

Co-cultivation of microalgae and macroalgae for the efficient treatment of anaerobic digestion piggery effluent (ADPE)

(PROJECT 4A-109)

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

By

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Executive Summary

Microalgal and macroalgal phytoremediation has been proposed as a practical green solution for the treatment of anaerobically digested piggery effluent (ADPE). This is mainly due to the algae's inherent ability to strip away and convert inorganic nutrients, especially nitrogen and phosphorous efficiently from various effluents. Our previous Pork-CRC (4A-106 and 4A-108) studies showed the potential of a microalgae consortium that could grow efficiently on undiluted ADPE (up to 1600 mg L⁻¹ of ammonium) and that of a macroalgae consortium (4A-107) which could treat diluted ADPE (below 250 mg L⁻¹ of ammonium). The main advantage of macroalgae over microalgae is their ease of harvest, especially if the aim is to use the generated biomass as a source of animal feed. There is a potential in co-culturing cultures of microalgae and macroalgae to increase the overall efficiency of ADPE treatment and improve the economics related to algal biomass production

In accordance, we evaluated the co-cultivation of both microalgae and macroalgae together in two distinctive studies. For both studies, previously isolated consortium of microalgae consisting of *Chlorella* and *Scenedesmus* sp. was initially grown on undiluted ADPE until the concentration of ammonium was reduced to desired levels. In order to identify the most suitable and efficient macroalgal species for co-cultivation with microalgae, a preliminary study was conducted to evaluate the growth and nutrient removal of four locally isolated macroalgae on ADPE.

In the first co-cultivation study, the ADPE grown microalgae was directly utilized as a cultivation media for the propagation of macroalgae (*Cladophora* sp.) which was found capable of growing in ADPE up to 150 mg L⁻¹ NH₄⁺. However, despite the different conditions evaluated, the growth and photo-physiology of *Cladophora* sp. was found to decline and eventually led to its death due to the dominancy of microalgal culture during the co-cultivation

period. Subsequently, based on this outcome, an outdoor inclined reactor was customized to evaluate the potential use of attached macroalgal culture as a way of scrubbing available nutrients and microalgae biomass from ADPE post microalgal treatment. Although, the inclined system was very efficient in scrubbing and harvesting microalgae biomass, nevertheless, nutrient removal rates (i.e. ammonium and nitrate) of the co-cultivated system was much lower than the control which was operated using macroalgae only.

In this work, despite multiple different approaches and cultivation systems, both algal groups were unable to co-exist for efficient growth in ADPE due to direct competition for available resources and the negative interaction of both algal groups. Nevertheless, through this study, it has been demonstrated that macroalgae could be potentially used for harvesting microalgae grown in ADPE.

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1.0 Introduction

The vast imbalance between the distribution of freshwater resources and the global human population is significantly expected to widen due to the exponential growth of the population as well as the expansion of global economy (Häder et al., 1998). As of now, already the demand for freshwater has been visibly exhausted in regions with approximately 40% of the world population while as much as 60% of the population is expected to undergo some form of water scarcity by the year 2025 that will most certainly affect their daily lifestyle (Hein et al., 1995; Phang et al., 2015; Yong et al., 2013). Therefore, there is great need for the sustainable and optimized use of natural resources (i.e. water, food and raw materials) as well as their recovery from waste streams, representing a shift from a traditional linear economy to a circular economy (Sharma, 1986). Nevertheless, among the major challenges towards such green environmental initiatives is the recovery and reuse of waste streams generated by a wide range of human activities such as industrial, domestic and agricultural practices. Consequently, water pollution brought forward by the discharge of untreated or inadequately treated wastewater of various origins has emerged as one of the most vital challenges that needs to be immediately addressed (Yamamoto et al., 2004). Agricultural wastewater arising from livestock production facilities are among the major contributor of nutrient rich (i.e. nitrogen) wastewaters that can be of great concern if not dealt with appropriately (Hoek et al., 1995; Nan & Dong, 2004). Pig production is a typical industry, which results in generating vast amount of organic waste effluents. For example, there are around 2700 commercial pig producers in Australia alone who contributed to the production of 397, 000 tonnes of pork in 2017 with a gross production value of \$1.277 billion (Smith & Horne, 1988). The environmental impacts of commercial pig production can be of great significance, as improper management of piggery waste streams can be detrimental to the environment via the emissions of greenhouse gases (carbon footprint),

spread of pathogens, and the pollution of soil, surface and ground waters through nutrient enrichment and leaching (Diez et al., 2001; Maraseni & Maroulis, 2008).

Therefore, efficient wastewater treatment methods are critical to remove or reduce the concentration of nutrients, pathogens, heavy metals and other contaminant of such waste streams down to acceptable thresholds before their release and reuse to restrict damage to environmental resources and human health (Abdel-Raouf et al., 2012).

1.1 Anaerobic Digestion of Piggery Effluent

Currently, anaerobic digestion (AD) systems are the most commonly employed primary method for the treatment of piggery wastewater (Buchanan et al., 2013). The AD systems allow for the simultaneous removal of organic carbon and the generation of methane that can be exploited as a source of bioenergy (Buchanan et al., 2013). These systems are typically made up of individual or a series of covered facultative ponds containing wastewater that are biologically treated in the absence of oxygen by anaerobic microorganism (Ayre, 2013; Buchanan et al., 2013). AD systems are responsible for the fragmentary degradation of organic matter, the sedimentation of solids through settling, production and capture of biogas and also odour control of the primary effluent (Steneck, 1982). Nonetheless, anaerobically treated piggery effluent (ADPE) arising from such systems are still restricted by elevated nutrient and organic content that can result in the eutrophication of water bodies if directly released to the environment leading to an increase in economic cost to the society (Tucker et al., 2010). Therefore, there is a need for innovative technologies that are not only efficient for the bioremediation of ADPE but would also allow for maximum nutrient recovery and potential reuse of treated water within the piggery facilities.

1.2 *Microalgae and Wastewater Treatment*

Algae in general represent a diverse group of simple structured aquatic organisms that can either be autotrophic or heterotrophic in nature and are typically categorized based on their size and morphology (Borowitzka, 1999a). Microalgae represent unicellular cells that are microscopic in size while macroalgae can be of large assemblages (up to several meters in length) such as kelps and are composed of multiple cells (Borowitzka, 1999a; John et al., 2011). Among the major intrinsic advantages of algae over terrestrial plants include their enhanced efficiency in utilizing and converting incoming light photons into biomass, faster growth rates, ability to grow on non-arable land and various wastewaters and also their ability to accumulate large quantities of valuable macromolecules (Flöder et al., 2006; Spolaore et al., 2006). In addition, algal biomass can also be directly exploited as an economical and environmentally sustainable source of food, animal feed, bio-fuel and nutraceuticals (Flöder et al., 2006; John et al., 2011; Spolaore et al., 2006).

Phytoremediation represents a sustainable and energy effective solution that exploits the use of algae (micro- and macro-algae) for the efficient removal or biotransformation of pollutants (i.e. nutrients) from various types of wastewater (Phang et al., 2015). Phytoremediation is achieved through the algae's inherent ability in stripping away and utilizing inorganic nutrients (NH_3 , NH_4^+ and P) for their growth and biomass propagation that can be of great value especially during the final (tertiary) phase of wastewater treatment (Abdel-Raouf et al., 2012; Phang et al., 2015).

Therefore, the integration of algal cultivation with piggery effluent management systems holds great potential as it significantly improves the removal of nitrogen and phosphorus loads from ADPE into regulatory acceptable limits required for discharge (Abdel-Raouf et al., 2012). Moreover, such innovation would also allow for the production of valuable biomass from a

waste stream, hence drastically reducing the high production cost commonly associated with algae production.

The symbiotic algal-bacteria relationships often established in wastewater treatments are also ideally synergetic for the bioremediation of wastewater as such an algal-bacteria consortium can reduce the need of artificial aeration, restricts the potential of pollutant volatilization and increase the overall process efficiency (Munoz & Guieysse, 2006) (Figure 1). Through photosynthesis, algae uses available sunlight and carbon dioxide to provide oxygen required by aerobic bacteria for the breakdown of organic matter (Munoz & Guieysse, 2006) (Figure 1). In return, carbon dioxide and fragmented nutrients supplied by the bacteria are utilized for the growth of algae (Figure 1).

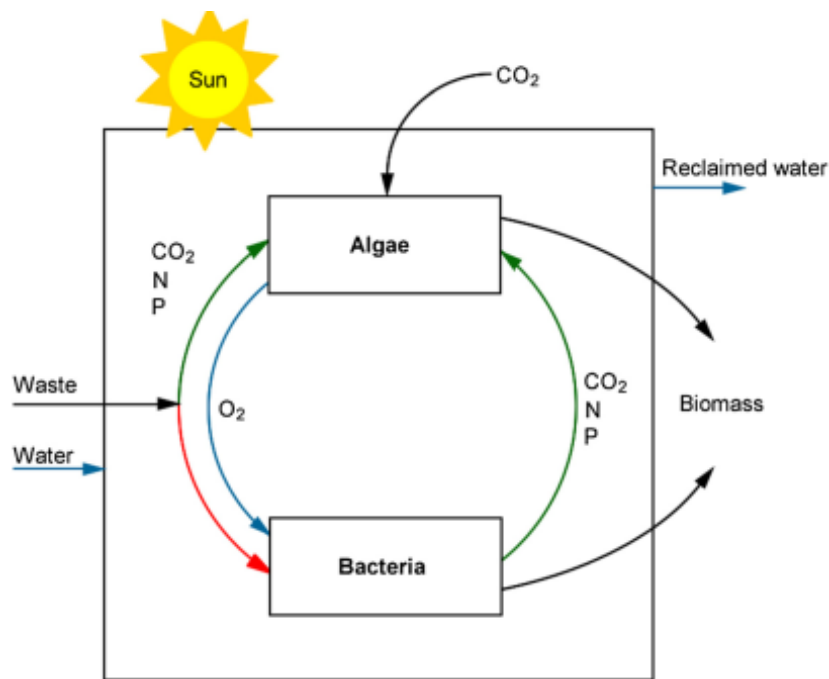


Figure 1: The overall outline of microalgae integrated wastewater treatment systems (from (Pedersen & Borum, 1996))

1.3 Algal Cultivation System

In order to meet commercial demand, a wide range of different algal cultivation systems are employed for the mass production of algal biomass (micro- and macro-algae). However, multiple corresponding factors need to be first taken into consideration in selecting the right cultivation setup for scaling up. Among them include: the biology and intrinsic properties of the selected microalgae, climatic conditions of a locality, desired final product, land and water availability and the utmost important factor which is the cost (capital and operating) (Borowitzka, 1999b) . Despite some recent innovations in designs, most systems are still classified as either open systems or closed photobioreactors (Borowitzka, 1999b). In open ponds, the algal culture is directly exposed to the environment. On the other hand, in closed photobioreactors cultures are confined in some sort of transparent vessels (tubes, tanks etc.) and not subjected to the open environment (Borowitzka, 1999b). It is to be noted that both of these cultivation systems are subjected to their own list of advantages and disadvantages (Table 1) (Borowitzka, 1999b).

Table 1: The advantages and disadvantages of different algal cultivation systems currently employed for wastewater treatment.

| Treatment | Advantages | Disadvantages |
|---|--|---|
| Microalgae Photobioreactors (closed systems) (Borowitzka, 1999b) | <ul style="list-style-type: none"> • Higher microalgae biomass productivity • Reduced/ free of contamination • Simple operation and better control of growth conditions (i.e. light, temperature and pH) • High removal efficiency of pollutants • No waste produced | <ul style="list-style-type: none"> • Higher capital and operational cost • Accumulates O₂ • More expensive to build |
| Tubular photobioreactors (microalgae) | Closed system made up of clear solar collecting tubing from either plastic or glass in which the microalgae recirculated or mixed by aeration or by using a pump which permits gas exchange of carbon dioxide and oxygen. Addition of heat exchange system can be made into the reactors to regulate and optimize growth temperatures of algae | <ul style="list-style-type: none"> • Build up oxygen in reactor which can be toxic to algae (Abdel-Raouf et al., 2012) • Heating up of cultures (Abdel-Raouf et al., 2012) • Expensive (Fong et al., 1993a) • Photo limitation of cells due to reduced availability of light (Fong et al., 1993a) |
| High rate algal ponds (HRAP) (Park et al., 2011) | <p>Shallow ponds used for growth of both microalgae and macroalgae</p> <p>HRAP ponds can:</p> <ul style="list-style-type: none"> • Removes 80% of BOD • Removes 90% of the nitrogen and phosphorus • Low capital costs • Low water footprint (if DWW is reused) • High nutrient removal | <ul style="list-style-type: none"> • Requires 50 times more land area than activated sludge systems • Limiting algae growth factors: <ul style="list-style-type: none"> • Temperature • Light (photoinhibition) • Nutrients • Carbon dioxide (CO₂) • Contamination risks |
| Raceway ponds (Borowitzka, 1999b) | Artificial shallow ponds (0.2-0.6m) made of concrete or plastic fiberglass. Mixed by paddle wheels and contain baffles. | <ul style="list-style-type: none"> • Large land mass required |

| Treatment | Advantages | Disadvantages |
|--|--|--|
| | Advantages include: <ul style="list-style-type: none"> • Low capital and operating costs • Reasonably high efficiency • Easily harvest microalgae | <ul style="list-style-type: none"> • Subjected to varying environmental parameters • Susceptible to contamination • Low microalgae productivity • Lower light penetration and availability with increasing depth • High water evaporation |
| Algal turf scrubbers (ATS) (Fong et al., 1993b) | It is an artificially created inclined flow way which has naturally growing macroalgae, bacteria and microalgae. The ATS is grown in a system where it is exposed to streams of wastewater. The benefits of ATS include: <ul style="list-style-type: none"> • Low maintenance- regularly harvest algae biomass from floway • Algal biomass absorbs toxic substances from wastewater • Algal biomass production- used for biofuels and other products • High nutrient removal system • Uses 60%-90% of nitrogen from sewage effluent (Slade & Bauen, 2013) • Removes 70% to 100% of phosphorous from faeces generated effluents (Roughgarden, 1983) | <ul style="list-style-type: none"> • Algal biomass cannot be used if it contains toxic substances from wastewater • Grazing- predation by herbivorous zooplankton and protozoa |
| Bottom Planting (Titman, 1976) | Used for the cultivation of marine macroalgae Macroalgae thalli is directly planted on pond sediments or attached to removable structures Simple to operate and allow for significant control over growth environment. | <ul style="list-style-type: none"> • Labour intensive • High capital cost |
| Long Line Cultivation (Huisman et al., 1999) | Can be used for a wide range of different macroalgae | <ul style="list-style-type: none"> • Contamination with microalgae • Difficult to operate |

1.4 Aim and Rationale of the Project

The overarching aim of any wastewater treatment system is the conservation of the environment in a manner that addresses and protects public health and socio-economic concerns. In accordance, the cultivation of algae for the bioremediation of ADPE does not only represent a sustainable production system for the treatment of ADPE but also contributes significant financial and environmental benefits to the pork industry (Ayre, 2013; Nwoba et al., 2016a). The cultivation of algae on piggery effluent generates revenue from what would otherwise be stagnant waste stream. Converting piggery effluent to algae biomass increases the productivity and profitability of piggeries as well as reducing their carbon footprint, representing substantial economic and environmental favorable opportunities for our national industry (Ayre, 2013; Nwoba et al., 2016a).

As illustrated in depth through our previous Pork CRC funded project and report: 4A-106, “Growth development and use of algae on untreated piggery anaerobic digestion effluent”, Ayre et al. (2017) isolated and identified multiple strains of microalgae capable of growing efficiently on undiluted ADPE with up to 1600 mg L⁻¹ ammonium in paddle wheel driven raceway ponds. This innovative study clearly highlighted the promise of exploiting locally isolated microalgae (i.e. *Chlorella* sp. and *Scenedesmus* sp.) for the bioremediation of undiluted ADPE enriched with high concentration of ammonium.

Building on this, we were also able to successfully cultivate a consortium of freshwater macroalgae (*Rhizoclonium* sp. and *Ulothrix* sp.) on 83% diluted ADPE up to 250 mg L⁻¹ d⁻¹ of ammonium through Pork CRC project 4A-107, “ Bio-prospecting and growth of macroalgae on anaerobic digestion piggery effluent (ADPE) (Nwoba et al., 2016b).

The ability of the isolated microalgae consortium to grow on undiluted ADPE is a significant innovation as it significantly eliminates the need of freshwater to dilute the ADPE (Ayre et al.,

2017). However, microalgal cultivation is limited by issues such as the operating costs associated with harvesting the algal biomass (de Boer et al., 2012). On the other hand, due to their larger size, the harvesting and dewatering of macroalgae is much easier and more economical than microalgae (Nwoba et al., 2016b). However, the ability of the isolated macroalgae to grow only on diluted ADPE (83% dilution) and the need of freshwater for dilution (see Figure 2, Option 2) is neither environmentally sustainable nor cost effective.

Therefore, there is great potential in combining the cultivation of both microalgae and macroalgae to increase the overall efficiency of ADPE treatment and to address current challenges. In this view, the overarching aim of this study was to develop and evaluate an integrated and sequential treatment process comprising of both microalgae and macroalgae for treating undiluted ADPE. Through this proposed system, previously isolated strains of microalgae (*Chlorella* sp. and *Scenedesmus* sp.) would be first cultivated directly on undiluted ADPE for initial treatment and nutrient recovery. Nutrients (ammonia and phosphorus) originally contained in the waste are to be recycled and used to produce biomass, which can be further used for various other purposes (i.e. bioenergy or animal feed). Following this initial treatment using microalgae, locally isolated strains of macroalgae will be subsequently cultivated in the pre-treated ADPE in conjunction with or without the initial microalgae consortium.

In order to avoid dilution of ADPE with freshwater, improve efficiency of ADPE nutrient removal rates and improve the ease of overall algal harvest and dewatering, we evaluated the integration of both micro- and macro-algae together in a stepwise cultivation system (see Figure 2 below, Options 3 and 4) in this study. This innovative strategy involved the sequential cultivation of microalgae first on undiluted ADPE followed by inoculation of macroalgae on the treated ADPE streams either post microalgae harvest (Figure 2, Option 3) or by introducing macroalgae together with the culture of microalgae (Figure 2, Option 4). A thorough literature

search indicated that no information is currently available on the potential mix of microalgae and macroalgae cultures. Due to ease of process, option 4 is by far our preferred strategy.

The combination of microalgae and macroalgae would most certainly allow for the algae to absorb and utilise different types of pollutants from ADPE, improving the overall waste stream quality for potential reuse and environmental discharge. For example, organic hydrophobic pollutants show a high tendency to accumulate within microbial cells such as microalgae (Pacheco et al., 2015) while dyes, colourants and heavy metals have been successfully shown to be absorbed by macroalgae which acts as a biofilter (Esmaeli et al., 2013; Zhou et al., 1998). The interaction of these two group of organisms represents an efficient and environmentally valid alternative for improving the conditions of ADPE. If successful, the proposed system has the key advantages of quality end product and reduced operating costs (i.e. water and nutrients source for algae growth is derived from ADPE). Combining the need to treat ADPE with the importance of reducing carbon emissions is the goal of this project. The system functions in a stepwise fashion.

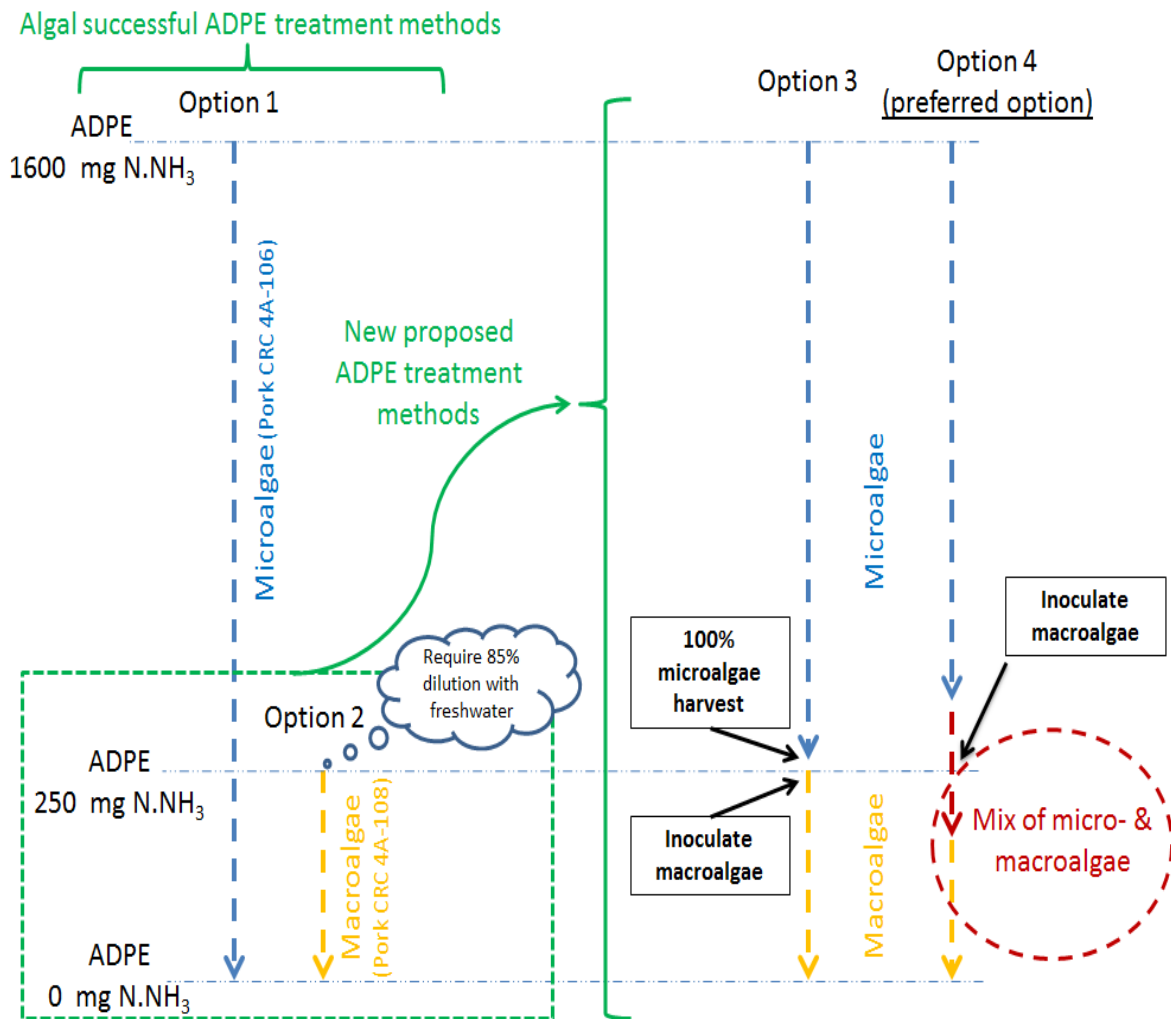


Figure 2: Proposed methodology for the co-cultivation of micro- and macro-algae for the efficient the efficient treatment of anaerobic digestion piggery effluent (ADPE).

2.0 Materials and Methods

In this study, preliminary experiments were conducted to identify the most robust and suitable species of macroalgae that was not only able to grow on the highest concentrations of ADPE (lowest dilution) but also with excellent nutrient removal rates. Once this was achieved, two subsequent individual experiments were carried out to evaluate the viability of co-cultivating both the previously established microalgae consortium (*Chlorella* and *Scenedesmus* sp.) and the identified macroalgae species together for the efficient bioremediation of ADPE. The first experiment represented an indoor trial combining both the cultivation of micro- and macro-algae together in ADPE under controlled environmental conditions (i.e. temperature and irradiance). The second experiment was an outdoor study evaluating the co-cultivation of micro- and macro-algae based on a customized flow-through inclined reactor under the outdoor climatic conditions of Western Australia.

2.1 Anaerobic Digestate of Piggery Effluent

The anaerobically digested piggery effluent (ADPE) used in the work was obtained from the Medina Research Station located in Kwinana, Western Australia (32.2376° S, 115.8285° E). This facility employs covered anaerobic digestion ponds to biologically treat its raw effluent generated on site. The ADPE obtained from site was sand filtered to remove suspended solids and subsequently used for algae cultivation. Physico-chemical properties of the sand-filtered ADPE were characterised using standard protocols (Table 2).

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/Nm³ CH₄), the average electrical efficiency of the generator engines was 34%, which is regarded as typical for biogas engines operating at piggery installations.

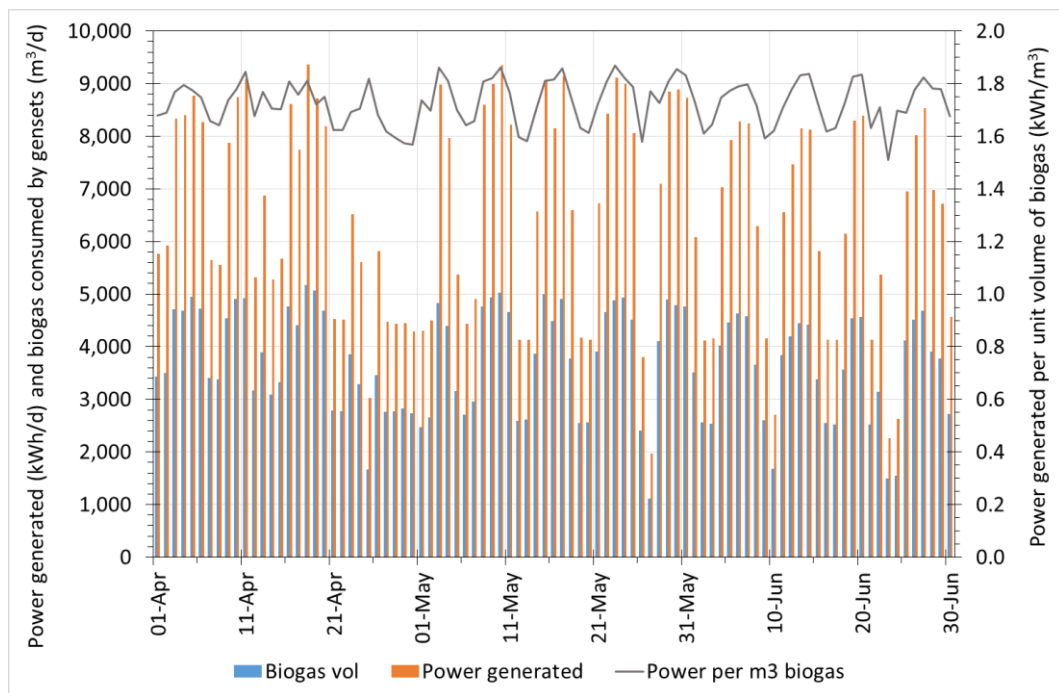


Figure 19. Daily biogas volumes consumed by the gensets, total genset power generation and power produced per unit volume of biogas over the 3-month monitoring period.

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 m³/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 m³ biogas and 287 m³ CH₄, 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/m³ 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 H₂S 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 O₂ in the air injected into the headspace effectively supported significant biological oxidation of H₂S inside the headspace of the hybrid CAP. However, the measured H₂S 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 H₂S 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 H₂S concentration measured downstream of the biological scrubber was very low (18 ppm) and instantaneous H₂S concentrations rarely exceeded 200 ppm. This showed that the combined biological oxidation in the hybrid CAP and external biological scrubber was effective at removing H₂S 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 H₂S. This sequence of reactions can progressively increase the H₂S 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 H₂S 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 O₂ is added to the CAP headspace, further oxidation of H₂S can occur to form sulphate instead of elemental sulphur. The resulting sulphuric acid (H₂SO₄) produced by this reaction, can cause severe corrosion of exposed metal or concrete surfaces. Supplying excess O₂ 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 CH₄ and CO₂ 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 N₂ 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 CH₄ concentration and/or increasing or decreasing H₂S 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.

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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 (CH₄), carbon dioxide (CO₂), oxygen (O₂) and hydrogen sulphide (H₂S) 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 ThermoFisher 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 |
|--|-----------|--------|----------------------|----------------------|
| <u>Gas Analyser</u> | | | | |
| 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 |
| <u>Flow Meter</u> | | | | |
| 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 in/out 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 |
| <u>Data Telemetry System</u> | | | | |
| Item: Data Logger and 3G Telemetry DataTaker DT80M with 3G modem 240V powered Wall mount enclosure Audible and visual alarm beacon DataTaker programming 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 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



by ALAN SKERMAN
Leader, Pork CRC Bioenergy
Support Program



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 re-

sponsible 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 avail-

able 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