Biogas Production by Covered Lagoons

— Performance data from Bears Lagoon piggery —

RIRDC Publication No. 10/023
Biogas Production by Covered Lagoons

Performance data from Bears Lagoon piggery

by Scott Birchall

May 2010
RIRDC Publication No 00/023
RIRDC Project No. PRJ-002705
Foreword

Methane is the dominant greenhouse gas emission from Australian agriculture and, within the livestock sector, has been identified as a priority area for emission reductions under the National Agriculture and Climate Change Plan 2006-2009. The potential for capture and use of methane is greatest in the intensive livestock industries, where manure management is estimated to contribute three percent of the emissions from Australian agriculture.

The project reported here was funded by the AM2MA program, which is a collaborative venture between government and industry funded by the Department of Agriculture, Fisheries and Forestry with industry funding and support from the Rural Industries Research and Development Corporation, Dairy Australia, Australian Pork, Meat and Livestock Australia, the Australian Lot Feeders’ Association, and the Australian Chicken Meat Federation.

Covered anaerobic lagoon systems offer the potential to mitigate greenhouse gas emissions and provide sustainable energy. Performance data collected from pilot sites operating under Australian conditions is a key part of reducing the uncertainty and risk for operators proposing to implement methane capture and use technology.

The monitoring program completed at the George Weston Foods owned Bears Lagoon piggery is the first comprehensive set of data on the performance of a covered anaerobic lagoon at a piggery in Australia. As a result of determining monthly methane yields, the work demonstrates the significant power generation potential from piggeries and that a large operation such as Bears Lagoon piggery could power approximately 270 households.

The report also presents a number of recommendations regarding the parameters to monitor and the basis of the results to allow data from different sites, and different industries, to be compared.

The objectives of the AM2MA program are:

1. development and adaptation of methane capture and use technology for application in the Australian intensive livestock industries
2. reduction of the uncertainty, risk and cost of installing methane capture and use systems
3. effective communication of project outcomes
4. facilitation of commercialisation of on-farm systems for methane capture and use technology.

This report adds to RIRDC’s diverse range of over 2000 research publications, forms part of our New Industries R&D program, which aims to encourage and enable development, adaptation and use of methane capture and use technology in the Australian intensive livestock industries.

Most of RIRDC’s publications are available for viewing, downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Tony Byrne
Acting Managing Director
Rural Industries Research and Development Corporation
Acknowledgments

Specific thanks must be offered to the following people and organisations:

- The management and staff at the George Weston Foods/Don KRC owned Bears Lagoon Piggery; in particular, Ian Connaughton and Russell Gladman for providing the assistance necessary to complete the 12 month-long intensive monitoring program
- Preethi Gopalan and Dr. Damien Batstone from The University of Queensland’s Advanced Water Management Centre
- Bruce Edgerton, former Manager (Environmental Sustainability), APL

Abbreviations

APL – Australian Pork Limited
CAL – covered anaerobic lagoon
CH$_4$ – methane
CO$_2$ – carbon dioxide
COD – chemical oxygen demand
HRT – hydraulic retention time
LHV – low heat value
MCF – methane conversion factor
RIRDC – Rural Industries Research and Development Corporation
RTD – resistance temperature device
SPU – standard pig units
TKN – total Kjeldahl nitrogen
TS – total solids
VFA – volatile fatty acids
VS – volatile solids
VSLR – volatile solids loading rate
Tables

Table 1. Climate statistics for Bendigo Airport (BOM Station 081123, 1991-2009) ............................................. 3
Table 2. Summary of monitoring provisions ......................................................................................................... 4
Table 3. Summary of characteristics of screened wastewater (June 2008 – March 2009) .................................... 16
Table 4. Mean methane (CH₄) and carbon dioxide (CO₂) concentrations (June 2008 – May 2009) ................... 17
Table 5. Methane yield ........................................................................................................................................ 18
Table 6. Comparable sludge accumulation rates ................................................................................................. 21
Table 7. VS/TS ratio for settled solids/sludge ..................................................................................................... 22
Table 8. Sensitivity analysis results ..................................................................................................................... 25

Figures

Figure 1. Wastewater treatment system – layout and monitoring/sampling points ............................................. 5
Figure 2. Wastewater flow meter at collection sump ........................................................................................... 5
Figure 3. Effluent temperature and pH probe mounted on a float in the discharge pit ........................................... 7
Figure 4. Ambient temperature screen and datalogger/power supply enclosure .................................................. 7
Figure 5. Biogas flow meter (in rectangle) ........................................................................................................... 8
Figure 6. Automatic sampling station ................................................................................................................ 10
Figure 7. Biogas sampling apparatus and 0.5L Tedlar bag ................................................................................ 10
Figure 8. The completed CAL earthworks (2004) ............................................................................................. 11
Figure 9. Daily wastewater inflow to the CAL ................................................................................................... 12
Figure 10. Mean monthly ambient and effluent temperatures ......................................................................... 13
Figure 11. VS concentrations in influent and effluent ........................................................................................ 14
Figure 12. COD concentrations in influent and effluent (excluding unscreened samples from April/May 2009) .......................................................... 15
Figure 13. Daily COD and VS load in influent ................................................................................................... 15
Figure 14. Gas production and methane concentration ................................................................................... 17
Figure 16. Conceptual components of a treatment lagoon (Chastain 2006) ......................................................... 20
Figure 17. TS in settled solids/sludge ................................................................................................................ 22
Figure 18. VS in settled solids/sludge ................................................................................................................ 22
Figure 19. Sludge extraction pump ...................................................................................................................... 23
Executive summary

What the report is about

This report documents the performance of a covered anaerobic lagoon during 12 months of intensive monitoring. The lagoon is the centre-piece of the waste treatment system for the Bears Lagoon piggery owned by George Weston Foods Limited.

The report collates the measured parameters (organic load, temperature, wastewater volumes, and biogas production and composition) and determines the methane yield for each month of the monitoring period.

Who is the report targeted at?

The target audience for this report includes:

- Researchers attempting to improve the state of knowledge regarding anaerobic digestion in ambient covered lagoons. Specific mention is made of the Advance Water Management Centre at The University of Queensland and their intent to validate an anaerobic digestion model for agricultural wastewaters.

- Advisors and proponents intending to complete a feasibility analysis for a potential biogas project.

Background

Covered lagoon systems offer the potential to mitigate greenhouse gas emissions, provide sustainable energy and improve community amenity via odour control. However, such technology is still in its infancy in Australia and only a small number of intensive agricultural sites have installed covers and systems for methane capture. Proponents are in need of data demonstrating the quantity and quality of biogas produced under Australian operating conditions rather than relying on estimates or data from overseas studies.

Aims/objectives

The project was designed to fill the need for reliable data on the production of methane from a covered anaerobic lagoon operating under ambient conditions. Such data will support the Australian pork industry move towards reduced greenhouse gas emissions and also assist other livestock industries to understand the potential offered by such systems.

Methods used

Instrumentation was installed to measure certain parameters continuously (ambient and wastewater temperature, pH, wastewater volume, biogas volume) or sample intensively over 7 consecutive days each month prior to laboratory analysis for total solids (TS), volatile solids (VS), chemical oxygen demand (COD), volatile fatty acids (VFA), total Kjeldahl nitrogen (TKN), methane (CH₄), and carbon dioxide (CO₂).

Sampling of the settled solids/sludge was carried out to assess the characteristics of the layers below the supernatant and identify the solids accumulation rate.
Results/key findings

The key findings of the project include:

- Lagoon temperatures were around 5°C warmer than ambient with some attenuation (of the maximum and minimum) and lag at 3.5 m depth.

- The measurement of VS for samples with significant VFA concentrations appear to be compromised by volatilisation of a portion of those VFA’s during dry matter (TS) determination. Approximately 22% of the total COD to the lagoon was due to the wastewater’s VFA content.

- The mean methane concentration in the biogas was 63.2%. Carbon dioxide accounted for 18.8% of the remainder.

- The mean methane production represented an energy yield of 71 400 MJ d⁻¹. Assuming a conservative electrical conversion efficiency of 25%, the power generation potential is 207 kW; enough to power 270 Australian households. The power generation potential was 0.9 kW per 100 standard pig units (SPU) or 0.009 kW per SPU (1 SPU is equivalent to 1 grower pig of 40kg nominal liveweight).

- The mean methane yield was 0.18 kg CH₄ kg⁻¹ COD (across 10 months of the 12 month period) and represents a methane conversion factor (MCF) of 72%

- The solids accumulation rate was determined to be 0.00094 m³ kg⁻¹ TS over 5 years of operation.

Implications for relevant stakeholders

Industry, advisors and researchers should be aware that the key findings for methane composition, yield and power generation all fall within the ranges reported in the literature. The solids accumulation rate was at the low end, but within the range reported by other researchers.

If confirmed, the loss of VFA’s during drying will have implications for effluent system design and investigation and requires further discussion.

Recommendations

For researchers working on biogas projects, the following recommendations are made:

- A positive displacement type biogas meter should be used if possible.

- Measure COD concentrations in the wastewater and sludge. If VS is to be used, VFA must also be measured.

- Reporting biogas production or yield in volumetric terms is to be avoided due to the potential application of incorrect gas conditions. Expressing the methane yield in terms of mass (kg CH₄ kg⁻¹ COD) is preferable.
Introduction

Covered lagoon systems offer the potential to mitigate greenhouse gas emissions, provide sustainable energy and improve community amenity via odour control. However, such technology is still in its infancy in Australia and only a small number of intensive agricultural sites have installed covers and systems for methane capture. Little data has therefore been generated demonstrating the quantity and quality of biogas actually produced.

In addition, there are currently no widely available tools to allow advisors/producers to investigate the feasibility of installing a cover and methane capture. Researchers at The University of Queensland are intending to modify and validate an existing anaerobic digestion model based on data from agricultural sites.
Objectives

The objectives of the project were to:


2. Determine methane productivity in terms of mass of methane per kilogram of volatile solids or chemical oxygen demand added (kg CH₄ kg⁻¹ VS added, or kg CH₄ kg⁻¹ COD added) over a range of ambient temperatures for piggery anaerobic lagoons.

3. Monitor sludge and inert solids volumes to determine the active treatment volume to which the digester performance applies.

4. Determine the sludge accumulation rate for comparison with the Barth Standard and recent work by Skerman (Australian Pork Limited project no. 2108).


6. Provide performance data to researchers at The University of Queensland Advanced Water Management Centre.
Site description

Bears Lagoon Piggery is a commercial grow-out operation (accommodating nursery through to finisher pigs) located approximately 60 km north-west of Bendigo, Victoria. The operation is owned by George Weston Foods Limited.

Pig numbers on-site averaged 23 000 standard pig units (SPU) during the 12 month monitoring period from June 2008 to May 2009.

The piggery operation comprises two separate units:

- Unit 1 houses nursery pigs from 18 days of age progressing through to weaner and grower pig groups (14 sheds in total)
- At 17 weeks, pigs are transported across to Unit 2 (12 sheds in total) for finishing before being sold at 23-24 weeks

All sheds have under floor flush alleys with bore water supplying the drinking water and water for flushing.

While the nursery, weaner and grower pigs (Unit 1) are located approximately 600m from the finishers (Unit 2), all wastewater is pumped to the main wastewater sump and treatment system located adjacent to Unit 2. The treatment system comprises a pair of static screens, an 18ML covered anaerobic lagoon (CAL), a 9ML partially aerated basin and a 120 ML winter storage. Treated effluent is distributed over an area of flood irrigation on-farm.

The 18 ML CAL and biogas flare was added to the system in June 2004 and has been operated without being desludged since that time.

Table 1. Climate statistics for Bendigo Airport (BOM Station 081123, 1991-2009)

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Ann</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Max. (°C)</td>
<td>29.5</td>
<td>29.4</td>
<td>26.0</td>
<td>21.2</td>
<td>16.6</td>
<td>13.3</td>
<td>12.5</td>
<td>14.2</td>
<td>16.7</td>
<td>20.3</td>
<td>23.9</td>
<td>26.9</td>
</tr>
<tr>
<td>Mean Min. (°C)</td>
<td>13.9</td>
<td>14.1</td>
<td>11.3</td>
<td>7.4</td>
<td>5.2</td>
<td>3.6</td>
<td>2.4</td>
<td>2.4</td>
<td>4.3</td>
<td>6.3</td>
<td>9.3</td>
<td>11.5</td>
</tr>
<tr>
<td>Median Rain (mm)</td>
<td>22.9</td>
<td>22.2</td>
<td>12.9</td>
<td>22.5</td>
<td>32.5</td>
<td>39.8</td>
<td>57.8</td>
<td>48.4</td>
<td>40</td>
<td>42.4</td>
<td>39.7</td>
<td>31.4</td>
</tr>
<tr>
<td>Mean Rain Days &gt;1 mm</td>
<td>3.9</td>
<td>2.9</td>
<td>3.2</td>
<td>4.0</td>
<td>6.4</td>
<td>7.7</td>
<td>8.9</td>
<td>7.4</td>
<td>7.9</td>
<td>5.6</td>
<td>5.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Mean clear days</td>
<td>12.7</td>
<td>12.8</td>
<td>13.7</td>
<td>12.1</td>
<td>7.9</td>
<td>6.1</td>
<td>5.4</td>
<td>7.2</td>
<td>6.7</td>
<td>7.4</td>
<td>8.6</td>
<td>10.5</td>
</tr>
<tr>
<td>Mean cloudy days</td>
<td>6.8</td>
<td>4.7</td>
<td>4.4</td>
<td>6.8</td>
<td>11.2</td>
<td>12.4</td>
<td>13.2</td>
<td>11.5</td>
<td>10.6</td>
<td>8.3</td>
<td>7.8</td>
<td>7.6</td>
</tr>
</tbody>
</table>
Methodology

To document the performance of the covered anaerobic lagoon, the parameters listed in Table 2 were continuously monitored or measured from samples taken at monthly intervals.

Table 2. Summary of monitoring provisions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Instrument/Procedure</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Continuous measurement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wastewater flow rate and volume</td>
<td>100 mm Siemens Sitrans Magflo electromagnetic flow meter</td>
<td>Main collection sump</td>
</tr>
<tr>
<td>CAL temperature at 0.5, 1.5 and 3.5 m below surface level</td>
<td>Hobo Pro V2 sealed logger units</td>
<td>Water column via emergency gas vent no. 8</td>
</tr>
<tr>
<td>CAL effluent temperature</td>
<td>Platinum resistance temperature device (RTD)</td>
<td>Effluent discharge pit</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>Platinum RTD</td>
<td>Effluent discharge pit</td>
</tr>
<tr>
<td>CAL effluent pH</td>
<td>Ionode IJ44 intermediate junction probe</td>
<td>Effluent discharge pit</td>
</tr>
<tr>
<td>Biogas flow</td>
<td>Yokogowa EJA orifice plate and differential pressure transducer</td>
<td>Blower/flare</td>
</tr>
<tr>
<td><strong>Monthly sampling events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influent TS, VS, COD, COD soluble, TKN, Ammonia, VFA</td>
<td>Sampling occurred continuously during each 24 hr period over 7 days via an automatic sampling station (paddle switch, cycling timer, Onga 421 open-impeller pump, and 750 L uninsulated tank). Each 24 hr composite was agitated before sub-samples were collected and refrigerated until the end of the 7 day event.</td>
<td>Influent pipeline to CAL</td>
</tr>
<tr>
<td>Effluent TS, VS, COD, COD soluble, TKN, Ammonia, VFA</td>
<td>20 L samples collected at 9 am on days 1, 3, 5 and 7; agitated, sub-sampled and refrigerated until the end of the 7 day event.</td>
<td>Effluent discharge weir</td>
</tr>
<tr>
<td>Biogas composition (CH₄, CO₂)</td>
<td>0.5 L samples collected in Tedlar bags at 9am and 4 pm on days 2 and 6 of every 7 day sampling event. Composition analysed by mass spectroscopy.</td>
<td>Blower/flare</td>
</tr>
</tbody>
</table>

The location of the monitoring and sampling points listed in Table 2 are shown in Figure 1.

Wastewater flow rate and volume

All wastewater from both Unit 1 and Unit 2 was either pumped or flowed via concrete box drain into the main collection sump. To keep solids in suspension, a paddle-type agitator operated continuously within the sump. A submersible pump (Flygt N3140) with float switch control transferred wastewater to the two run-down screens (up until April 20, 2009) or directly to the CAL (after April 20, 2009).

The electromagnetic flow meter installed in the discharge pipe from the sump (Figure 2) logged daily total flow volumes to internal memory for up to 26 days.
Figure 1. Wastewater treatment system – layout and monitoring/sampling points

Figure 2. Wastewater flow meter at collection sump
Effluent temperature and pH, and ambient temperature

The three Hobo Pro V2 temperature probes were suspended on stainless steel trace through an emergency gas vent (number 8 of 9) in the cover near the discharge end. The probes were suspended at depths of 0.5 m, 1.5 m and 3.5 m below water surface and logged the wastewater temperature at 5 minute intervals. To download data, the probes were pulled to the surface and connected to a handheld data shuttle.

The 0.5 m depth temperature probe was also used to indicate a shutdown in the biogas blower/flare. As the cover tended to lift off the surface at the discharge end when gas was not being extracted, any sharp spike in the temperature recorded indicated that it had been lifted out of the liquor as biogas pressure built and ‘inflated’ the cover.

Effluent temperature and pH were measured below a HDPE float in the open pit on the effluent discharge pipeline (Figure 3). Ambient temperature is measured using a screened RTD mounted at 1.8m beside the effluent discharge pit (Figure 4). Effluent temperature and pH, and ambient temperature, were measured every minute, and a Datataker DT50 logged the average over each 15 minute period.

Measurement of gas production

The orifice plate and differential pressure transducer was located between the blower and flare (Figure 5). It measured the flowrate every second and produces a 4-20 mA output logged by a Datataker DT81. The Datataker reports an average and maximum flowrate over each 15 minute period.
Figure 3. Effluent temperature and pH probe mounted on a float in the discharge pit

Figure 4. Ambient temperature screen and datalogger/power supply enclosure
Figure 5. Biogas flow meter (in rectangle)
Sampling station for wastewater inflows

At the start of the project there was some concern that having 26 sheds, each cleaned once per week with each group of pigs cleaned on a different day of the week, would produce significant variation in the organic load from day to day. Therefore we made the decision to install the automatic sampling station and sample each day of a 7 day period (Figure 6).

Whenever the paddle switch detected a flow in the pipeline (which ran full), it activated the cycling controller/timer. The cycling controller/timer then started the sampling pump to run for approximately 30 seconds in each 4 minute period; a ratio designed to almost completely fill the 750 litre fibreglass temporary storage tank over the 24 hour period. A note was made if the tank overflowed as that had the potential to increase the apparent solids content.

At the end of each 24 hour period, the site manager agitated the contents of the temporary storage tank, filled a 20 L container using a bleed valve on the pump return (agitation) line. He then collected the necessary samples while agitating the 20 L container.

Effluent sampling

Prior to September 2008, effluent samples were collected using a suction pump to draw from below the water level in the discharge pit. We became concerned that this method was picking up some of the solids settled in the pit. From the September sampling event onwards, a small rectangular plastic basin was used to catch effluent as it passed over the discharge weir avoiding any chance of entraining settled solids from the discharge pit.

Biogas sampling

Biogas samples were extracted via a 12 mm ball valve between the blower and gas flow meter. A 12 mm BSP fitting with two LDPE tubes attached (Figure 7) was screwed onto the ball valve. The valve was opened to flush the tubing and then the bag was attached and filled. By exerting pressure on the 0.5 L Tedlar bag, the gas collected was expelled via the second tube before being refilled with biogas. The bags were flushed three times to avoid sample contamination.

Sample transportation

On the final day (day 7) of each sampling event, all samples were taken from the refrigerator and packed into an esky with disposable ice packs for overnight transportation to the laboratory at the Advanced Water Management Centre, The University of Queensland.

Biogas samples were road freighted to UQ and arrived within 2 to 3 days.
Figure 6. Automatic sampling station

Figure 7. Biogas sampling apparatus and 0.5L Tedlar bag
Topographic survey

Investigations with the contractors that built the CAL revealed that an as-constructed survey of the structure was not carried out after completion of the earthworks.

Therefore in order to estimate the volume of the CAL, we surveyed the lagoons’ liquid surface area (identifying the point where the floating HDPE cover met the earthen batter) and the depth to the base (through the emergency vent ports). The liquid depth in the CAL was measured at 7.48 m.

We assumed that the bed width was 2.4 m (the minimum width for earthmoving equipment) based on the photograph shown in Figure 8.

The volume of the CAL was subsequently calculated to be 17.9 ML; close to the design volume of 18 ML.

![Figure 8. The completed CAL earthworks (2004)](image)

Sludge sampling

In March 2009, a sludge sampling event was conducted to determine the volume and characteristics of sludge in the CAL. A 12V open-impeller submersible pump (OD 50 mm) was attached to a graduated steel probe and lowered down into the water column through the emergency gas vents. A 12 mm HDPE tube delivered the discharged sludge back to the surface for sampling.

Samples were collected at 0.5m intervals starting at 2.0m and progressing to the bottom (or the depth at which the solids content of the sludge exceeded the pump capabilities) at vent locations 2, 5 and 8 (2 being the second vent numbered from the inlet end of the CAL). The depth at which the discharge changed colour from brown to black was noted at each vent.
Performance data and methane yield

Data was collected over the period from June 2008 to May 2009 and summaries of that data follow. Longer data sets are available for the continuously monitored parameters. All monitoring instruments, with the exception of pH, were left in place (logging at a reduced frequency) at the completion of the May sampling event in the expectation that further work will be required.

Wastewater flow rate and HRT

The median flow over the 12 month period was 493 kL d\(^{-1}\) (1\(^{st}\) decile flow 340 kL d\(^{-1}\), 9\(^{th}\) decile flow 735 kL d\(^{-1}\)). Inflows to the CAL were higher in the warmer months (Figure 9); partly a result of increased water use for pig cooling.

![Figure 9. Daily wastewater inflow to the CAL](image)

Based on a volume of 17.9 ML, the median hydraulic retention time (HRT) was 36 days for the above period. Note that this does not take into account the volume occupied by sludge (see ‘Sludge accumulation and desludging’).

Effluent and ambient temperature

The mean ambient temperature over the 12 month period at the site was 15.2°C with a mean monthly temperature ranging from 8.0°C to 24.1°C. Lagoon temperatures were around 5°C warmer than ambient with a mean of 19.9°C measured in the discharge pit and 20.6°C at 3.5 m depth. The temperature at 3.5 m depth showed both some moderation and lag compared to that measured in the...
discharge pit (Figure 10). Temperatures at 0.5 and 1.5 m depth were similar to those recorded at the discharge pit.

![Figure 10. Mean monthly ambient and effluent temperatures](image)

**Organic load**

For the design and investigation of agricultural waste systems, organic load is most commonly described by the amount of volatile solids (VS) added. In this project, chemical oxygen demand (COD) was also measured as the relationship between COD destruction and methane (CH₄) production is fixed – 1 kg COD yields 0.35 m³ CH₄ at 0°C and 101.3 kPA (Metcalf & Eddy 2003). For VS, the amount of methane produced depends on the composition of the VS destroyed; that is, the relative proportions of lipids, proteins and carbohydrates. It will therefore vary between species and also within species according to the diet fed which complicates comparisons of system performance.

**Volatile Solids**

The mean VS concentration (influent) was 8210 mg L⁻¹ for screened wastewater (June 2008 to March 2009) and 18 090 mg L⁻¹ for unscreened wastewater (April/May 2009; the only two sampling events completed for unscreened wastewater).

The mean effluent VS concentration was 3230 mg L⁻¹ from June 2008 to March 2009 and 4520 mg L⁻¹ for April/May 2009.

The VS/TS ratio averaged 0.67 for screened wastewater and 0.78 for unscreened wastewater.

The mean daily VS load for influent was 4340 kg d⁻¹ for screened wastewater and 7280 kg d⁻¹ for unscreened wastewater (Figure 13).
The impact of bypassing the pair of rundown screens was significant with an apparent 40% increase in VS load. Separately, Rural Industries Research and Development Corporation project PRJ 2831 ‘Estimates of Manure Production from Animals for Methane Generation’ had estimated that the same screens were responsible for removing 38% of the VS during the July sampling event. It is noted however, that this number was based on one only VS analysis and relied on the mass being estimated by the number of truck loads of manure removed by the screens over the week long period.

The mean VS removal (partitioned to the pond) was 64% but ranged from 0 to 91% (note that 0% removal was recorded in September 2008 and led to the revision of effluent sampling procedure as discussed in ‘Methodology’).

The digester’s volatile solids loading rate (VSLR) based on a load of 4340 kg VS d\(^{-1}\) and 17.9 ML was 0.24 kg VS m\(^3\).

**COD**

The mean COD concentrations were 15 650 mg L\(^{-1}\) for influent and 4350 mg L\(^{-1}\) for effluent. The mean COD removal was 71%.

No analysis of COD was attempted for the higher solids content of the unscreened wastewater collected during the April and May 2009 sampling events. The Advanced Water Management Centre at The University of Queensland had concerns about the magnitude of errors occurring during COD analysis of samples with TS concentrations exceeding 1% and decided to delay such analysis until the procedure is improved.

The mean daily COD load for influent was 8300 kg d\(^{-1}\) for screened wastewater.
Figure 12. COD concentrations in influent and effluent (excluding unscreened samples from April/May 2009)

Figure 13. Daily COD and VS load in influent
COD/VS ratio and VFA’s

One kg of VS is normally considered to be equivalent to 1.4 kg of COD for animal manure “with no or hardly any VFA present” (Zeeman & Gerbens 2002). The data presented above represents a COD/VS ratio of 1.9 for the period from June 2008 to March 2009 (range 1.3 to 3) which is notably larger than expected. However, as the mean VFA concentration recorded for the influent to the Bears Lagoon CAL was 2650 mg L⁻¹ (range 1970 to 3580 mg L⁻¹), the contribution from VFA was significant.

Conn et al. (2007) suggests that together, acetic acid and propionic acid typically comprise 80 to 90% of the total VFA’s in pig manure, with longer chain VFA’s such as butyric acid comprising the remainder. Assuming a composition of 65/20/15 parts acetic, propionic and butyric acid respectively, an equivalence of 1.27 g COD g⁻¹ VFA was used to assess the contribution by VFA’s. (Rossle & Pretorius (2001) give an equivalence of 1.067 g COD g⁻¹ acetic acid, 1.514 g COD g⁻¹ propionic acid, and 1.818 g COD g⁻¹ butyric acid). Therefore a VFA concentration of 2650 mg L⁻¹ represents approximately 22% of the mean influent COD (1.27 x 2650 mg L⁻¹ / 15 650 mg L⁻¹).

This is important as researchers have documented that a significant proportion of the VFA in a sample is lost (volatilised) during the dry matter determination for TS and VS (Hayward & Pavlicik 1990, Derikx et al. 1994). Derikx et al. (1994) suggests that at a pH of 7.5, approximately 75% of the VFA is lost. As it is not lost from the digester itself, this has the potential to increase the apparent biogas yield on a kg CH₄ kg⁻¹ VS basis and increase the apparent COD/VS ratio. This area requires further investigation and laboratory procedures to minimise VFA loss should be considered.

Table 3. Summary of characteristics of screened wastewater (June 2008 – March 2009)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS</td>
<td>mg L⁻¹</td>
<td>12 220</td>
</tr>
<tr>
<td>VS</td>
<td>mg L⁻¹</td>
<td>8 210</td>
</tr>
<tr>
<td>COD total</td>
<td>mg L⁻¹</td>
<td>15 650</td>
</tr>
<tr>
<td>COD soluble</td>
<td>mg L⁻¹</td>
<td>5 180</td>
</tr>
<tr>
<td>VFA</td>
<td>mg L⁻¹</td>
<td>2 650</td>
</tr>
<tr>
<td>VS/TS</td>
<td></td>
<td>0.67</td>
</tr>
<tr>
<td>COD/VS</td>
<td></td>
<td>1.9</td>
</tr>
</tbody>
</table>

Biogas production and methane concentration

Between June 2008 and May 2009, the mean daily biogas production was 3350 m³ d⁻¹ and ranged from 2550 m³ d⁻¹ (July) to 4030 m³ d⁻¹ (November) for screened wastewater; see Figure 14. Note that the gas volumes are reported at standard conditions of 15°C and 101.3kPa.

A mean daily biogas production of 4160 m³ d⁻¹ was recorded for May 2009 after the rundown screens were taken off-line and raw wastewater was pumped directly to the CAL; reversing what should have been a declining trend as lagoon temperature dropped. In fact, daily biogas production increased each month following the removal of the pre-treatment screens with means of 4370 m³ d⁻¹ (June), 4890 m³ d⁻¹ (July) and 5490 m³ d⁻¹ (August) in response to the additional organic load being introduced to the CAL. The magnitude of the increase exceeded expectations (the screens were estimated to be responsible for a 40% reduction in load) and longer monitoring is needed to understand the response.

The composition of the biogas was as shown in Table 3.
Table 4. Mean methane (CH₄) and carbon dioxide (CO₂) concentrations (June 2008 – May 2009)

<table>
<thead>
<tr>
<th></th>
<th>CH₄</th>
<th>CO₂</th>
<th>Remainder</th>
</tr>
</thead>
<tbody>
<tr>
<td>(％)</td>
<td>63.2</td>
<td>18.8</td>
<td>18.0</td>
</tr>
</tbody>
</table>

Other than ruling out the presence of any hydrogen, no analysis was done on the composition of the residual gas component. Figure 14 shows the variability in methane concentration which ranged from 54.0 to 70.4％.

The methane production shown in Figure 14 is the volume calculated by applying the methane concentrations from Table 4 to the mean daily biogas production. The mean methane production was 2110 m³ d⁻¹ (or 1430 kg d⁻¹ using a density of 0.678 kg m⁻³ for methane at 15°C) from June 2008 to May 2009.

No data is available from October 2008; vibrations from the blower had loosened the power supply to the datataker so it did not function for most of that month.

Figure 14. Gas production and methane concentration
Power generation potential

With a low heat value (LHV) of 50.0 MJ kg$^{-1}$ CH$_4$, the mean methane production represents an energy yield of 71 400 MJ d$^{-1}$. Assuming a conservative electrical conversion efficiency of 25%, a generator could produce 5000 kWh d$^{-1}$ from the methane produced; a power output of 207 kW (range from 160 to 250 kW). With an average electrical consumption being 6755 kWh per annum (Energy Efficient Strategies 2008), the mean potential power output from Bears Lagoon would be sufficient to power 270 Australian households.

Based on the mean stock numbers over the monitoring period (23 000 SPU), the mean output represents a power generation potential of 0.9 kW per 100 SPU or 0.009 kW per grower pig (40kg nominal liveweight). This potential should increase by approximately 40% to 1.26 kW per 100 SPU when the wastewater pumped to the CAL remains unscreened (see ‘Organic load’). These numbers are similar to those reported by GHD (2008).

Methane yield

Using the data for organic load (Figure 13) and methane production (Figure 14), we calculated the methane yield in terms of both VS and COD added to the CAL. That data is presented in Table 5.

Table 5. Methane yield

<table>
<thead>
<tr>
<th>Month</th>
<th>Month methane yield</th>
<th>Methane yield</th>
<th>Methane yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m$^3$ CH$_4$ kg$^{-1}$ COD</td>
<td>kg CH$_4$ kg$^{-1}$ COD</td>
<td>m$^3$ CH$_4$ kg$^{-1}$ VS</td>
</tr>
<tr>
<td>June</td>
<td>0.23</td>
<td>0.15</td>
<td>0.51</td>
</tr>
<tr>
<td>July</td>
<td>0.20</td>
<td>0.14</td>
<td>0.37</td>
</tr>
<tr>
<td>August</td>
<td>0.21</td>
<td>0.14</td>
<td>0.43</td>
</tr>
<tr>
<td>September</td>
<td>0.26</td>
<td>0.18</td>
<td>0.38</td>
</tr>
<tr>
<td>Oct/Nov</td>
<td>0.32</td>
<td>0.21</td>
<td>0.94</td>
</tr>
<tr>
<td>December</td>
<td>0.43</td>
<td>0.29</td>
<td>0.58</td>
</tr>
<tr>
<td>January</td>
<td>0.31</td>
<td>0.21</td>
<td>0.59</td>
</tr>
<tr>
<td>February</td>
<td>0.22</td>
<td>0.15</td>
<td>0.43</td>
</tr>
<tr>
<td>March</td>
<td>0.20</td>
<td>0.13</td>
<td>0.44</td>
</tr>
<tr>
<td>April</td>
<td></td>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>May</td>
<td></td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>Mean</td>
<td>0.27</td>
<td>0.18</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Note that the volumes shown in Table 5 are for methane at 15°C and 101.3 kPa. As data is often compared without stipulating gas conditions, the yields were converted to a mass basis using a density of 0.678 kg m$^{-3}$ (methane at 15°C) to avoid confusion.

Note also that the yields are calculated based on organic load added to the CAL and that a portion of that load is discharged with the effluent. From the section ‘Organic load’ above, approximately 64% of influent VS was partitioned to the pond and 71% of COD. The yields of Table 5 would be higher if calculated on the basis of load partitioned to the pond (influent minus effluent).

Stoichiometrically, the destruction of 1 kg of COD produces 0.35 m$^3$ of CH$_4$ at 0°C and 101.3 kPA (Metcalf & Eddy 2003). Using the universal gas law, this is equivalent to 0.37 m$^3$ of CH$_4$ at 15°C and 101.3 kPA. However, to avoid possible confusion as a result of differing gas conditions, it is advisable to use a mass-based constant of 0.25 kg CH$_4$ kg$^{-1}$ COD and compare yield results on that basis.
It is apparent that the result recorded for December 2008 (a yield of 0.29 kg CH₄ kg⁻¹ COD) is therefore only possible if some COD added remains undigested during the colder months and is carried over and digested as lagoon temperatures increase. Such behaviour is expected but cannot be verified without detailed sludge surveys. Figure 15 shows a reduction in methane yield on a COD basis before the lagoon temperature peaks suggesting that organic load carry over is an important factor in CAL function.

![Figure 15. Methane yield and temperature](image)

Over the period from June 2008 to March 2009, the mean yield was 0.18 kg CH₄ kg⁻¹ COD. Note that as COD was not measured for the April/May 2009 sampling event (due to concerns about the accuracy of COD tests on the unscreened wastewater discussed in section ‘Organic load’) the mean does not reflect a true 12 month period.

The term methane conversion factor (MCF) is used to represent the degree to which the maximum methane producing capacity (Bₒ) is achieved. On the basis of COD, the maximum methane producing capacity must be 0.25 kg CH₄ kg⁻¹ COD, so the mean yield of 0.18 kg CH₄ kg⁻¹ COD represents a MCF of 72% It is noted that IPCC (2006) estimate that an uncovered anaerobic lagoon operating under an average annual temperature of 15°C would have a MCF of 74%.

In terms of VS added, the mean yield (June 2008 to May 2009) was 0.33 kg CH₄ kg⁻¹ VS. IPCC (2006) adopt a Bₒ of 0.48 m³ kg VS⁻¹ for USA and 0.45 m³ kg VS⁻¹ for Oceania (both ± 15%) unless country-specific data is available. As IPCC (2006) use gas conditions of 20°C and 101.3 kPa, those estimates of Bₒ are equivalent to 0.32 and 0.30 kg CH₄ kg⁻¹ VS respectively. From our recorded yield of 0.33 kg CH₄ kg⁻¹ VS, one would therefore incorrectly conclude that negligible VS was partitioned to settled solids/sludge or lost with effluent. However, it is very likely that the high apparent yield is a result of some VS indeed being lost during VS determination, or that the measurement of gas production is inaccurate. The latter issue is investigated in the following section ‘Biogas measurement’.
Sludge accumulation and desludging

Definitions of sludge and settled solids

Sludge can be defined as the non-degradable volatile solids and the fixed solids (or ash) that accumulates at the bottom of a treatment lagoon. Above the sludge lie the layers of active settled solids; these comprise the VS recently settled and the older VS in various stages of decomposition (Chastain 2006); see also Figure 16.

Alternately, lagoons are sometimes defined as only having two components; supernatant (active volume) and sludge. The problem with this approach is that significant settling occurs in as little as 30 minutes after suspended solids enter a stilled water body and biological activity logically continues in the retained solids for some time afterwards.

Figure 16. Conceptual components of a treatment lagoon (Chastain 2006)

Two corollaries of using the three-component definition are:

i. that the space occupied by sludge could not be considered part of the active volume as the material is biologically inert, and

ii. that the boundary between sludge and settled solids (and therefore the ‘active volume’) is difficult to determine.

The boundary between supernatant and settled solids is however, readily identifiable; it is characterised by a change from the brownish colour of fresh wastewater to a much darker substance, often black in colour. It is expected that this is consistent with the boundary identified by a sudden increase in turbidity when using a turbidity sensor or nephelometer. The following section will therefore refer to a ‘solids accumulation rate’ encompassing both settled solids and sludge layers. It is presumed that authors such as Barth used the term sludge accumulation rate to refer to the top of the settled solids.

Depth of solids and solids accumulation rate

During the ‘sludge’ survey performed in March 2009, the average depth (across three vent locations) at which the pump discharge changed in colour from brown to black was 1.65 m (below surface level). The volume in the CAL below this depth was calculated to be 10.5 ML based on the topographic survey described in ‘Methodology’.
The solids accumulation rate is calculated from:

\[
\text{Solids volume (m}^3\text{)} = \text{solids accumulation rate (m}^3\text{ kg}^{-1}\text{ TS)} \times \text{solids added (kg TS d}^{-1}\text{)} \times \text{days (d)}
\]

Construction of the CAL was completed in June 2004; the duration over which solids has accumulated is therefore approximately 1730 days. As pig numbers have not changed significantly since that time, we have assumed that the mean TS recorded from June 2008 to March 2009 (6460 kg d\(^{-1}\) screened wastewater only) is a valid basis for estimating historical TS loading.

\[
\text{Solids accumulation rate} = \frac{10\ 500\ m^3}{(6460\ kg\ d^{-1} \times 1730\ d)} = 0.00094\ m^3\ kg^{-1}\ TS
\]

Table 6 summarise that result against current industry benchmarks; the rate is approximately one-third of the commonly used estimate by Barth & Kroes (1985) but within the range proposed by Chastain (2006) in his review of additional data from the USA. In Queensland, Skerman et al. (2008) identified a sludge accumulation rate of “less than 0.001 m\(^3\) kg\(^{-1}\) TS” after 22 months of operating a highly loaded lagoon.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sludge accumulation rate (m(^3) kg(^{-1}) TS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barth &amp; Kroes (1985)</td>
<td>0.00303</td>
</tr>
<tr>
<td>Chastain (2006)</td>
<td>0.00129</td>
</tr>
<tr>
<td>(range 0.00073 to 0.00234)</td>
<td></td>
</tr>
</tbody>
</table>

Settled solids and sludge characteristics

In an effort to identify the respective characteristics of the settled solids and sludge layers, and subsequently the active volume of the lagoon, samples of the material extracted by the submersible pump during the ‘sludge’ survey were sent to the laboratory for TS and VS determination. The results are summarised in Figures 17 (TS) and 18 (VS).

With the limitations posed by having to gain access via the 50 mm gas vents, the submersible pump had a limited capacity to pump high TS material and would not deliver any discharge once exceeding 5.0 m depth at vent number 2 (11.8% TS). At subsequent locations, the pump failed at 2.75 to 3.25 m depth for reasons that remain unclear but are suspected to relate to an overloaded transformer used to power the pump. Samples were therefore not obtained from any depth within 2.5 m of the base of the pond.

Within the limited data collected, is apparent that both TS and VS show a reasonably uniform increase in concentration with depth. There was no indication of a sudden increase in TS that may indicate a transition to denser, inert sludge over the depth investigated.

Any transition to sludge might alternately be indicated by a decrease in the VS/TS ratio as the proportion of inert solids increases compared to degradable solids. Table 7 shows the VS/TS ratio with depth, however it is noted that from a depth of 3.5 m, the data relates to one sample only (albeit analysed in triplicate).

While table 7 does indicate a decrease in the proportion of VS at 5 m depth, identifying any transition between settled solids and sludge is not possible without sampling to the full depth (7.5 m) and specific methanogenic activity testing to evaluate the actual activity of the material recovered.
Table 7. VS/TS ratio for settled solids/sludge

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>2.0</th>
<th>2.5</th>
<th>3.0</th>
<th>3.5</th>
<th>4.0</th>
<th>4.5</th>
<th>5.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS/TS ratio (%)</td>
<td>60</td>
<td>61</td>
<td>61</td>
<td>63</td>
<td>59</td>
<td>56</td>
<td>45</td>
</tr>
</tbody>
</table>

Figure 17. TS in settled solids/sludge

Figure 18. VS in settled solids/sludge
Sludge extraction system

Figure 19 shows the sludge extraction pump that was designed to recover sludge from four separate points along the base of the CAL. The pump is a positive displacement helical rotor operating at ~380 rpm with a discharge of approximately 6 L s⁻¹. Both suction and discharge pipe-work comprises DN 110 mm, PN 10 HDPE so the flow velocity was estimated to be 0.85 m s⁻¹.

The system has not been used to extract any sludge from the CAL since it was commissioned in 2004 as there is currently no option to discharge sludge out of the system (only return it the inlet end as seen in Figure 19). The operator reports that infrequent checks were carried out to ensure that the pump was functioning up until 2008. However, when started in early 2009, the pump would not prime and the stator was damaged as a result. Subsequent investigations identified some concerns about air leaks at the valves, and that the sludge at inlet number 4 (furthest from the inlet) had solidified and had to be removed by vacuum pump prior to the getting the repaired pump restarted.

As the pump was inoperable for much of the first half of 2009, and without a drying bay to discharge the sludge into, the characteristics of sludge recovered by the in-situ extraction system remain unclear. More research is needed to identify how frequently and for what duration the system should be operated to control sludge build up and prevent it from blocking inlets.

Figure 19. Sludge extraction pump
Biogas measurement

Orifice plate meters are an economical and simple tool for gas measurement. As the gas in question passes through the flow-restricting orifice plate, it creates a pressure reduction that is measured by a differential pressure transducer. The magnitude of that pressure drop is proportional to the square of the rate of flow if factors such as gas density remain constant. However, gas density is a function of temperature and gas composition; both of which could only be assumed at the time of meter calibration and remain variable throughout this project. Therefore, the sensitivity of the instrument to the likely variation in gas temperature and composition was assessed.

Meter calibration data

Gasco Pty Ltd provided the calibration datasheet for the installation as completed (dated October 20, 2005). The datasheet documented the assumed gas temperature (49°C) and composition (82% CH₄ and 18% CO₂). Based on those parameters the full-scale measurement for the orifice plate/differential plate meter was 402 m³ hr⁻¹ (at 15°C and 101.3 kPa).

Sensitivity analysis

While the proportion of methane (CH₄) and carbon dioxide (CO₂) was assessed each month, the composition of the residual was not. The mean CH₄ and CO₂ analysis (63.2 and 18.8% respectively) leaves 18% unaccounted for. Without knowing what the composition of the residual was, we assumed a mixture of nitrogen (N₂) and oxygen (O₂) for the purposes of the sensitivity analysis; both with a higher density than CH₄. Every sample tested negative to the presence of hydrogen (H₂).

The error attributable to the assumption of gas concentration during calibration was calculated to be up to 6% at full scale (scenario 3, Table 8). As the average biogas flowrate while the blower was operating was 184 m³ hr⁻¹, the actual error would be less than 3%.

Unfortunately, there was no provision made for monitoring biogas temperatures. At best, we can only estimate the gas temperature to fall somewhere between the surface water temperature (mean of approximately 20°C) and the air temperature recorded under the cover when gas build-up occurred (20 to 30°C in winter, 50 to 70°C in summer). See ‘Methodology’ for more detail on probe configuration.

As the maximum temperatures are not substantially different to the temperature assumed for calibration (49°C) and would only be possible for a limited proportion of time, a higher temperature scenario was not assessed. Scenario 4 and 5 used a temperature of 20°C as a minimum temperature and determined a possible error of -1 to +1% at full scale.

Without time weighted temperature data, the sensitivity analysis cannot be used to estimate the likely error in the data collected. It is recommended that prior to any future monitoring using the existing orifice plate meter, the options for installing a temperature sensor on the gas line be investigated and the suite of gas parameters extended to identify the residual components.
Table 8. Sensitivity analysis results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Assumptions</th>
<th>Full-range flowrate $\left(\text{m}^3\text{hr}^{-1}\right)$</th>
<th>Error at full scale (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Calibration</td>
<td>Temperature 49°C</td>
<td>402</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>82% CH₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18% CO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Mean gas composition, temperature unchanged</td>
<td>Temperature 49°C</td>
<td>389</td>
<td>+3%</td>
</tr>
<tr>
<td></td>
<td>63.2% CH₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.8% CO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Residual component has density equal to mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Modified gas composition, temperature unchanged</td>
<td>Temperature 49°C</td>
<td>379</td>
<td>+6%</td>
</tr>
<tr>
<td></td>
<td>63.2% CH₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.8% CO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13% N₂ (assumed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5% O₂ (assumed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Mean gas composition, minimum temperature</td>
<td>Temperature 20°C</td>
<td>408</td>
<td>-1%</td>
</tr>
<tr>
<td></td>
<td>63.2% CH₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.8% CO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Residual component has density equal to mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Modified gas composition, minimum temperature</td>
<td>Temperature 20°C</td>
<td>398</td>
<td>+1%</td>
</tr>
<tr>
<td></td>
<td>63.2% CH₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.8% CO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13% N₂ (assumed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5% O₂ (assumed)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note that the errors identified in Table 8 are in addition to the normal instrument error typically considered to be ±2% for this type of device when installed and calibrated correctly.
Conclusions and implications

This report contains the first detailed analysis of the performance of an ambient covered anaerobic lagoon (CAL) at a piggery in Australia. As the Bears Lagoon piggery CAL had been in operation for approximately 4 years at project start-up, the 12 month dataset represents a system that was operating with reasonable stability.

Over the monitoring period, the CAL removed 64% of VS and 71% of COD from the screened wastewater. Investigation of the higher than normal COD/VS ratio (1.9) revealed that approximately 22% of the COD was from the VFA content and that we have some concerns that a significant portion of that is being lost from the VS result during dry matter determination.

The methane yield was 0.18 kg CH₄ kg⁻¹ COD with a VSLR of 0.24 kg VS m⁻³ and HRT of 36 days (neglecting sludge volume). The mean temperature of the lagoon discharge was 19.9°C while the mean ambient temperature for the site was 15.2°C. The mean temperature of the lagoon contents at 3.5 m depth was 20.6°C.

Assuming an electrical conversion efficiency of 25%, the biogas produced represents a power generation potential of 0.9 kW/100 SPU or 0.009 kW/grower pig (40kg nominal liveweight). Bypassing the pre-treatment screens could increase the power generation potential by approximately 40%.

After almost 5 years of operation, the solids accumulation rate was calculated to be 0.0094 m³ kg⁻¹ TS which is at the lower end of the range of current industry estimates.
Recommendations

For any further work at the Bears Lagoon site, the following recommendations apply:

1. Investigate options to determine the error in measurement by the orifice plate meter/differential pressure transducer. This would involve at a minimum, installing a temperature probe on the biogas supply line from blower to flare.

2. Extend the biogas analysis suite to determine the composition of the residual component (also impacts recommendation #1).

3. Source and develop equipment to enable sampling to the full depth (7.5m) of the CAL so that the settled solids and sludge can be investigated in more detail and the mass balances based on COD and VS can be verified.

For any biogas project, the following recommendations are made:

4. Consider using a positive displacement type biogas meter as used for natural gas supply and billing.

5. COD data provides a better basis than VS for a detailed investigation of system performance due to the fixed relationship between COD and methane production. However, COD measurements are currently prone to error for samples with TS > 1% and procedures to reduce that error need to be validated.

6. If VS measurements are to be used, the magnitude of VFA loss upon dry matter determination must be investigated.

7. Reporting biogas production or yield in volumetric terms is to be avoided due to potential misapplication of incorrect gas conditions. Expressing the methane yield in terms of mass (kg CH₄ kg⁻¹ COD) is preferable.
References

Barth, C.L. & J. Kroes 1985, 'Livestock waste lagoon sludge characterisation', Agricultural Waste Utilization and Management, proceedings of the 5th International Symposium on Agricultural Waste, Chicago, IL, December 16-17, 1985, ASAE.


GHD 2008, 'Assessment of methane capture and use from the intensive livestock industry’, Pub. No. 08/025, RIRDC.


IPCC 2006, ‘IPCC Guidelines for national greenhouse inventories’, Volume 4: Agriculture, forestry and other land use, IPCC.


Zeeman, G. & S. Gerbens 2002, ‘CH4 emissions from animal manure’, Background papers IPCC expert meetings on good practice guidance and uncertainty management in national greenhouse gas inventories, IPCC.
Covered anaerobic lagoon systems offer the potential to mitigate greenhouse gas emissions and provide sustainable energy. The monitoring program completed at the George Weston Foods owned Bears Lagoon piggery is the first comprehensive set of data on the performance of a covered anaerobic lagoon at a piggery in Australia.

As a result of determining monthly methane yields, the work demonstrates the significant power generation potential from piggeries and that a large operation such as Bears Lagoon piggery could power approximately 270 households.

The Program is funded by the Department of Agriculture, Fisheries and Forestry from the Natural Heritage Trust and the National Landcare Program. Industry funding and support has been received from the Rural Industries Research and Development Corporation, Dairy Australia, Australian Pork, Meat and Livestock Australia and the Australian Lot Feeders' Association.

RIRDC is a partnership between government and industry to invest in R&D for more productive and sustainable rural industries. We invest in new and emerging rural industries, a suite of established rural industries and national rural issues.

Most of the information we produce can be downloaded for free or purchased from our website <www.rirdc.gov.au>.

RIRDC books can also be purchased by phoning 1300 634 313 for a local call fee.

---

Cover photo: The covered lagoon at Bear’s Lagoon piggery