Figure 19 shows strong correlation between the daily biogas volume consumed by the generators and the total power generated. The power generated per unit volume of biogas is also plotted on this Figure. The average power generated per cubic metre of biogas was 1.73 kWh with a range from 1.51 to 1.87 kWh. The efficiency of biogas use appears to increase on the days of higher biogas consumption when both generator engines were operating at high outputs (approximately 460 kW = 92% of nominal rated power output). Based on the average biogas methane content of 54.96% measured using the MRU SWG 100 analyser and the lower heating value of methane (33.35 MJ/Nm^3 CH_4), the average electrical efficiency of the generator engines was 34%, which is regarded as typical for biogas engines operating at piggery installations.

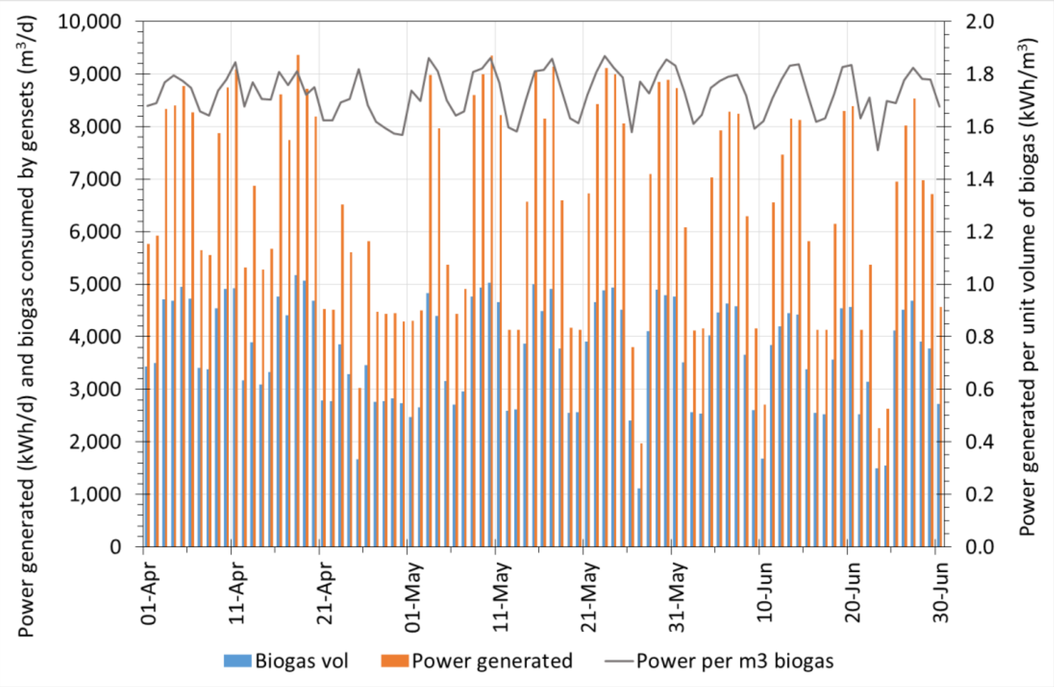

Figure 19. Daily biogas volumes consumed by the gensets, total genset power generation and power produced per unit volume of biogas over the 3-month monitoring period.

3.6 Recommendations for Piggery A

Based on the findings described above, the following recommendations are provided specifically for Piggery A:

- Continue monitoring to identify whether mitigation strategies should be employed to address the potential longer term performance issues highlighted in Section 3.4.
- Consider dosing air into the biogas pipeline, immediately upstream of the biological scrubber, rather than into the hybrid CAP headspace (as described in Talking Topic 4), to prevent accumulation of elemental sulphur inside the hybrid CAP and corrosion of solid surfaces exposed to the biogas headspace.

- If air is dosed into the biogas pipeline immediately upstream of the biological scrubber, a high dosage rate is recommended to minimise the accumulation of elemental sulphur on the packing inside the biological scrubber.

4. Application of Research

Installation of biogas system monitoring instrumentation, similar to that installed with the assistance provided by this project, has considerable potential for improving the management of these systems. More specifically, the high quality, real-time data provided by such installations could be used for:

- Early diagnosis of operational irregularities or system faults which may avoid costly damage to system components such as generator engines.
- Measuring biogas system operating efficiency and evaluating the effects of incremental management changes.
- Evaluation of a range of operating strategies and biogas treatment methods.
- Managing changes in biogas composition resulting from co-digestion feed stock variations.
- Validating the energy and economic value of the available biogas.
- Assessing short and long-term seasonal variations in biogas production and quality.
- Managing biogas use options to maximise economic benefit.

The initial installation at piggery A has provided a pilot resource for long-term evaluation and possible modification prior to more widespread deployment across the industry.

5. Conclusions

Over the three month monitoring period, from April to June 2018, the hybrid CAP at Piggery A received unscreened effluent from flushing and pull-plug sheds housing separate grower and breeder units (total capacity of 38,200 SPU). The average biogas production from the hybrid CAP was 5,601 m^3/d. There was a relatively small reduction in biogas production from April to June, despite falling maximum and minimum temperatures at the piggery site. The resulting biogas and methane yields were 523 m^3 biogas and 287 m^3 CH_4, respectively, per tonne of VS discharged into the hybrid CAP. Based on previous biochemical methane potential (BMP) testing results for this piggery (Skerman et al., 2017), the recorded methane yield indicated that the hybrid CAP was achieving a high methane recovery of 88% of the BMP, and was therefore performing as well as could be expected during the monitoring period.

Approximately two-thirds of the biogas produced by the hybrid CAP was used to run two 250 kWe Camda combined heat and power (CHP) generator units while the remaining third of the biogas was burnt in a shrouded flare. There was strong correlation between the measured flare temperature and metered biogas flow through the flare. The substantial consumption of excess biogas in the flare suggests that there is considerable potential for adopting additional, more productive biogas use options.

The two CHP units generated an average of 809 kWh/day over the monitoring period (average output 270 kWe). Sixty-two percent of the electrical power generated by the CHP units was used in the pig sheds, predominantly running cooling fans, lights and heat lamps, 26% of the power was used to operate the on-site feed mill, and the remaining 12% (34 kWe) was used to run the hybrid CAP and onsite biogas production and use infrastructure.

The average power generated per cubic metre of biogas was 1.73 kWh/m^3 biogas. Based on the average biogas methane content of 55% (measured using the MRU SWG 100 analyser, which was upgraded using funds provided through this project), the average electrical efficiency of the generator engines was 34%. This electrical efficiency is regarded as typical for biogas engines operating at piggery installations.

The average H_2S concentration in the biogas extracted from the hybrid CAP (223 ppm) was much lower than typically observed in untreated piggery biogas and was only marginally higher than the typically recommended maximum of 200 ppm for use in generator engines. This suggested that the O_2 in the air injected into the headspace effectively supported significant biological oxidation of H_2S inside the headspace of the hybrid CAP. However, the measured H_2S concentrations exceeded 200 ppm over 32% (678 hours) of the total 3-month monitoring period and were periodically very high, generally following generator stoppages. These findings demonstrate that removal of H_2S by biological oxidation in the hybrid CAP headspace was generally inadequate for safe operation of the generator engines, without further biogas treatment in the external biological scrubber.

The average H_2S concentration measured downstream of the biological scrubber was very low (18 ppm) and instantaneous H_2S concentrations rarely exceeded 200 ppm. This showed that the combined biological oxidation in the hybrid CAP and external biological scrubber was effective at removing H_2S from the biogas.

It may be preferable to inject air into the biogas line upstream from an external biological scrubber, rather than into the CAP headspace. This will prevent the formation of elemental sulphur in the CAP headspace and subsequent deposition in the CAP liquid phase, where it can be converted back into H_2S. This sequence of reactions can progressively increase the H_2S load on the subsequent biogas treatment processes. Based on the limited data acquired over the relatively short monitoring period, this sequence of reactions may be responsible for the general increase in biogas H_2S concentrations observed from April to June (Table 3); however, longer term monitoring would be required to more confidently attribute the observed increase to this process.

When excess air or O_2 is added to the CAP headspace, further oxidation of H_2S can occur to form sulphate instead of elemental sulphur. The resulting sulphuric acid (H_2SO_4) produced by this reaction, can cause severe corrosion of exposed metal or concrete surfaces. Supplying excess O_2 upstream from a separate biological scrubber may be advantageous, by reducing the deposition of elemental sulphur on the scrubber packing elements. In this case, the scrubbing liquid should not be recycled back to the CAP.

High levels of balance gas and relatively low levels of CH_4 and CO_2 measured by the fixed MRU SWG 100 biogas analyser, in comparison to readings taken using portable analysers, suggested that the MRU SWG 100 biogas analyser may require re-calibration. Alternatively, the air dosing rate may be higher than expected, resulting in higher N_2 concentrations in the biogas. This issue has been discussed with the analyser supplier and the piggery project coordinator.

The three-month monitoring period at Piggery A provided considerable useful data regarding the biogas system performance and operation. However, there was insufficient data to conclusively identify issues which currently warrant any major changes to system operations. Consequently, it is recommended that the detailed monitoring program be continued at Piggery A.

Installation of monitoring instrumentation, similar to that installed at Piggery A, with the assistance provided by this project, has considerable potential for improving the management of on-farm biogas systems. More specifically, the high quality, real-time data provided by such installations will assist piggery managers to promptly diagnose operational irregularities and system faults, thereby avoiding costly damage to system components such as generator engines. The resulting data will also assist in evaluating of a range of operating strategies and biogas treatment methods to maximise economic benefit.

The initial installation of monitoring instrumentation at Piggery A has improved the knowledge and experience of researchers, service providers and piggery managers with regard to the available monitoring technology and its practical application in the Australian pork industry. It also provides a model for the further development and more widespread deployment of similar systems across the industry.

6. Limitations/Risks

The monitoring data for Piggery A were recorded over a limited 3-month period, and so were not able to conclusively identify potential longer-term performance issues highlighted in Section 3.4 of the report.

Piggery A is representative of several large Australian piggeries which could potentially benefit from the adoption of biogas systems; however, it is not representative of many smaller Australian piggeries for the following reasons:

- The hybrid CAP at Piggery A receives effluent from a relatively large piggery by Australian standards (35,800 SPU grower unit + a separate 1,200 sow breeder unit; Total = 38,200 SPU).
- The herd composition at Piggery A is not representative of normal farrow to finish units because the grower unit at Piggery A receives the progeny from two separate off- site breeder units (total 3800 sows), in addition to the progeny from a 1,300 sow breeder unit, which was recently established on-the same site as the grower unit.
- A relatively large proportion of the electricity generated by the biogas system is used to power an on-site feed mill. This is atypical for many smaller farrow to finish piggeries.
- The hybrid CAP employed at Piggery A is one of only four similar systems currently operating in Australia. The majority of the remaining 21 biogas systems operating at Australian piggeries are unheated, unstirred CAPs.

While monitoring systems deployed at smaller piggeries would measure smaller biogas flows, they would provide similarly useful analysis and troubleshooting assistance, as for Piggery A in the present report.

Piggeries are increasingly considering co-digestion of pig manure with by-products and wastes imported from other industries, to boost methane production and to receive gate fees for diverting wastes away from landfill. Co-digestion of other wastes together with pig manure can change biogas composition, either increasing or decreasing CH_4 concentration and/or increasing or decreasing H_2S concentration. Therefore, the biogas composition at piggeries that co-digest may be dissimilar to monitoring results observed at Piggery A in the present study.

Unlike the majority of piggery biogas installations in Australia to date, Piggery A uses a hybrid heated, mixed CAP to produce biogas. Unfortunately Piggery D, which operated an unmixed and unheated CAP, was unable to source suitable quotations within the project period and as such could not participate in the project. The project results therefore did not permit a cross-comparison of performance of a CAP and a hybrid CAP, to quantify the net performance benefits of heating and mixing. Heating and mixing requires considerable additional capital investment, so such a cross-comparison and relative cost-benefit analysis would have been particularly useful for further industry consideration.

7. Recommendations

The data collected and analysed for Piggery A, provided a very good understanding of current performance, and also highlighted some key issues to consider in the longer-term with respect to biogas treatment (Section 3.4). Clearly, there is value in being able to monitor and troubleshoot on-farm biogas systems, using similar monitoring infrastructure to that installed at Piggery A, with assistance from this project.

As a result of the outcomes of this study it is recommended that:

- Piggery A regularly recalibrate monitoring instrumentation and continue to monitor longer term performance of onsite biogas production and use;
- Other piggery biogas installations in Australia use the suggested instrumentation specifications provided in this report, and install similar infrastructure onsite to monitoring system performance.

8. References

Canda website, accessed 9 August 2018. https://cncamda.en.alibaba.com/product/918965358-219099780/CE_marked_250_kw_biogas_generator_250kw_natural_gas_generator_gas_cogeneration.html

Ryckebosch, E., Drouillon, M. and Vervaeren H. (2011) Techniques for transformation of biogas to biomethane. Biomass and Bioenergy 35(5): 1633 – 1645. https://doi.org/10.1016/j.biombioe.2011.02.033

Sell, S.T., Burns, R.T., Moody, L.B., Raman, D.R. (2011) Comparison of methane production from bench- and sub pilot-scale anaerobic digesters. Applied Engineering in Agriculture, 27(5), 821-825.).

Skerman, A. (2013) Methane recovery and use at Grantham piggery, Addendum to Final Report - RIRDC Project No. PRJ-005672, RIRDC Publication No. 13/107, RIRDC, Barton, ACT. Published on the RIRDC website: https://agrifutures.infoservices.com.au/items/13-107

Skerman, A.G., Heubeck, S., Batstone, D.J. and Tait, S. (2018) On-farm trials of practical options for hydrogen sulphide removal from piggery biogas, Process Safety and Environmental Protection, 117, 675–683, https://doi.org/10.1016/j.psep.2018.06.014

Skerman, A.G., Willis, S., Batstone, D.J., Yap S.D. and Tait S. (2017) Effect of feed wastage on piggery effluent characteristics. Animal Production Science 57(12) 2481-2481. https://doi.org/10.1071/ANv57n12Ab024

Skerman, A.G. (2016) Practical options for cleaning biogas prior to on-farm use at piggeries. A thesis submitted for the degree of Master of Philosophy at The University of Queensland, School of Chemical Engineering. Pork CRC Project 4C-104.

Staunton, E.T., Bunk, S.R., Walters, G.W., Whalen, S.C., Rudek, J., Aitken, M.D. (2015). Coupling Nitrogen Removal and Anaerobic Digestion for Energy Recovery from Swine Waste through Nitrification/Denitrification. Environmental Engineering Science, 32(9), 741-749.

Tait, S. and Skerman, A.G. (2016) Talking Topic 4 - Cleaning piggery biogas, Pork CRC Bioenergy Support Program. http://porkcrc.com.au/wp-content/uploads/2016/06/Talking-Topic-4_web.pdf

Tait, S. (2017) Bioenergy support program – transition (research). Final Report prepared for the Cooperative Research Centre for High Integrity Australian Pork for Project 4C-115.

Wellinger, A. and Linberg A. (2005) Biogas Upgrading and Utilization - IEA Bioenergy Task 24: Energy from biological conversion of organic wastes. International Energy Association, Paris, France. http://www.iea-biogas.net/files/daten-redaktion/download/publi-task37/Biogas%20upgrading.pdf

Appendix 1 - Monitoring instrumentation specifications

The following specifications were provided to producers to assist in obtaining quotations for the required instrumentation:

Pork CRC Project 4C-122:
Installation of instrumentation for remote monitoring of biogas composition and operational data at commercial piggeries

The following minimum requirements are applicable for instrumentation to be installed at existing on-farm biogas plants under the grants program associated with the above project:

Monitoring Parameters

The instrumentation must be capable of monitoring the following parameters:

1. The total flowrate of biogas delivered from the digester or covered anaerobic pond (CAP) to each of biogas treatment systems, engines, boilers or flares.
2. The concentrations of methane (CH_4), carbon dioxide (CO_2), oxygen (O_2) and hydrogen sulphide (H_2S) in the raw biogas, and following one or more respective biogas treatment steps. (Ideally, the instrumentation should be capable of monitoring biogas quality before and after each successive treatment step; e.g. following both biological primary treatment and iron-based chemisorption secondary treatment.
3. The raw biogas temperature and the temperature and moisture content of the biogas following treatment.

It is recognised that program participants would currently have some existing instrumentation in place. Consequently, it will be important for all participants to ensure that the new instrumentation installed under this grant program is compatible with the existing instrumentation (wherever possible) and that the new instrumentation can be integrated into the existing system in the most practical and cost-effective manner.

Remote Monitoring

The monitoring system must include provision for recording (logging at regular intervals), and remotely accessing data relating to each of the parameters described above. Individual participants may also choose to install monitoring systems that incorporate alarms to alert key personnel when the data indicates potential safety hazards or equipment faults.

Data access

The data recorded by the monitoring system must be made available in a timely manner for remote access by the Pork CRC Bioenergy Support Program (BSP) Program Leader and Technical Support Officer, until the scheduled program termination date (30 June 2018). This data will be used for industry research purposes only, and the release of any of such data will be subject to privacy conditions negotiated with the participants.

Instrumentation and installation standards

All instrumentation procured and installed under this program must comply with the APL Code of Practice for on-farm biogas production and use (piggeries) (2015) and any relevant local, state or federal legislation or standards.

Appendix 2 - Monitoring instrumentation quotations

The following quotation was obtained from ThemoFisher Scientific for supply of two sets of the required instrumentation:

Product code, Description & Availability	Pack size	Qty	Unit Price, excl GST	Nett Value, excl GST
Gas Analyser				
Item: GTIBG3KPLUSD-25000 GEOTECH IECEx Fixed BIOGAS 3000 Fixed Analyser with 2 sample points with H2S 200ppm & H2S 5000ppm (**MISCCONS-Q-EA)** **Availability: 2 - 4 weeks**	EA	Qty: 2	**$21,800.00**	**$43,600.00**
Item: GTIADR GA3000 Auto Drain option **Availability: 2 - 4 weeks**	EA	Qty: 2	**$2,300.00**	**$4,600.00**
Flow Meter				
Item: GPAMV80VTP24S150LDDAC3AHSTP1CC **MV80 -** In-line multi-variable Vortex Flow Meter **VTP -** Mass measurement with pressure and temperature compensation **24-S-**150 - 3-inch (80mm) ANSI 150 lb Flanged, 316L **L -** Local Electronics NEMA 4X Enclosure Mounted on Meter **DD -** Digital Display and Programming Buttons **AC -** 100-240 VAC, 50-60Hz Line Power, 2 Watts maximum, 1AH, 1AM, 3AH, 3AM output options **3AH -** Three Analog Outputs (4-20mA), three alarms, one pulse, HART communication protocol - Requires DC4 or AC inout power **ST -** Standard Temperature -400 to 500°F (-400 to 205°C) **P1 -** Maximum 30 psia (2 bara), Proof 60 psia (4 bara) **CC -** MV80/MV82 Certificate of Conformance **(MISCPANA)** **Availability: 8 - 10 weeks**	EA	Qty: 2	**$11,241.00**	**$22,482.00**
Data Telemetry System				
Item: Data Logger and 3G Telemetry DataTaker DT80M with 3G modem 240V powered Wall mount enclosure Audible and visual alarm beacon DataTaker programing Data service – Web hosted data	EA	Qty: 2	**$7,563.00**	**$15,126.00**

Appendix 3 - Expression of interest flyer

The following flyer was distributed to producers by Dr Roger Campbell through a Pork CRC email distribution list on 18 September 2017. Additional emails with this flyer attached were also sent directly to producers with known existing biogas systems.

Funds available to assist producers with biogas system monitoring

The Pork CRC is funding grants to pork producers to assist with installing instrumentation for remotely monitoring the operation of existing on-farm biogas systems. This new initiative is being administered by the Department of Agriculture and Fisheries (DAF), Queensland. A total grant amount of $30,000 is available to share equally between a maximum of three pork producers. These grants must be used to purchase and install instrumentation for monitoring the volume, moisture content, temperature and composition of biogas used in existing on-farm biogas systems. The instrumentation will log the composition of the biogas (methane, carbon dioxide, oxygen and hydrogen sulphide concentrations) at regular intervals, both upstream and downstream from the biogas treatment system. The instrumentation must also include a data logger and communications system to allow remote monitoring of the system operation. The total cost of purchasing and installing the entire biogas monitoring and communication instrumentation is estimated at $50,000 per farm; however, this cost may vary substantially, depending on the existing system components, costs associated with complying with the relevant state gas safety legislation and the amount of labour provided by the producer to assist with system installation.
The comprehensive monitoring data which will become available following installation of this instrumentation is expected to greatly assist producers in the daily operation of their on-farm biogas systems, particularly in relation to:

- early diagnosis of operational irregularities or system faults,
- evaluating operating strategies and biogas treatment methods,
- managing changes in biogas composition,
- validating the energy and economic value of the biogas,
- assessing short- and long-term seasonal variations in biogas production and quality, and
- managing biogas use options to maximise economic benefit.

All expressions of interest submitted by producers will be assessed by Pork CRC representatives and a maximum of three producers will be selected to receive the subsidies. If fewer than 3 expressions of interest are received, the available funds ($30,000) will be shared equally between eligible producers. Agreements will then be negotiated between the successful producers and DAF. Under these agreements, each producer will be responsible for the purchase, installation and commissioning of the instrumentation, in accordance with all relevant regulatory standards and legislation. This will require a substantial investment by the participating producer(s) to fund the shortfall between the grant amount and the total cost of the installation. Pork CRC Bioenergy Support Program (BSP) researchers will be available to provide technical support with the installation of the monitoring equipment. The agreements will also require participating producers to grant Pork CRC BSP researchers with full access to the data collected by the biogas monitoring instrumentation for a minimum period of 2 years (subject to reasonable privacy provisions).

For further information on how to participate in this initiative, please contact Mr Alan Skerman (07 4529 4247, alan.skerman@daf.qld.gov.au). The deadline for receiving expressions of interest is Friday, 22 September, 2017.

Appendix 4 - APN article

It’s a gas article published in the September 2017 edition of Australian Pork Newspaper.

Taking biogas system monitoring for granted

Pork CRC

by ALAN SKERMAN
Leader, Pork CRC Bioenergy Support Program

PORK CRC is funding grants to a limited number of Australian pork producers with existing biogas systems to help them install remote monitoring instrumentation on their Australian biogas systems.

This initiative is being administered by the Queensland Department of Agriculture and Fisheries.

A total of $30,000 is available to share equally between a maximum of three pork producers.

Grants must be used to buy and install instrumentation for monitoring flow volume, moisture, temperature and composition of biogas used in existing Australian on-farm biogas systems.

The instrumentation, which will regularly log the composition of the biogas (methane, carbon dioxide, oxygen and hydrogen sulphide concentrations), upstream and downstream of biogas treatment, must also include a data logger and communications system to allow remote monitoring of the system operation.

The total cost of buying and installing the entire biogas monitoring and communication instrumentation is estimated at $50,000 per farm, however this may vary depending on existing system components, costs associated with complying with the relevant state gas safety legislation and labour to assist with system installation.

The purpose of the monitoring is to provide full data collected to the Pork CRC Bioenergy Support Program for a minimum of two years (subject to reasonable privacy provisions).

This monitoring data is to be used for the following purposes:

- Early diagnosis of operational irregularities or system faults;
- Evaluating operating strategies and biogas treatment methods;
- Managing changes in biogas composition;
- Validating the energy and economic value of biogas;
- Assessing short and long-term seasonal variations in biogas production and quality;
- Managing biogas use options to maximise economic benefit; and
- Quantifying biogas production in the pork industry.

Expressions of interest are to be submitted to the email address below and will be assessed to select a maximum of three for receipt of the grants.

If fewer than three eligible expressions are received, the available funds ($30,000) will be shared equally between eligible expressions received.

Agreements will be negotiated between the successful producers and DAF Queensland.

Under these agreements, each producer will be responsible for the purchase, installation and commissioning of the instrumentation, in accordance with all relevant regulatory standards and legislation.

This will require a substantial investment by the participating producer(s) to fund the shortfall between the grant amount and the total cost of the installation.

Pork CRC Bioenergy Support Program researchers will be available to provide technical support with the installation of the monitoring equipment.

For further information on how to participate or make a submission, contact me on 07 4529 4247 or email submissions to alan.skerman@daf.qld.gov.au

Please note, expressions of interest close Friday, September 22, 2017.

www.porkcrc.com.au