional benefits associated with covering a lagoon including odour reduction. Covering a lagoon can decrease odour emission by up to 90% (Tucker *et al*., 2010). This odour reduction may have a positive effect on neighbours and may also allow a piggery to expand operations in the future (Tucker *et al*., 2010).

C3. Waste-to-Energy project comparisons

In the Australian pork industry, Waste-to-Energy projects involve collecting the biogas produced from anaerobic digestion of the effluent discharged from piggery sheds. This effluent consists of manure, shed flushing and hosing water (which may include some recycled effluent), waste drinking water and spilled feed. Following collection of the biogas, the most cost effective Waste-to-Energy options may be selected after considering the following factors:

- amount of biogas and methane created
- heating requirements of the site
- cooling requirements of the site
- electricity demand of the site.

Options currently being used by the Australian pork industry include:

- on-site electricity generation
- piglet nest heating.

Additional options considered in this study include:

- shed Cooling
- chilled drinking water
- cool-sow system.

It is estimated that Piggery C could produce up to 21m^3 per hour of CH_4 or 0.78 GJ of thermal energy every hour, on average. This estimate is used to appropriately size the Waste-to-Energy system at this piggery.

This methane potential is sufficient for the on-site thermal solutions discussed in Section 3.1 below, which are also applicable to the subsequent electricity generation solutions.

C3.1 Site Thermal Solutions

Heat from the combustion of methane, in either a hot water boiler or cogeneration system, may be used to provide on-farm heating requirements, including shed heating and piglet nest heating.

Utilising the heat from biogas combustion to produce cooling energy (e.g. absorption chilling) for on-farm use, was also investigated. The primary piggery cooling requirements identified in this study included chilling sow drinking water, sow cooling and piggery shed space cooling. These cooling energy uses peak during warmer months.

Mechanical air cooling of sheds was deemed to be difficult to achieve due to the large volume of air requiring cooling and the nature of the ventilation systems required to maintain shed air quality. Chilling lactating sow drinking water to 20°C was considered to be a more cost-effective use of the available energy generated from biogas.

Micro absorption chillers were investigated for converting biogas heat energy into chilled water for use in mechanical air cooling and producing chilled drinking water; however, pricing and technical information was difficult to obtain for micro absorption chillers in the required range (10 to 50 kW). Consequently, it was concluded that absorption chillers were not currently a viable option for on-farm utilisation of piggery biogas and that drinking water is most effectively chilled using an electric chiller. Electric chillers consume a minimal amount of energy (approximately 20 kWh per pig per annum), and can be installed at a relatively low capital cost, either through retro-fitting or new installation. Providing electric chillers are powered using excess electricity generated on-site from biogas, this option represents an effective use of a renewable energy resource. However, it should be noted that this assumption may not be valid in cases where there is insufficient on-site electricity generated from biogas to satisfy all on-site demands and in cases where the electric chiller electricity consumption reduces export to the grid.

C3.1.1 Chilled Drinking Water

Willis and Collman (2007) found that sows provided with chilled drinking water during hot weather consumed 6.6 L more water and 0.252 kg more feed per day than a control group. In the same study the weaning weight of piglets was 0.7 kg higher amongst litters where sows were provided chilled drinking water. It was estimated by the authors of this study that the increase in weaning weight from providing chilled drinking water would have an economic benefit of $61/sow/year. This includes the cost of the additional feed.

This study estimates the cost of integrating a chilled drinking water system in sow crates to be $98 per crate. This includes a 2 kW Summit Matsu electric chiller, water storage tank and installation. Due to the simplistic nature of this solution, it is assumed the cost to install is equivalent for a new build and a retro-fit.

C3.1.2 Piggery Shed Space Heating

Piggery C employs LPG fired radiant heaters which are activated when the shed ambient temperatures fall below 18°C. Based on incomplete LPG consumption data for a nearby farrow to finish piggery, it is estimated that Piggery C may conservatively consume 80-100 litres of LPG per annum. Utilising heat from the Waste-to-Energy system for shed space heating will increase the overall value of the system by reducing LPG consumption.

Shed heating may be provided by circulating hot water, from a biogas-fired boiler or cogeneration system, through Reventa Deltapipes and/or Twinpipes (Figures 8 and 9) to provide shed space heating. Capital expenditure, including installation costs, is estimated to be $240/kW (0.3 kW per metre). This includes thermal integration with the heat source(s) as required.

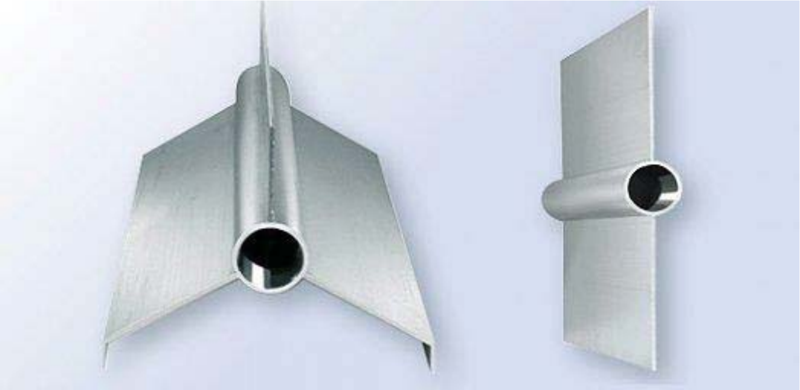

Figure 8. Reventa 'Deltapipe' and 'Twinpipe' finned tube convectors (Reventa website).

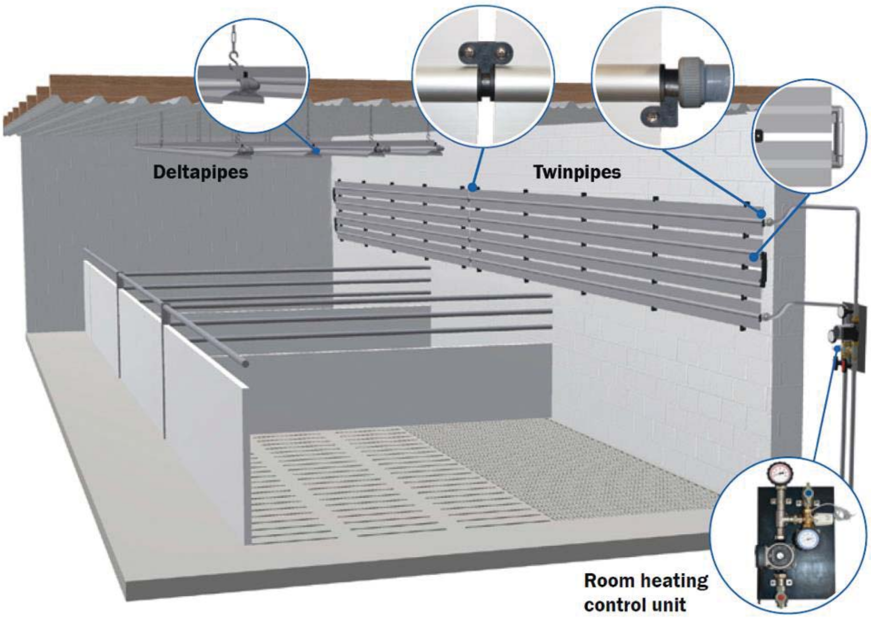

Figure 9. Typical installations of Reventa 'Deltapipe' and 'Twinpipe' finned tube convectors in a piggery building (Reventa website).

It is anticipated that installing 30 kW of Delta/Twinpipe would replace the use of LPG for space heating at Piggery C. More detailed analysis considering air flows and ventilation rates for each shed would be required to confirm this assumption.

Assuming that space heating is operational across the four coldest months for 10 hours per day, Piggery C would currently require an average of 30 kW of space heating. It is estimated this 30 kW may be entirely offset through the use of Delta/Twinpipe. It is anticipated that there will be ample energy available to satisfy this requirement.

C3.1.3 Piglet Nest Heating

A single 100W infrared heat lamp has been installed in each farrowing crate for zone heating piglets. Use of these electric heat lamps could be offset by installing an under-floor hydronic piglet heating system. In this type of system, hot water from a biogas boiler or cogeneration system is circulated through under-floor heating pads installed in each farrowing pen. An example of this type of system is the Reventa Thermo Plus piglet nest heating system. This feasibility study estimates the cost of installing Thermo-Plus heating pads to be $504 per farrowing crate. This cost includes flow and return pipework but does not include any heat source.

Figure 10. Reventa Thermo-Plus piglet nest heating (Reventa website)

This study assumes the 144 sucker heating lamps in the farrowing sheds are active approximately 6,000 hours per annum consuming approximately 84,000 kWh of electricity. This feasibility study assumes the installation of piglet nest heating will reduce electricity consumption by these heat lamps by 75% (from the base case). This assumes the heat lamps are still required during the night in the coldest months. Therefore, after installing the new piglet heating system, it is estimated the electricity demand at Piggery C will be reduced by 64,800 kWh from 176,500 to 111,700 kWh per annum.

Table 6. Costs and benefits of thermal solutions for Piggery C.

Activity	Description	Cost per unit	Total Cost	First year returns	Return on Investment
Piglet heating	144 sow stalls	$504	$72,576	$16,200	21%
Sow chilled drinking water	144 sow stalls	$98	$14,112	$8,784	61%
Space heating	Delta Pipe (30kW)	$240 / kW	$7,200	$3,500	49%
Total	Includes installation	$842	$93,888	$28,484	30%

C3.2 80 kW Hot Water Boiler

Installing an 80 kW biogas-fired boiler would be the lowest cost Waste-to-Energy solution for Piggery C. Hot water from the boiler could supply hydronic piglet heating pads to offset heat lamp electricity consumption. The boiler can also supply heat to the installed delta pipes for shed space heating thereby offsetting LPG use, during the winter months.

Figure 11. Biogas hot water boiler and ancillary equipment at Grantham Piggery (Skerman, 2012)

C3.2.1 Capital Expenditure

Table 7 outlines the estimated capital costs of installing an 80 kW boiler at Piggery C.

Table 7. Estimated capital costs of installing an 80 kW boiler at Piggery C.

Activity	Description	Cost
Biogas Conditioning	Chiller (to condense biogas moisture), knock out pot & plant room	$33,720
Boiler System	80 kW Hot Water Capacity	$22,800
Installation & Commissioning	Mechanical & electrical integration to site	$15,000
Total Cost ex GST		$71,520

Running an 80 kW boiler does not necessarily require a ferric oxide scrubber. Biogas boilers may tolerate biogas hydrogen sulphide (H_2S) concentrations up to 1000ppm. Because, H_2S concentrations up to 3000 ppm have been recorded in biogas produced by Australian piggeries, some form of biogas scrubbing may be required to avoid excessive corrosion and increased health risks associated with high biogas H_2S concentrations. Chilling the biogas to 4°C is expected to condense the biogas moisture, thereby reducing the risk of excessive corrosion.

C3.2.2 Operating Costs

Table 8 outlines the estimated operating costs for an 80 kW hot water boiler at Piggery C.

Table 8. Estimated operating costs for an 80 kW boiler at Piggery C.

Activity	Description	Annual Cost to Owner
Boiler Maintenance	Service, consumables	$1,000
Biogas Chiller operation	Electricity usage	$100
Biogas system Maintenance	General maintenance	$1,000
Total Operating Expenditure (Opex)		$2,100

Installing the biogas fuelled hot water boiler represents the lowest cost Waste-to-Energy option explored in this study. The boiler will produce enough thermal energy for the piglet nest heating and shed space heating discussed in section 3.1 (with the associated financial returns). Total capital expenditure for the thermal heat only solution is $151,296 (boiler, biogas conditioning and piglet nest and shed heating) with a net benefit of $17,600 for a first year project Return on Investment (RoI) of 11.6%.

This option will not provide electricity (from a renewable source) for chilled drinking water or the site requirements. This option will offset a portion of the site's electricity consumption (piglet nest heating) and most, or all, of the sites LPG requirements. Additional Waste-to-Energy options including on-site electricity generation are discussed in the following sections to understand if Waste-to-Energy projects can achieve returns higher than 11.6% per annum.

C3.3 Yanmar 25 kW Cogeneration Systems

Yanmar 25 kW biogas driven cogeneration units could be installed modularly to increase total electrical and heat output on the piggery site. Due to the reduced site electricity demand (following installation of the Thermo-Plus creep heating pads) a 25 kW cogeneration system is the optimal size for on-farm electricity generation and consumption. The Yanmar 25 kW cogeneration system is able to load-follow the site's electricity demand, to match site needs below 25 kW.

Operating the cogeneration system at low loads will decrease the overall electrical efficiency relative to operations at full load. As Piggery C will be producing more methane than will be required to operate the 25 kW, this inefficiency is not consequential. All biogas that is not used in the waste-to-energy system cannot be stored efficiently and must be flared. The Yanmar

25 kW unit will produce 38 kW of recoverable thermal energy in addition to the electricity generation.

Because a single Yanmar 25 kW cogeneration unit consume less than half of the estimated methane potential of the site, it is recommended that this unit be installed in conjunction with the 80 kW biogas boiler described previously. This will allow the site to convert as much methane as possible into usable energy.

C3.3.1 Capital Expenditure

Table 9, below, outlines the estimated capital expenditure for a single Yanmar 25 kW micro Combined Heat and Power (CHP) system, combined with a hot water boiler of approximately 80 kW capacity which will provide supplementary heat when the cogeneration system is running at low capacity.

Table 9. Estimated capital costs of installing a single Yanmar 25 kW cogeneration unit at Piggery C.

Activity	Description	Capital Expenditure
Biogas Conditioning	Chiller, ferric oxide scrubber, knock out pot & plant room	$66,120
25 kW Cogeneration System		$75,000
Installation & Commissioning	Mechanical & electrical integration to site	$50,000
Total Cost ex GST		$191,120

The biogas conditioning equipment purchase and installation is assumed to be the same for all Waste-to-Energy projects included in this feasibility study. Market research suggests there are limited options for biogas conditioning for small to medium sized Waste-to-Energy systems.

C3.3.2 Operating costs

Table 10, below, outlines the estimated operating costs for a single Yanmar 25 kW micro CHP system, combined with a hot water boiler of approximately 80 kW capacity. Cogeneration maintenance and overhauls are calculated per kWh operated.

Table 10. Estimated annual operating costs for a single Yanmar 25 kW cogeneration unit and 80 kW boiler at Piggery C.

Activity	Description	Annual Cost to Owner
Cogeneration Maintenance	Oil Change, consumables	$3,015
Cogeneration overhauls	Changing heads, boring cylinders, rebuilds	$7,096
Biogas system Maintenance	General maintenance & ferric oxide replacement	$6,005
Total Operating Expenditure (Opex)		$16,117

C3.3.3 Returns from electricity generation

Table 11, below, outlines the estimated annual returns from electricity generation for a single Yanmar 25 kW cogeneration unit. Cogeneration maintenance and overhauls are calculated per kWh operated.

Table 11. Estimated annual returns from electricity generation for a single Yanmar 25 kW cogeneration unit at Piggery C.

Activity	Description	Annual Benefit
Electricity Generation utilised on-site	97,800 kWh @ $0.25/kWh	$25,113
Renewable Energy Certificates	97,800 kWh*0.9*$0.0395	$3,574
Project returns from electricity generation		$28,706

Figure 9, below, shows the site's baseline electricity demand (red dashed line), the new demand following installation of piglet nest heating, and the expected power generated by the Yanmar 25 kW cogeneration unit.

This figure shows that the 25 kW cogeneration system is expected to produce approximately 90% of the electricity required on-site, operating for approximately 7,100 hours per annum. While the Yanmar 25 kW unit can operate at very low load, it may be more cost effective to channel excess biogas to the boiler overnight and other times of low site electricity demand.

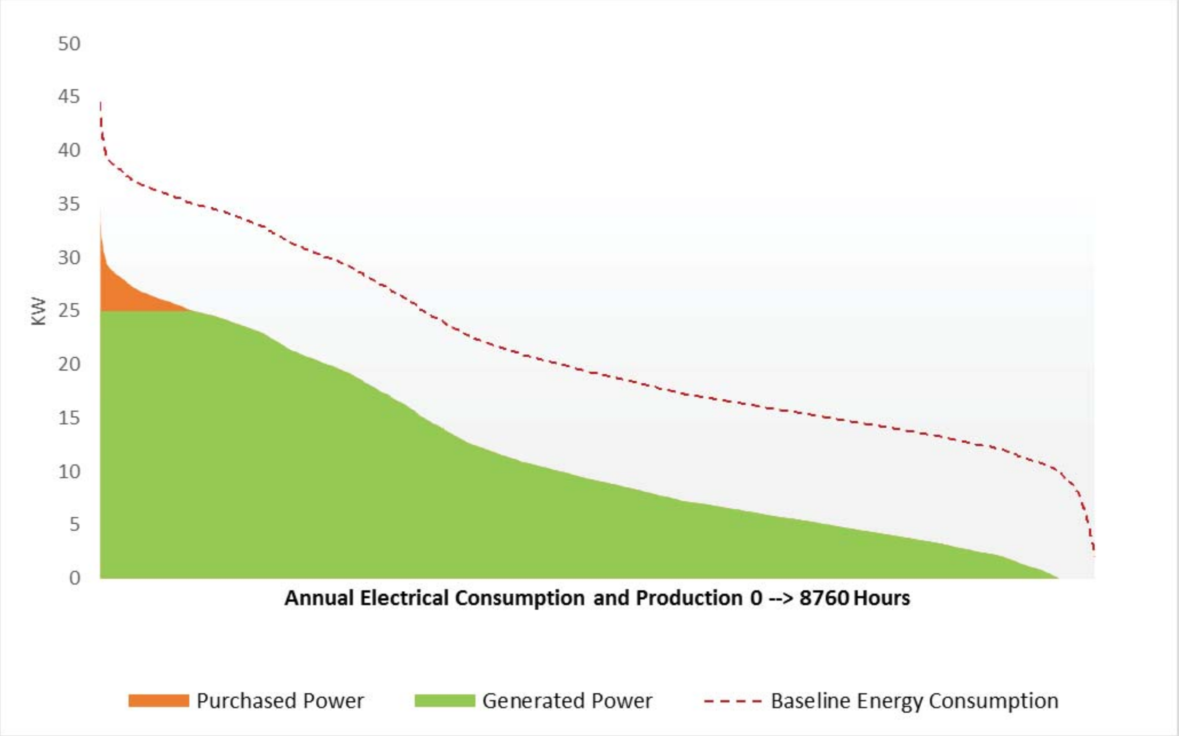

Figure 12. New electricity demand and on-site electricity generation.

C3.3.4 Project cash-flows

Table 12, below, outlines the estimated cash flows for a single Yanmar 25 kW micro CHP system, combined with a hot water boiler of approximately 80 kW capacity.

Table 12. Estimated annual cash flow for a single Yanmar 25 kW cogeneration unit at Piggery C.

Activity	Capital Expenditure	Operating Expenditure	Benefit	Net Benefit	Return on Investment
Yanmar 25 kW inc biogas conditioning	$191,120	$16,111	$28,706	$12,590	7%

The figures above are for electricity generation only. They do not take into account the thermal integration or cost of the 80kW hot water boiler that would be required for both piglet nest heating and shed space heating. The total project returns including a hot water boiler and thermal integration are discussed in the conclusion.

C3.4 Ener-G 80 kW Cogeneration System

The largest cogeneration system possible at Piggery C (based on the estimated methane production from the proposed CAL) is an 80 kW system. The Ener-G 80 kW is unable to produce electricity below 50% of nameplate capacity and operates optimally no lower than 75% of nameplate capacity. This is typical of most cogeneration systems running on either natural gas or biogas.

After accounting for the reduction in electricity demand from the electric heat lamps (by utilising the Thermo-Plus piglet nest heating) the new site electricity demand is under 25 kW much of the time. For the 80 kW system to operate optimally it must export significant amounts of total electricity generation to the grid.

C3.4.1 Ener-G 80 kW cogeneration system capital expenditure

Table 13, below, outlines the estimated capital costs associated with the installation of an Ener-G 80 kW cogeneration system.

Table 13. Estimated capital costs associated with the installation of an Ener-G 80 kW cogeneration system.

Activity	Description	Cost
Biogas Conditioning	Chiller, ferric oxide scrubber, knock out pot & plant room	$66,120
Cogeneration System	80 kW generation capacity	$201,600
Installation & Commissioning	Mechanical & electrical integration to site	$90,000
Total Cost ex GST		$357,720

C3.4.2 Ener-G 80 kW operating costs

The table below outlines the estimated annual operating costs associated with the Ener-G 80 kW cogeneration system.

Table 14. Estimated annual operating costs associated with the installation of an Ener-G 80 kW cogeneration system.

Activity	Description	Annual Cost to Owner
Cogeneration Maintenance	Oil Change, consumables	$18,921
Cogeneration overhauls*	Changing heads, boring cylinders, Rebuilds	$6,572
Biogas system Maintenance	General maintenance & ferric oxide replacement	$11,307
Total Operating Expenditure (Opex)		$36,800

C3.4.3 Project returns

Market research suggests the prevailing contracts for electricity generation and export to the grid attracts relatively low returns per kWh. Retailers may pay a 'pool price pass through' where exported electricity is valued at the registered pool price for the half-hour exported (up to $0.30/kWh). Based on average spot prices in 2014 (adjusted for the most recent carbon policy), it seems likely that exported electricity may not receive more than $0.03/kWh on average.

The estimated annual returns for the Ener-G 80 kW cogeneration system are outlined in Table 14.

Table 15. Estimated annual returns for the Ener-G 80 kW cogeneration system

Activity	Description	Project returns
Electricity generation utilised on-site	100,530 kWh	$25,133
Exported electricity	530,190 kWh*$0.025	$15,905
Renewable Energy Certificates	630,720kWh*0.9*0.0395	$22,422
Total project returns		$63,460

Figure 10, below, shows the site's electricity baseline demand (red dashed line), the new demand for power (after the installation of piglet nest heating), electricity generated for on-site consumption (green area), and electricity exported and sold to the grid (blue area). Any remaining electricity required for the site that is not supplied by the cogeneration system would be purchased from the grid.

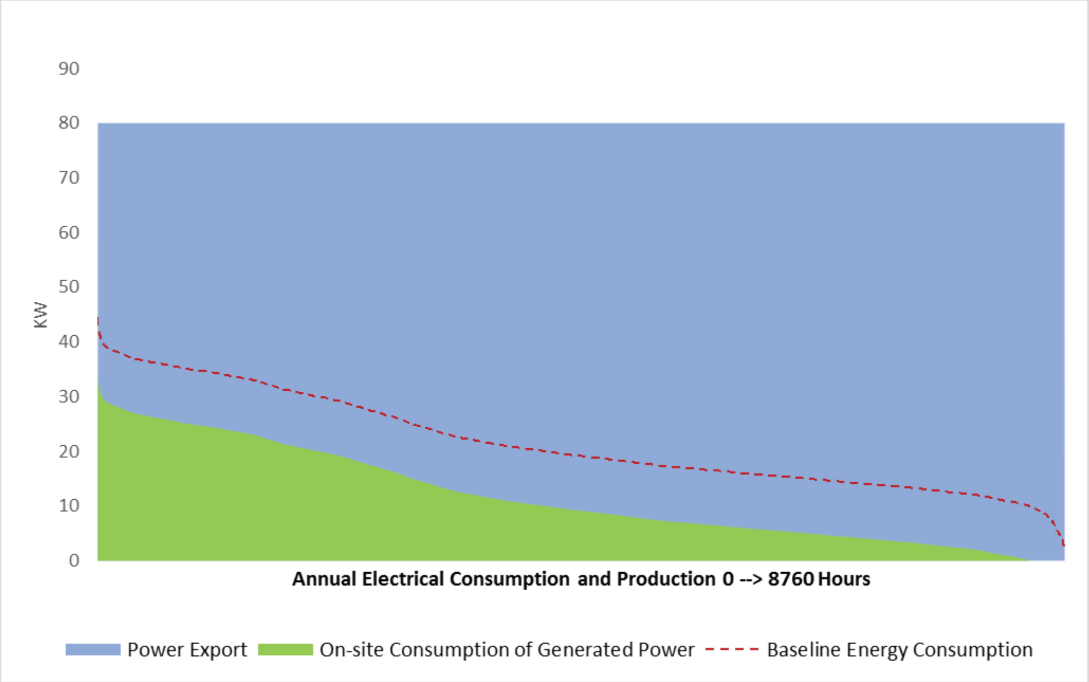

Figure 13. New site electricity demand and generation

As outlined in Table 15, the Ener-G 80 kW system will satisfy approximately 90% of the on-site electricity demand (taking into account maintenance and forced outages) while exporting most of the electricity generated to the grid.

Table 16. Estimated costs, benefits and return on investment for Ener-G 80 kW cogeneration system.

Activity	Capital Expenditure	Operating Expenditure	Benefit	Net Benefit	Return on Investment
Ener-G 80 kW & biogas conditioning	$357,720	$36,800	$63,460	$25,113	6%

C3.5 Scenario Comparison & conclusion

Table 16 provides a comparison of costs and returns associated with the 2 x 25 kW Yanmar and Ener-G 80 kW cogeneration system options.

Table 17. Comparison of costs and returns associated with the three biogas use options.

Scenario:	(1) 80kW Boiler	(2) 1 x 25 kW Yanmar cogeneration system and 80 kW biogas boiler	(3) 80 kW Ener-G cogeneration system
Total Capital Expenditure inc thermal integration	$151,296	$317,808	$451,608
Cost per kW(e) installed	NA	$5,8,517	$4,472
Net project returns	$17,600	$38,974	$55,145
Return on Investment (RoI)	11.6%	12.3%	12.2%

Installing the biogas boiler results in the lowest capital expenditure while still monetising the methane in a Waste-to-Energy project. The project satisfies the bulk of the heating requirements of both the piglet nests through the installation of hydronic piglet nest heating pads and delta pipes for shed space heating. Scenario1 (boiler only) does not produce electricity, hence the offsets for both electricity generation and chilled drinking water for the sows are not applicable.

Scenario 2 adds on-site electricity generation in addition to the 80 kW boiler. This scenario does not include any export of electricity but satisfies the bulk of the site's electricity demand. With the inclusion of the 80 kW hot water boiler, the system will satisfy much of the site's heating requirement. Due to the onsite electricity generation, the chilled drinking water is also added to the project which increases the RoI.

While Scenario 3 utilises all of the available methane potential for Waste-to-Energy, based on the site's energy requirement, it does not warrant the increased capital expenditure and operating costs.

In conclusion, it appears that Scenario 2 offers the best overall outcome, producing enough electricity and usable thermal energy to offset most of the on-site energy requirement without needing to export electricity. Export of electricity has a relatively low value, based on existing incentives.

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Appendix I Estimates of conservative and possible production of volatile solids, biogas, methane, thermal energy and equivalent CO_2 emissions.

Parameter	Units	Conservative	Possible
VS from sheds	kg VS/SPU/yr	90	110
	t VS/yr	673	823
VS removal in solids separator	%	25	25
VS to CAL	t VS/yr	505	617
Biogas production rate	m^3 biogas/kg VS added	0.43	0.46
Biogas production	m^3 biogas/yr	217,078	283,828
Biogas methane content	%	65	65
Methane (CH_4) production rate	m^3 CH_4/kg VS	0.28	0.30
Methane (CH_4) production	m^3 CH_4/yr	141,101	184,488
Methane lower heating value (LHV)	MJ/Nm^3 CH_4	33.35	33.35
Methane thermal energy	GJ/yr	4,706	6,153
	kW.hr/yr	1,307,207	1,709,164
CO_2 emissions	t CO_2-e/yr	2,010	2,628

Appendix II Assumptions used in calculating the required dimensions for a 'fit-for-purpose' CAL to service the Piggery C.

Parameter	Units	Values
Possible VS discharge to CAL	t VS/yr	823
Anaerobic pond activity ratio, k		0.96
Baseline VS loading rate	kg VS/m^3/day	0.4
Adjusted VS loading rate	kg VS/m^3/day	0.384
Treatment volume	m^3	4,399
Assumed VS/TS ratio		0.83
Estimated TS to pond	kg TS/day	2,035
Sludge accumulation rate	m^3/kg TS	0.00303
Desludging interval	years	2
Required sludge storage volume	m^3	4,505
Total storage volume	m^3	8,904
Total storage volume per SPU	m^3/SPU	1.19
Total storage depth	m	6
Batter - lengthwise, (1 vertical : Z horizontal)		2
Batter - breadthwise, (1 vertical : Z horizontal)		2
Freeboard - full storage level to crest	m	0.5
Length - at embankment crest	m	98.00
Breadth - at embankment crest	m	31.10
Length - at full storage level	m	96.00
Breadth - at full storage level	m	29.10
Length - at base	m	72.00
Breadth - at base	m	5.10
Cover additional anchorage allowance	m	2
Cover length	m	102.24
Cover breadth	m	35.33
Cover area - trenched into bank	m^2	3,612

Piggery D

D1. Site appreciation

Piggery D is located in the Upper Burnett region of Queensland. This region is characterised by the owner as a hot, dry climate with summer maximum daily temperatures commonly near or above 40°C and winter minimum temperatures commonly below 0°C. Air humidity is low throughout the year.

The piggery owners are considering a significant expansion of piggery operations at the Piggery D site, and as such, are interested in assessing the viability of a Waste-to-Energy system servicing the expanded piggery. Consequently, this feasibility study will address the Waste-to-Energy potential of the proposed expanded piggery rather than the existing unit. An aerial photograph of the piggery is provided in Figure 1.

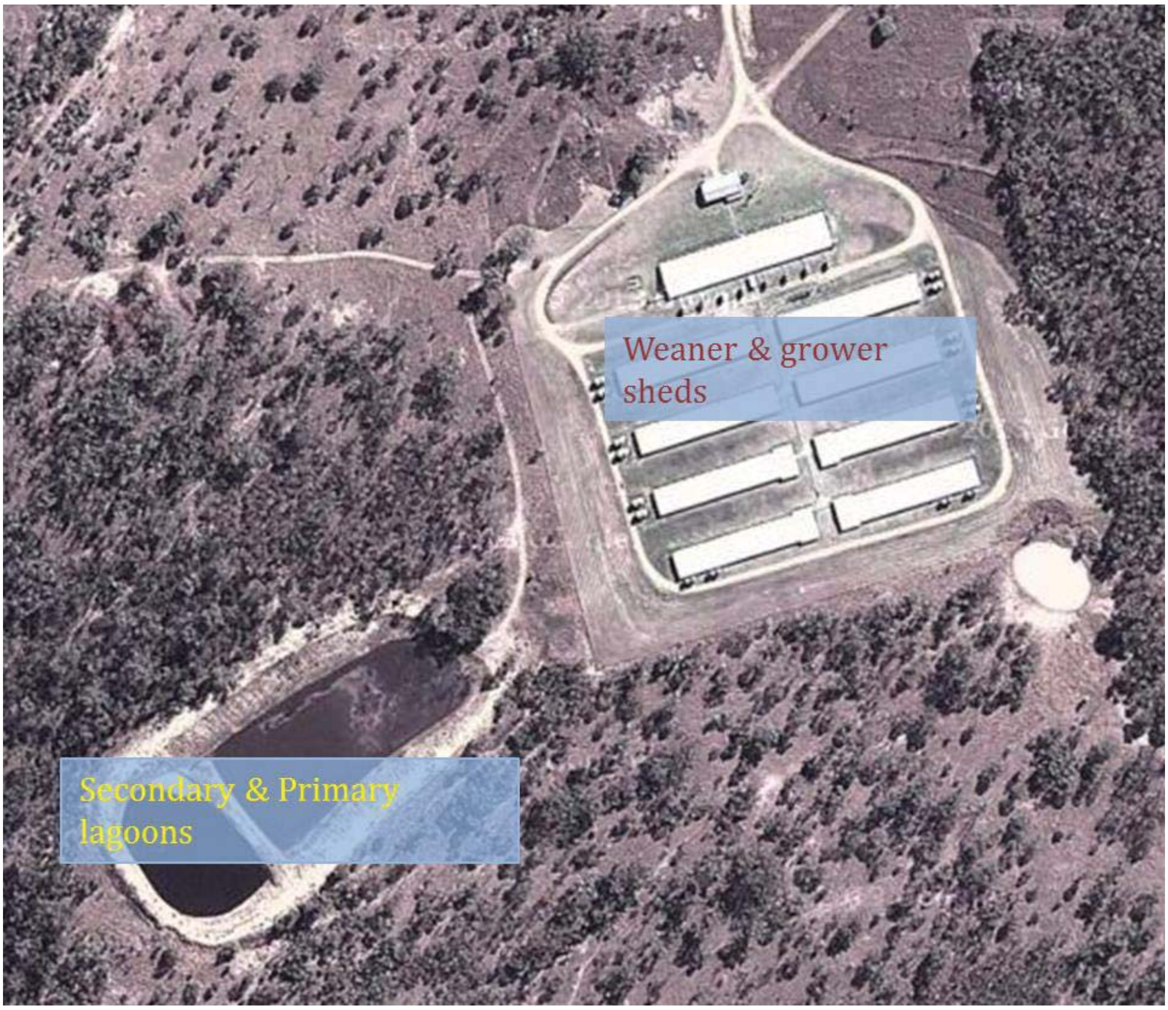

Figure 1. Existing Piggery D grower unit (from Google Maps).

It is anticipated that additional piggery sheds will be constructed on the hill north and east of the existing sheds and a new Covered Anaerobic Lagoon (CAL) will be constructed to treat the effluent from the entire expanded piggery operation.

The expanded Piggery D will consist of a proposed 1,200 sow farrow to finish unit (14,662 SPU) in addition to the existing grower unit (10,176 SPU) which grows out the progeny from a nearby 997 sow breeder unit. The total capacity of the expanded piggery will be 24,838 Standard Pig Units (SPU). A new primary CAL will be constructed to service the entire expanded piggery. A new secondary lagoon may be constructed, if required.

All pigs will be housed in conventional flushed sheds with partial or fully slatted floors. It has been assumed that a static run-down screen will be used to remove solids from the raw effluent discharged from all of the piggery sheds into the effluent management system. Recycled effluent from the secondary lagoon will be used for shed flushing and irrigation onto land to enhance agriculture production. Based on the estimated methane and energy potential of expanded piggery, a feed mill could be established on-site.

D1.1 Project objectives

Discussions with the piggery manager identified the following project objectives:

- reduce on-farm energy costs
- institute best practice for resource use and energy efficiency
- cover lagoons to reduce odour emissions and improve the likelihood of obtaining an approval for the expansion of the piggery.

D1.2 Sheds

The sows will be housed in conventional farrowing and gestating sow sheds. Additional sheds will be provided to house weaner, grower and finisher pigs. All of these sheds will be mechanically ventilated with heating and cooling systems providing conditions suitable for the age of pigs housed in the various sheds.

D1.2.1 Farrowing sheds

There will be a total of 250 farrowing crates in the new farrowing sheds at Piggery D. All of the farrowing sheds will be mechanically ventilated with evaporative cooling pads. For the comfort of the sows, the farrowing shed temperature is ideally maintained within the range from 18 to 20°C; however, this may increase to 25°C during summer.

Heating requirements for the farrowing sheds are expected to be as follows:

- 1 x 100W heat lamps operating continuously on electricity, installed in the creep areas of each farrowing crate. Heat lamps will provide zone heating from 32°C for new-born piglets to 28°C at weaning (see photo below).

- Space heating in the farrowing sheds will be provided by diesel-fired, fan-forced space heaters and LPG fired radiant heaters on only the coldest nights.

The heat lamps and radiant heaters will be controlled thermostatically based on sensor readings in the creep areas and throughout the farrowing sheds, respectively. There will be significantly more energy consumption for heating in winter compared to summer. Heating is still required in summer, mostly in the creep areas.

Figure 2. Heat lamp installed in covered creep area

D1.2.2 Gestating sow, weaner, grower and finisher sheds

The gestating (dry) sow sheds may be either naturally ventilated with additional electrically-driven fans or fully climate controlled using mechanical ventilation, evaporative cooling pads and Programmable Logic Control (PLC) systems.

The existing weaner and grower sheds at the Piggery D are all mechanically ventilated using electrically driven fans with evaporative cooling pads. The shed cooling systems are all controlled by PLC units. The weaner sheds are cross-ventilated (Figure 3) to limit the velocity of air movement in the shed, while the grower units are longitudinally ventilated (Figure 4). It is expected that the new weaner and grower sheds will employ similar cooling systems.

LPG or biogas fuelled radiant heaters may be required for space heating the weaner sheds. These heaters are generally activated at 18°C shed ambient temperature or as required depending on shed type.

Figure 3. Existing weaner shed with cross ventilation.

Figure 4. Existing grower shed with longitudinal tunnel ventilation

D1.3 Site energy consumption

The expanded piggery will consume significantly more energy than the existing piggery and this energy will be utilised differently, primarily due to the addition of breeder pigs to the site. The energy use for the site has been estimated based on the expanded piggery accommodating 1200 sows, 250 farrowing crates and 24,838 SPU, with a feed mill operating approximately 10 hours per day.

Energy use records for the nearby farrow to finish Piggery C have been used along with the existing grower Piggery D records. It has been assumed that the proposed feed mill will consume 50 kW of electrical energy for 10 hours per day.

D1.3.1 Site electricity consumption

Based on the above assumptions the site is likely to consume approximately 730,000 kWh of electricity per annum. In Figure 5, below, the estimated half-hourly site electricity demand is represented in order from the highest electricity (193 kW) to the lowest (20 kW) consumption. Due to the limitations in the available energy data, it is anticipated that the peak electricity demand could be significantly higher than 193 kW for a few hours each year.

Figure 5. Estimated electricity demand for the expanded Piggery D.

Seasonal variation in electricity consumption is anticipated due to increased fan use for evaporative cooling during the warmer months (Figure 6). It has been assumed that the sucker heating lamps in the farrowing sheds will be active for 6,000 hours per annum consuming approximately 150,000 kWh of electricity per annum. The mill is expected to consume 182,500 kWh and the remaining 397,500 kWh will be consumed by the evaporative cooling fans and other ancillary farm operations.

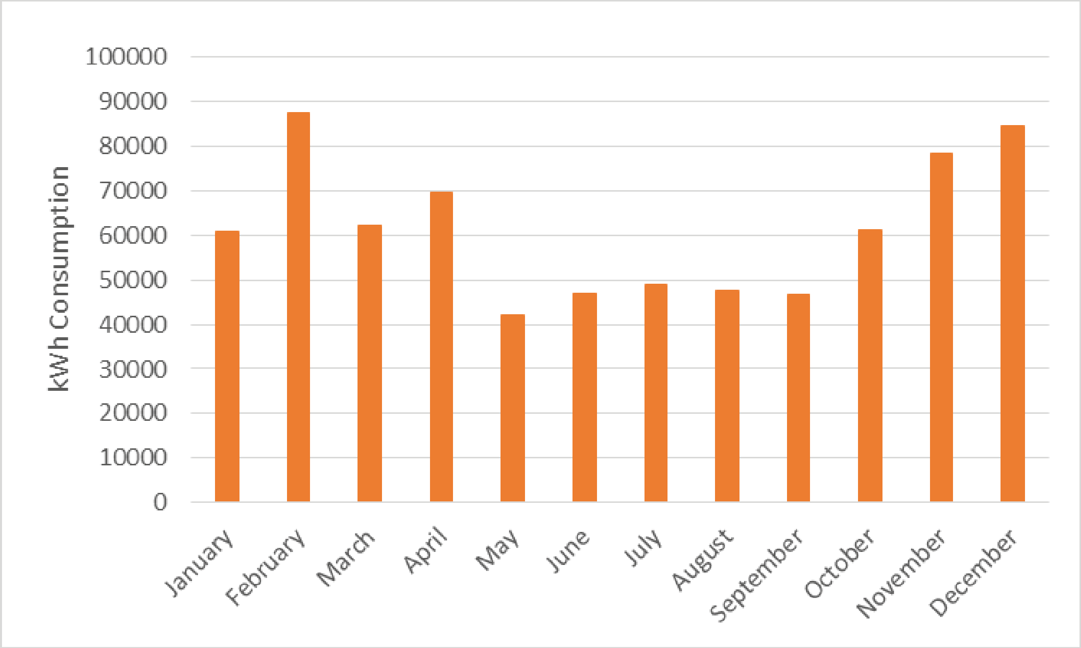

Figure 6. Estimated monthly electricity demand.

D1.3.2 Site LPG consumption

The expanded piggery may use up to 350 litres of LPG per annum for space heating using radiant heaters. This is based on incomplete data and extrapolation from the other nearby farms.

D1.4 Expanded piggery biogas potential

Methane production estimates were produced based on the piggery shed effluent being discharged into a new CAL specifically designed and constructed (as outlined in Appendix II) to suit the current piggery operation. It has been assumed that a solids separation device (such as a static rundown screen) will remove 25% of the volatile solids (VS) flushed from the sheds, prior to discharge into the CAL. The biogas, methane and energy potential estimated in Table 1, below, are considered 'possible'. Further details and 'conservative' estimates are provided in Appendix I.

Table 1. Expanded Piggery D biogas potential estimates (possible).

Description	Units	Hourly	Annual
Sows	Quantity	1,200	1,200
Piggery operating capacity	SPU	24,838	24,838
Volatile Solids (VS)	kg	233.8	2,049,000
Biogas production rate	m^3 biogas	107.5	942,710
Methane collection	m^3 CH_4	69.9	612,524
Energy	kWh	718.4	6,293,988
Energy	GJ	2.59	23,615
CO_2-e	kg	979	8,577,500

D2. Covered Anaerobic Lagoon (CAL)

Federal Government estimates in 2012 suggested 690 piggeries in Australia may be able to capture and destroy methane. Research also suggests that by 2017, methane generated by 15-20% of the Australian pig herd will be captured and destroyed, increasing to 25-30% by 2020 (Tait, 2014). These estimates suggest CALs (or in some instances engineered digesters) will become a Business-as-Usual (BAU) scenario for many Australian piggeries. This section addresses the first stage in any Waste-to-Energy project, methane collection and destruction in a CAL.

D2.1 CAL dimensions and estimated costs

In addition to lagoon and cover construction Fit-for-Purpose CAL requires a flare, safety and monitoring equipment. The table below outlines the total estimated costs for a CAL with associated methane destruction and safety apparatus.

Table 2. Estimated sizing and costs for a Fit-for-Purpose CAL.

Activity	Description	Cost
Lagoon design & construction earthworks	29,571 m^3	$308,000
Supply and install lagoon cover	8,343 m^2	$266,500
Supply and install flare & control/monitoring system	Includes Development Application	$64,932
Total Cost		$639,432

D2.2 CAL operating costs & benefits

Capture and destruction of methane through the use of a CAL can attract a financial benefit through the Federal Government's Emissions Reduction Fund (ERF) policy. Through a reverse auction, a new carbon abatement project can 'sell' Australian Carbon Credit Units (ACCUs) to the Federal Government. ACCUs will only be generated for the initial seven years of a methane destruction project. The first auction has recently closed and the average price for a tonne of carbon abatement is $13.95 (Clean Energy Website). For the purposes of this feasibility study a price of $10/tonne of CO_2-e has been assumed for remaining auctions in 2015.

Table 3. Estimated annual benefits for the expanded Piggery D under the Emission Reduction Fund (ERF) (possible).

Activity	Description	Annual Benefit to Owner
Annual ERF participation & ACCU Creation	8,577 tonnes of CO2-e destroyed	$85,770
Total Project Returns from ACCU creation	Initial seven years of Project	$600,390

A CAL also incurs additional operating costs relative to an uncovered lagoon. It is estimated an industry best practice lagoon cover (made from low-density polyethylene (LDPE) or polypropylene (PP)) will need replacement after 10 years in operation. Sludge management may also be more labour intensive and costly due to the cover (relative to an uncovered lagoon). Two audits must also be conducted where ACCUs are being created during the first seven years of the project.

Table 4. CAL operating cost estimates for capturing and destroying methane.

Activity	Description	Annual Average Operating Expenditure
Lagoon Cover replacement	Replacement every 10 years	$26,650
Sludge management	Periodic extraction	$20,000
Daily inspection	15 minutes visual inspection	$1,000
ERF Auditing	Twice in seven years	$2,285
Total Operating Expenditure	Annualised	$49,935

There are additional benefits associated with covering a lagoon including odour reduction. Covering a lagoon can decrease odour emission by up to 90% (Tucker *et al*., 2010). This odour reduction may have a positive effect on neighbours and may also allow a piggery to expand operations in the future (Tucker *et al*., 2010).

D3. Waste-to-Energy Project comparisons

In the Australian pork industry, Waste-to-Energy projects involve collecting the biogas produced from anaerobic digestion of the effluent discharged from piggery sheds. This effluent consists of manure, shed flushing and hosing water (which may include some recycled effluent), waste drinking water and spilled feed. Following collection of the biogas, the most cost effective Waste-to-Energy options may be selected after considering the following factors:

- methane potential
- heating requirements of the site
- cooling requirements of the site

- electricity demand of the site.

Options currently being used by the Australian pork industry include:

- on-site electricity generation
- piglet nest heating.

Additional options in this study include:

- shed Cooling
- chilled drinking water
- cool-sow system.

It is estimated that the expanded Piggery D may produce up to 69.9 m^3 of CH_4 or 2.59 GJ of energy every hour, on average. This estimate has been used to appropriately size the Waste-to-Energy system at the piggery.

In the following sections the recommended thermal and electricity generation solutions are discussed. The final section will compare the entire Waste-to-Energy solutions, including the thermal integration options.

D3.1 Site Thermal Solutions

Heat from the combustion of methane, in either a hot water boiler or cogeneration system, may be used to provide on-farm heating requirements, including shed heating and piglet nest heating. Utilising the heat from biogas combustion to produce cooling energy (e.g. absorption chilling) for on-farm use, was also investigated. The primary piggery cooling requirements identified in this study included chilling sow drinking water, sow cooling and piggery shed space cooling. These cooling energy uses peak during warmer months.

Mechanical air cooling of sheds was deemed to be difficult to achieve due to the large volume of air requiring cooling and the nature of the ventilation systems required to maintain shed air quality. Chilling lactating sow drinking water to 20°C was considered to be a more cost-effective use of the available energy generated from biogas.

Micro absorption chillers were investigated for converting biogas heat energy into chilled water for use in mechanical air cooling and producing chilled drinking water; however, pricing and technical information was difficult to obtain for micro absorption chillers in the required range (10 to 50 kW). Consequently, it was concluded that absorption chillers were not currently a viable option for on-farm utilisation of piggery biogas and that drinking water is most effectively chilled using an electric chiller. Electric chillers consume a minimal amount of energy (approximately 20 kWh per pig per annum), and can be installed at a relatively low capital cost, either through retro-fitting or new installation. Providing electric chillers are powered using excess electricity generated on-site from biogas, this option represents an effective use of a renewable energy resource. However, it should be noted that this assumption may not be valid in cases where there is insufficient on-site electricity generated from biogas to satisfy all on-site demands and in cases where the electric chiller electricity consumption reduces export to the grid.

D3.1.1 Chilled Drinking Water

Willis and Collman (2007) found that sows provided with chilled drinking water during hot weather consumed 6.6 L more water and 0.252 kg more feed per day than a control group. In the same study the weaning weight of piglets was 0.7 kg higher amongst litters where sows were provided chilled drinking water. It is estimated by the authors of this study that the increase in weaning weight from providing chilled drinking water will have a benefit of $61/sow/year. This includes the cost of the additional feed.

This study estimates the cost of integrating a chilled drinking water system in sow crates to be $98 per crate. This includes a 2 kW Summit Matsu electric chiller, water storage tank and installation. Due to the simplistic nature of this solution it is assumed the cost to install is equivalent for a new build and a retro-fit.

D3.1.2 Piglet nest heating from biogas

A single 100W infrared heat lamp will be installed in each farrowing crate for zone heating piglets. Use of these electric heat lamps could be offset by installing an under-floor hydronic piglet heating system. In this type of system, hot water from a biogas boiler or cogeneration system is circulated through under-floor heating pads installed in each farrowing pen. An example of this type of system is the Reventa Thermo Plus piglet nest heating system (Figure 7). This study estimates the cost of installing Thermo-Plus heating pads to be $504 per farrowing crate. This cost includes flow and return pipework but does not include any heat source.

Figure 7. Reventa Thermo-Plus piglet nest heating (Reventa website)

It is assumed the 250 sucker heating lamps in the farrowing sheds will be active approximately 6,000 hours per annum and will consume approximately 150,000 kWh of electricity. This feasibility study assumes the installation of piglet nest heating will reduce electricity consumption of these heat lamps by 75% (from the base case). This assumes the heat lamps are still required during the night in the coldest months. Therefore, after installing the new piglet heating system, it is estimated that the on-site electricity demand at the expanded Piggery D will be reduced by 112,500 kWh per year, from the estimated 730,000 kWh to 617,500 kWh per annum.

D3.1.3 Piggery Shed Space Heating

Piggery D employs LPG fired radiant heaters which are activated when the shed ambient temperatures fall below 18°C. Based on incomplete LPG consumption data for a nearby farrow to finish piggery, it is estimated that the expanded Piggery D may conservatively consume 250-300 litres of LPG per annum. Utilising heat from the Waste-to-Energy system for shed space heating will increase the overall value of the system.

Shed heating may be provided by circulating hot water, from a biogas-fired boiler or cogeneration system, through Reventa Deltapipes and/or Twinpipes (Figures 8 and 9) to provide shed space heating. Capital expenditure, including installation costs, is estimated to be $240/kW (0.3 kW per metre). This includes thermal integration with the heat source(s) as required.

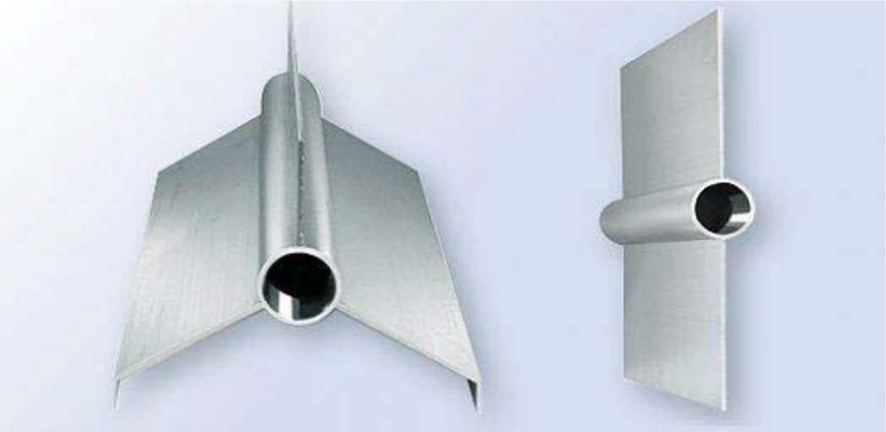

Figure 8. Reventa ;Deltapipe' and 'Twinpipe' finned tube convectors (Reventa website).

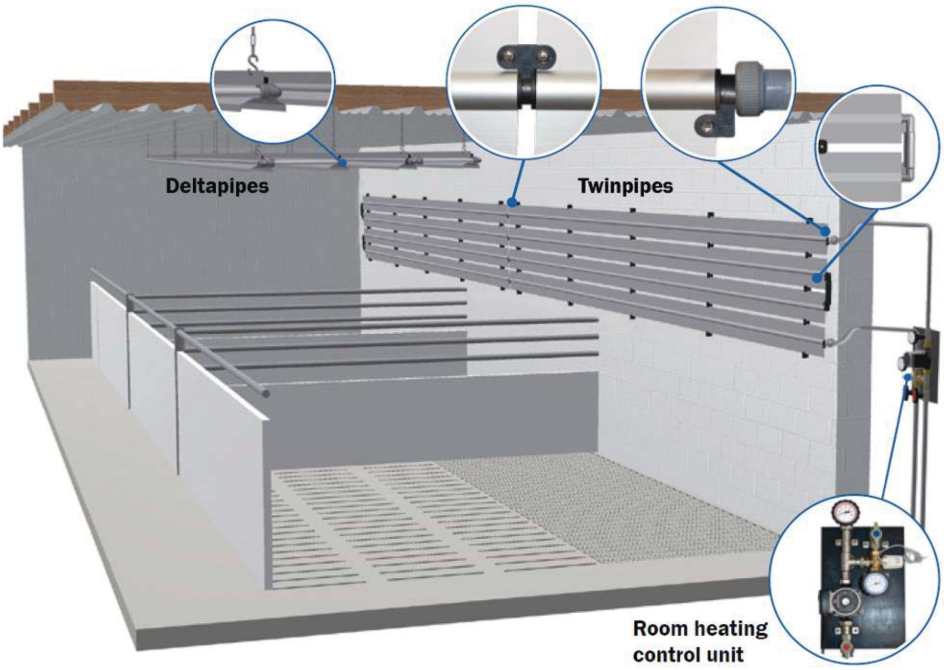

Figure 9. Typical installations of Reventa 'Deltapipe' and 'Twinpipe' finned tube convectors in a piggery building (Reventa website).

It is anticipated that installing 100 kW of Delta/Twinpipe would replace the use of LPG for space heating at the expanded Piggery D. More detailed analysis considering air flows and ventilation rates for each shed would be required to confirm this assumption.

Assuming that space heating is operational across the four coldest months for 10 hours per day, Piggery D would currently require an average of 31 kW of space heating. Assuming that expanded piggery will require approximately three times this amount of space heating, 100 kW of delta pipe is specified. It is anticipated that there will be ample energy available to satisfy this requirement.

The estimated costs and benefits of the thermal solutions are outlined in Table 5.

Table 5. Estimated costs and benefits of thermal solutions.

Activity	Description	Cost per unit	Total Cost	First year returns	Return on Investment
Piglet heating	250 sow stalls	$504	$126,000	$28,125	22%
Sow chilled drinking water	250 sow stalls	$98	$24,500	$15,250	62%
Space Heating	Delta Pipe 100 kW	$240 / kW	$24,000	$10,000	42%
Total cost	Includes installation	$842	$174,500	$53,375	30.5%

D3.2 250 kW Hot Water Boiler

Installing a 250 kW biogas-fired hot water boiler would be the lowest cost Waste-to-Energy solution for Piggery D. A photograph of a biogas-fired hot water boiler installed at a Queensland piggery is provided in Figure 10 (Skerman, 2012). Hot water from the boiler would supply the hydronic piglet heating pads to offset heat lamp electricity consumption. The boiler would also supply heat to the installed delta pipes for shed space heating thereby offsetting LPG use.

Figure 10. Biogas hot water boiler and ancillary equipment at Grantham Piggery (Skerman, 2012)

D3.2.1 Capital Expenditure

Table 6 outlines the estimated capital costs associated with the installation of a 250 kW biogas boiler.

Table 6. Estimated capital costs of installing an 80 kW boiler at Piggery C.

Activity	Description	Cost
Biogas Conditioning	Chiller (to condense biogas moisture), knock out pot & plant room	$33,720
Boiler System	250 kW Hot Water Capacity	$58,000
Installation & Commissioning	Mechanical & electrical integration to site	$20,000
Total Cost ex GST		$111,720

Running the 250 kW boiler does not necessarily require a ferric oxide scrubber. Biogas boilers may tolerate biogas hydrogen sulphide (H_2S) concentrations up to 1000ppm. Because, H_2S concentrations up to 3000 ppm have been recorded in biogas produced by Australian piggeries, some form of biogas scrubbing may be required to avoid excessive corrosion and increased health risks associated with high biogas H_2S concentrations. Chilling the biogas to 4°C is expected to condense the biogas moisture, thereby reducing the risk of excessive corrosion.

D3.2.2 Operating Costs

Table 7. outlines the estimated operating costs for a 250 kW hot water boiler.

Activity	Description	Annual Cost to Owner
Boiler Maintenance	Service, consumables	$2,000
Biogas Chiller operation	Electricity usage	$300
Biogas system Maintenance	General maintenance	$2,000
Total Operating Expenditure (Opex)		$4,300

Installing the biogas fuelled hot water boiler represents the lowest cost Waste-to-Energy option explored in this study. While this option will not provide electricity (from a renewable source) for chilled drinking water or the site requirements, the boiler will produce enough thermal energy for the piglet nest heating and shed space heating discussed in section 3.1 (with the associated financial returns). Total capital expenditure for the thermal heat only solution is $261,720 (boiler, biogas conditioning and piglet nest and shed heating) with a net benefit of $33,825 for a first year project Return on Investment (RoI) of 13%. Additional Waste-to-Energy options for the expansion site, including on-site electricity generation, are discussed in the following sections.

D3.3 Ener-G 100 kW + Yanmar 25 kW Cogeneration Systems

This solution involves installing a 100 kW Ener-G Combined Heat and Power (CHP) biogas-fired generator, with waste heat recovery, combined with a Yanmar 25 kW micro CHP system, resulting in a total of 125 kW of instantaneous electricity generation capability. This combination will allow a greater amount of site 'load following' than a single 125 kW system. It is estimated that the system will generate 185 kW of thermal energy while the engines are running which is less than the thermal energy required for the piglet nest and space heating. Therefore, this solution will also require the installation of a 100 kW biogas boiler for use during the coldest periods. An added benefit of the boiler is redundancy to provide heat when the cogeneration system is not operating. This section does not include the costs or benefits of the thermal integration and hence the cost of the boiler is not included. These costs will be addressed in the comparison and conclusion of the different scenarios.

D3.3.1 Capital Expenditure

Table 8 outlines the estimated capital cost of the suggested 125 kW biogas-fired cogeneration system, incorporating a 100 kW Ener-G CHP unit and a Yanmar 25 kW CHP unit.

Table 8. Estimated capital cost of 125 kW cogeneration system (100 kW Ener-G + Yanmar 25 kW biogas-fired CHP systems)

Activity	Description	Capital Expenditure
Biogas Conditioning	Chiller, ferric oxide scrubber, knock out pot & plant room	$66,120
Cogeneration System	25 kW Yanmar + 100 kW Ener-G	$357,000
Installation & Commissioning	Mechanical & electrical integration to site	$155,000
Total Cost ex GST		$578,120

The biogas conditioning equipment purchase and installation is assumed to be the same for all Waste-to-Energy projects considered in this feasibility study. Market research suggests there are limited options for biogas conditioning for small to medium sized Waste-to-Energy projects.

D3.2.2 Project Cash-flows

Table 9, below, describes the annual operating costs of the proposed 125 kW cogeneration system. Both the maintenance and overhauls are calculated on a per kWh basis and the overhaul costs have been annualised. Table 10 outlines the estimated annual project returns.

Table 9. Estimated operating costs for 125 kW cogeneration system (100 kW Ener-G + Yanmar 25 kW biogas-fired CHP systems)

Activity	Description	Annual Cost to Owner
Cogeneration Maintenance	Oil Change, consumables	$13,893
Cogeneration overhauls	Changing heads, boring cylinders, rebuilds	$12,300
Biogas system Maintenance	General maintenance & ferric oxide replacement	$9,631
Total Operating Expenditure (Opex)		$35,825

Table 10. Estimated annual project returns for 125 kW cogeneration system (100 kW Ener-G + Yanmar 25 kW biogas-fired CHP systems)

Activity	Description	Annual Benefit
Electricity Generation utilised on-site	468,000 kWh @ $0.25/kWh	$117,200
Renewable Energy Certificates	468,000 kWh*0.9*$0.0395	$16,637
Total project returns		$133,837

Figure 10, below, shows the site's baseline electricity demand (red dashed line), the new demand for power after the installation of piglet nest heating and the power generated by the 125 kW cogeneration system.

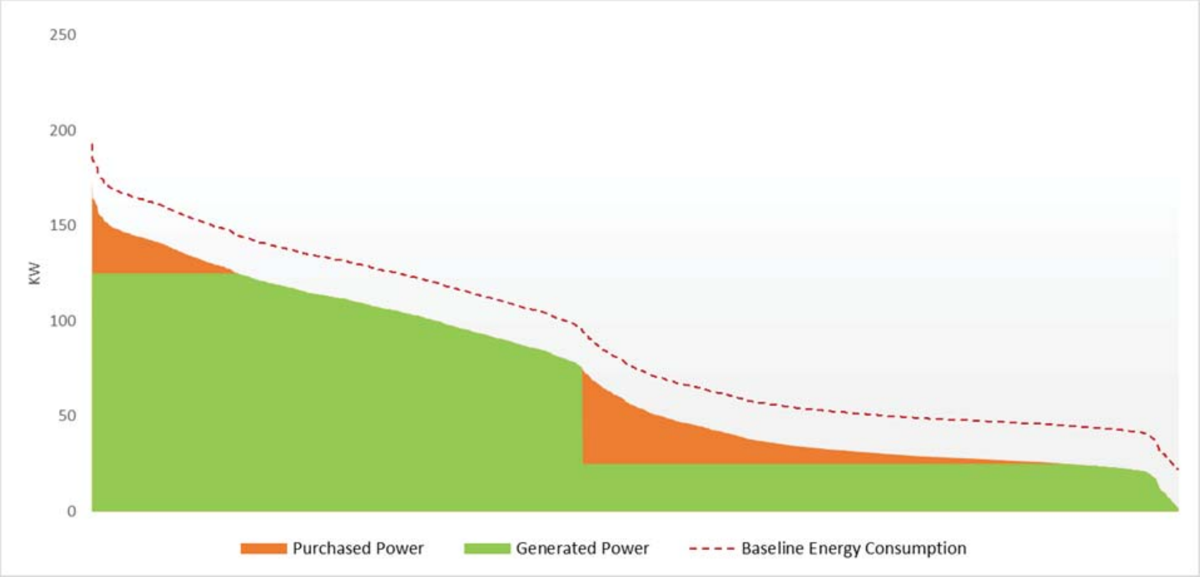

Figure 10. New site electricity demand and on-site generation

Table 11, below, summarises the financial outcome for the suggested 125 kW cogeneration system (100 kW Ener-G + Yanmar 25 kW biogas-fired CHP units).

Table 11. Financial outcome summary for 125 kW cogeneration system (100 kW Ener-G + Yanmar 25 kW biogas-fired CHP systems)

Activity	Capital expenditure	Operating expenditure	Project returns	Net project returns	Return on Investment (RoI)
125 kW electricity generation	$578,120	$35,8225	$132,245	$96,420	17%

D3.3 Ener-G 230 kW cogeneration system

The largest cogeneration system possible at Homestead Expansion (based on the methane production in a CAL) is a 230 kW system. The Ener-G 230 kW is unable to produce electricity below 50% of nameplate capacity and operates optimally no lower than 75% of nameplate capacity. This is typical of most cogeneration systems running on either natural gas or biogas.

After accounting for the reduction in electricity demand from the electric heat lamps (by utilising the Thermo-Plus piglet nest heating) the new site electricity demand is under 200 kW all of the time (possibly excluding a few hours every year). For the 2300 kW system to operate optimally it must export significant amounts of total electricity generation to the grid.

D3.3.1 Ener-G 230 kW Capital Expenditure

Table 12 outlines the estimated capital expenditure for the Ener-G 230 kW cogeneration system.

Table 12. Estimated capital expenditure for the Ener-G 230 kW cogeneration system.

Activity	Description	Cost
Biogas Conditioning	Chiller, ferric oxide scrubber, knock out pot & plant room	$66,120
Cogeneration System	230 kW generation capacity	$421,200
Installation & Commissioning	Mechanical & electrical integration to site	$156,000
Total Cost ex GST		$642,120

In comparison to the 125 kW cogeneration option, the capital expenditure required to utilise most of the methane potential at the expanded piggery increases overall; however, the fixed costs associated with the installation decrease. Cogeneration system capital costs also decrease per kW, as expected under an ‘economies of scale’ scenario.

D3.3.2 Ener-G 230 kW Operating Costs

Table 13, below, outlines the estimated operating expenditure associated with the Ener-G 230 kW cogeneration system.

Table 13. Estimated operating expenditure for the Ener-G 230 kW cogeneration system.

Activity	Description	Annual Cost to Owner
Cogeneration Maintenance	Oil Change, consumables	$53,375
Cogeneration overhauls	Changing heads, boring cylinders, rebuilds	$13,142
Biogas system Maintenance	General maintenance & ferric oxide replacement	$23,113
Total Operating Expenditure (Opex)		$90,674

The significant increase in maintenance costs reflect both the increase in kWh of electricity produced and the amount of biogas requiring H_2S scrubbing for the system to perform optimally.

Table 14. Estimated project returns for the Ener-G 230 kW cogeneration system.

Activity	Description	Project returns
Electricity generation utilised on-site	576,000 kWh * $0.25	$138,938
Exported electricity	1,314,720 kWh*$0.025	$37,772
Renewable Energy Certificates	1,890,720 kWh*0.9*0.0395	$64,464
Total project returns		$241,128

Figure 11, below, shows the site's baseline electricity demand (red dashed line), the new demand for power after the installation of piglet nest heating and the power generated by the Ener-G 230 kW. It is assumed that the cogeneration system is operational 90% of the time, or available after scheduled maintenance to generate electricity.

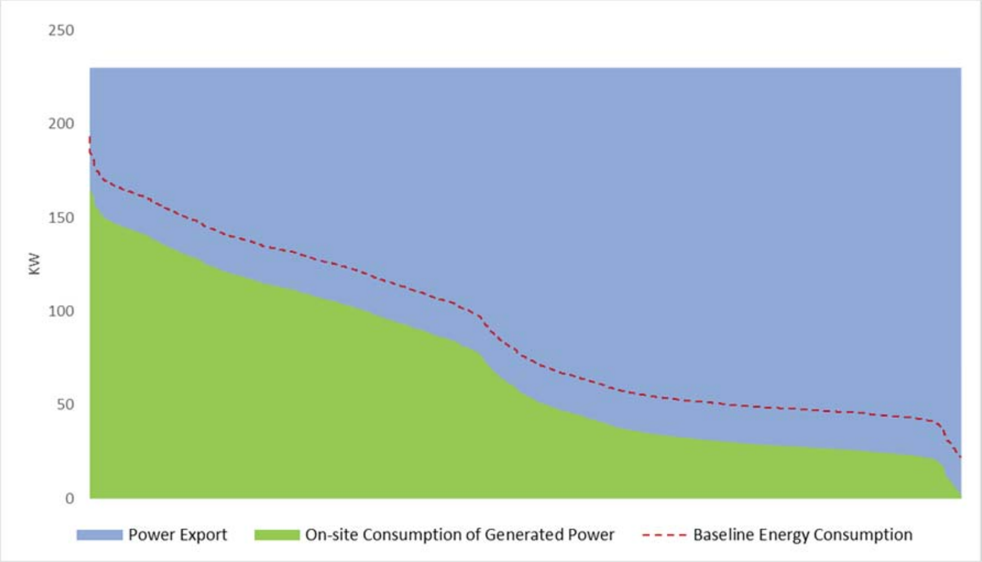

Figure 11. New site electricity demand and on-site generation.

Table 15, below, summarises the financial outcome for the suggested Ener-G 230 kW biogas-fired cogeneration system.

Table 15. Financial outcome summary for the Ener-G 230 kW biogas-fired cogeneration system

Activity	Capital Expenditure	Operating Expenditure	Benefit	Net Project Returns	Return on Investment
Ener-G 230 kW & biogas conditioning	$643,320	$90,674	$241,128	$150,545	25%

D3.4 Scenario comparison and conclusion

Table 16 provides a comparison of costs and returns associated with the 125 and 230 kW cogeneration system options.

Table 16. Comparison of costs and returns associated with the two biogas use options, including thermal integration.

	125 kW Cogeneration System with Thermal Integration	230 kW Cogeneration System with Thermal Integration
Total Capital Expenditure cogeneration system	$578,120	$643,320
Cost per kW(e) installed	$4,625	$2,797
Cost of thermal integration	$174,500	$174,500
Total project costs (ex CAL)	$827,620	$817,820
Net project returns	$149,795	$203,829
Return on Investment	18%	25%

In conclusion, it appears that the 230 kW cogeneration system with thermal integration option offers the best overall outcome, producing almost all of the electricity required to satisfy the on-site demand, while exporting significant amounts of electricity to the grid. The thermal energy generated by the system is also expected to satisfy the recommended on-site thermal integration heating requirements. While the exported electricity has a relatively low value, based on existing incentives, the larger cogeneration system allows a higher percentage of the on-site electricity consumption to be offset from on-farm generation. Furthermore, the cost per kW(e) installed is considerably lower for this option. The total project RoI is estimated at 25% (not including the CAL construction costs or ERF subsidy).

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Appendix I Estimates of conservative and possible production of volatile solids, biogas, methane, thermal energy and equivalent CO_2 emissions.

Parameter	Units	Conservative	Possible
VS from sheds	kg VS/SPU/yr	90	110
	t VS/yr	2,235	2,732
VS removal in solids separator	%	25	25
VS to CAL	t VS/yr	1,677	2,049
Biogas production rate	m^3 biogas/kg VS added	0.43	0.46
Biogas production	m^3 biogas/yr	720,923	942,602
Biogas methane content	%	65	65
Methane (CH_4) production rate	m^3 CH_4/kg VS	0.28	0.30
Methane (CH_4) production	m^3 CH_4/yr	468,600	612,691
Methane lower heating value (LHV)	MJ/Nm^3 CH_4	33.35	33.35
Methane thermal energy	GJ/yr	15,629	20,434
	kW.hr/yr	4,341,276	5,676,190
CO_2 emissions	t CO_2-e/yr	6,676	8,729

Appendix II Assumptions used in calculating the required dimensions for a 'fit-for-purpose' CAL to service the proposed expanded Piggery D.

Parameter	Units	Value
Possible VS discharge to CAL	t VS/yr	2,732
Anaerobic pond activity ratio, k		0.96
Baseline VS loading rate	kg VS/m^3/day	0.4
Adjusted VS loading rate	kg VS/m^3/day	0.384
Treatment volume	m^3	14,610
Assumed VS/TS ratio		0.83
Estimated TS to pond	kg TS/day	6,759
Sludge accumulation rate	m^3/kg TS	0.00303
Desludging interval	years	2
Required sludge storage volume	m^3	14,961
Total storage volume	m^3	29,571
Total storage volume per SPU	m^3/SPU	1.19
Total storage depth	m	6
Batter - lengthwise, (1 vertical : Z horizontal)		2
Batter - breadthwise, (1 vertical : Z horizontal)		2
Freeboard - full storage level to crest	m	0.5
Length - at embankment crest	m	150.00
Breadth - at embankment crest	m	49.89
Length - at full storage level	m	148.00
Breadth - at full storage level	m	47.89
Length - at base	m	124.00
Breadth - at base	m	23.89
Cover additional anchorage allowance	m	2
Cover length	m	154.24
Cover breadth	m	54.12
Cover area - trenched into bank	m^2	8,348