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Potential for Biogas Production and Emissions Reduction at Equestrian Centre

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Abstract:

While good information exists on the use of pig and cow manure biomass for heat and electricity generation, no published case studies on the use of horse manure to meet loads in equestrian facilities could be found. These facilities often have significant loads for lighting and hot water, and therefore offer an opportunity for onsite renewable energy generation to offset loads.

A study was undertaken to investigate options for Centennial Parklands to achieve Zero Carbon status - using less energy than produced - by reducing energy demand and the use of renewable energy generation. Within this project, the potential to use horse manure in biogas digestion as a fuel source at Centennial Parklands Equestrian Centre (CPEC) was assessed. This paper presents the results of the study.

Horse manure is not a common biogas fuel, but offered an excellent opportunity to meet the heating and electrical loads of CPEC through a cogeneration system. Analysis suggests that it would be possible to completely meet the energy demands of CPEC using the biogas produced on site - over 100MWh/pa of heat energy and electricity. It was found that the savings on energy and waste disposal costs would pay for the large scale project in 5 years, saving a minimum of 1300 tonnes of carbon dioxide equivalent every year.

The analysis presented in this paper provides useful information about the potential for biogas generation at equestrian facilities, and the method developed in this paper could be applied to a wide range of animal husbandry facilities.

1. Introduction:

This study on the potential to use horse manure in biogas digestion as a fuel source at Centennial Parklands Equestrian Centre (CPEC) is part of a broader goal of Centennial Parklands (CP) NSW to achieve Zero Carbon status, largely for social and economic reasons. A review of the current energy loads (see section 2 of this paper) indicated the potential for alternative energy generation to contribute to this goal. In particular, the use of horse manure biomass was selected for further investigation, as CPEC load profile was not well matched to a photovoltaic (PV) generation profile, the energy required for hot water was a large portion of the load, and the methane from the horse manure was potentially a significant source of greenhouse gas emissions.

This paper is the summary of the investigation into the feasibility of a biogas-powered combined heat and power (CHP) generator to meet the energy needs of CPEC, with the horse manure produced by CPEC as a feedstock. Biogas digestion is a relatively well-established technology, but the majority of studies into the technology utilise cow or pig manure, since it is nowhere near as common to have a high concentration of horses in one location as it is to have a similar concentration or cows or pigs. However, equestrian centres and horse studs do have a high enough concentration of animals to facilitate gathering the waste material. As such, it is of value to investigate whether the generating potential of horse manure would make it a viable energy generation option for facilities like equestrian centres.

The second section of this paper will describe the load assessment process and selection of biogas CHP for further investigation. In the third section, the methods used for assessing the potential for biogas generation will be described. The fourth section of the paper will outline the results and discuss them, and the final section of the paper will cover the conclusions and recommendations for further investigation.

2. Load Analysis and Technology Choice

In order to determine an appropriate technology to meet the energy needs of CPEC, the load was analysed. The load profile (Figure 1) was at its peak at morning and evening twilight, and a large portion of the energy needed was heat energy.

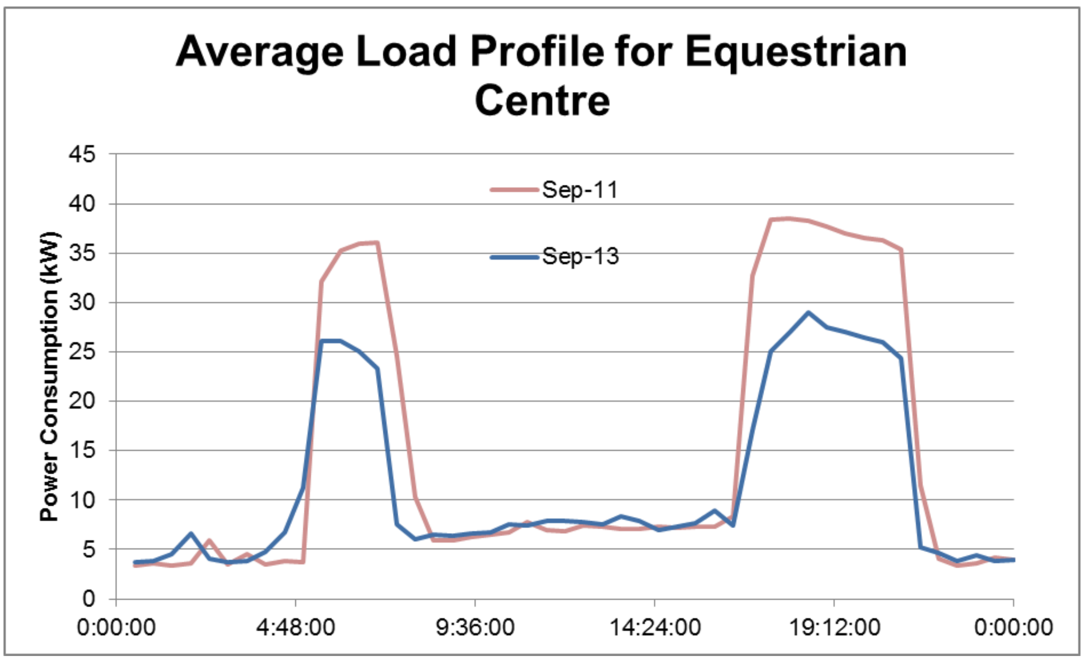
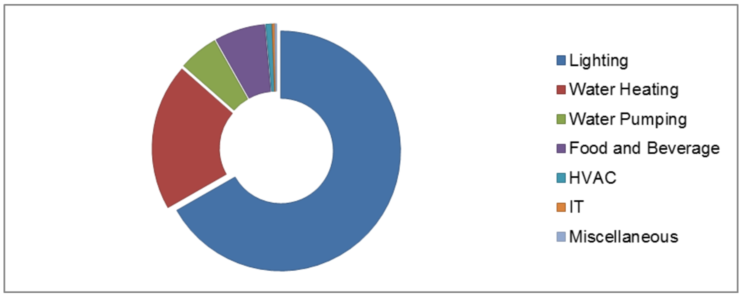


Figure 1: Average load profile for Sept 2011 and Sept 2013

An analysis of the energy loads at CPEC was carried out by Fairbairn in 2012 to identify energy saving opportunities [1], and the data used in this section is based on his work. Some of the recommendations have been implemented by CPEC, reducing the electrical loads by 23% after the installation of efficient lighting. However the loads are still substantial and it is possible that the heating load would be larger if the system were able to meet demand.

Figure 1 shows the load profiles for typical September days in 2011 and 2013. The drop between the peak demand during 2011 and 2013 is due to the efficient lighting upgrade that reduced the lighting load by 23%, from 38kW to 29kW. This efficiency measure is expected to reduce the annual electrical load due to lighting from the recorded 112,556kWh to approximately 86,000kWh. The other issue is that of the real hot water load. Fairbairn (2012) noted in his observations that although the hot water heaters were running at full power for most of the day, the temperature of the hot water system dropped significantly during the day, which suggests that the current system is significantly undersized for the needs of CPEC. Based on the consumption information provided by Fairbairn, it was possible to estimate the heat energy needed per horse on a daily basis if the system were adequately sized. While the recorded hot water load is 33,247kWh pa, based on the calculated energy consumption per wash, the heat energy needed for an adequate system is conservatively estimated to more than double to at least 75,000kWh per year. Figure 2 shows the differences in the proportions of the load as changes are implemented. Prior to any changes, the lights make up the largest portion of the load. When the lights have been replaced with more efficient units and the hot water demand is not limited by the system size, the heat energy makes up a much larger portion of the energy load of CPEC.



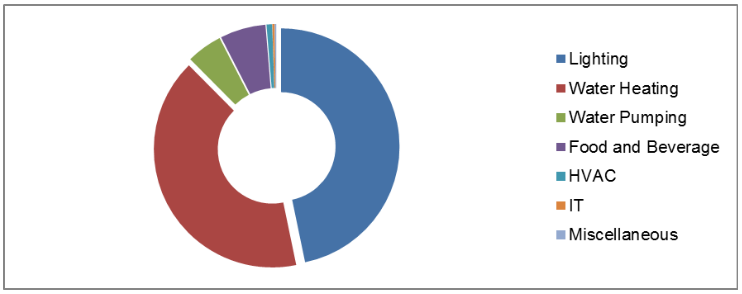


Figure 2: Load profile before (above) and after (below) the changes including energy efficient lights and cogeneration have been implemented.

If photovoltaics were employed to meet a significant fraction of the load, due to the morning and evening peaks a substantial amount of storage would be required to avoid having large amounts of energy exported to the grid.[1] At over $800/kWh installed [2], the cost of the storage was likely to render the project non-viable economically. It was therefore necessary to review other means of generation.

Based on the high heat load, combined heat and power (CHP) generation would be a good fit to the needs of CPEC. As horse manure is available at CPEC in abundant quantities as a waste material, it was investigated to determine if the available fuel could potentially meet the needs of CPEC. Using the manure from CPEC offered additional benefits: capturing the methane that would have otherwise been released to the atmosphere and finding a valuable use for the waste material from CPEC.

[1] In NSW, network service providers typically make little or no payment for the exported electricity.

3. Horse Manure Biogas Digestion Potential and System Sizing

In order to conduct a feasibility study of the use of biogas digestion in CPEC, preliminary costing was required. A number of Australian biogas system providers put forward proposals, the most detailed of which were reviewed and used as a reference in the feasibility study [3, 4]. These proposals also provided a benchmark for expected output and system design.

Biogas digestion is also known as anaerobic digestion. It is a form of biologically driven chemical decomposition in an oxygen-limited environment where the significant product is biogas. Biogas is primarily comprised of methane and carbon dioxide with trace amounts of sulphides and nitrides. The typical composition of biogas is approximately 60% methane and 40% carbon dioxide, with the other trace gases making up less than 1% of the final output [5]. The other output of the digestion process is the digestate, which is comprised of any undigested volatile solids and the non-digestible solids. Often the input manure is mixed with water to allow better movement and encourage hydrolysis, so the digestate is in the form of slurry. After de-watering the slurry, the digestate can be used as fertiliser, as the digestion process removes almost all traces of pathogens and breaks down the material into small pieces that distribute evenly onto plant beds.

All forms of digestible material will be made up of a certain proportion of solids, known as the total solids (TS), and a remainder that is usually water. Not all solids in a material will be digestible in the anaerobic process. Out of the TS, the proportion that is able to break down through digestion is known as the volatile solids (VS). The amount of methane produced in biogas digestion is directly proportional to the amount of volatile solids in the material. The energy density of biogas is proportional to the methane content and generally ranges from 21-29MJ/kg.VS [5]. Kusch et al give a value of 170L CH_4/kg.VS for horse manure after 6 weeks of mesophilic digestion [6]. This corresponds well with values found elsewhere in literature and will be the value used for all calculations.

Animal manure is typically described as a 'wet' material, as it usually is made up of at least 50% water. Wartell et al state that horse manure is made up of 37% TS and of that proportion, 84% are VS [7]. In effect, 0.31kg out of every kg of manure can be digested to produce biogas. However Wartell also states that in most biogas digestion, only half of the VS will be digested, so for every kg of horse manure, we can expect approximately 0.15kg will be broken down into biogas, producing approximately 25.5L CH_4/kg manure. The actual output of biogas digestion is affected by many variables – the time taken, the temperature of the process and the type of bacteria will all have an impact, as will the quality of the feedstock and how it is initially treated [8]. Mesophilic digestion is optimised at 32-38°C, and the output will decrease with changes in temperature. Faster rates can be obtained through thermophilic digestion, starting at temperatures above 45°C, but this is hard to achieve for large systems. Estimates of non-optimal production have been calculated from the models produced by Cullimore et al.[9] Most calculations relating to biogas output are done on the basis of empirical observations and testing the bio-methane potential (BMP) of the material.

Table 1: Projected mesophilic digestion output at different temperatures after 6 weeks

Temperature	15°C	20°C	26°C	32-38°C
Output (6 wks)	75L CH_4/kg.VS	94L CH_4/kg.VS	117L CH_4/kg.VS	170L CH_4/kg.VS

In the biogas digestion process, the material is first treated before it is transferred to the main digestion chamber. Primary treatment involves chopping and mixing with water to facilitate digestion and improve output [10]. Additional processes can be added to facilitate more effective and speedy digestion, such as sonication. Sonication is the process of breaking down the material using ultra-sonic frequencies of 20kHz – 25kHz and is often used in digestion processes [11]. However, it is not a technology that is suitable in this situation. Horses in equestrian centres are kept in a close environment that would be near to the proposed location of the digester. The frequencies of sonication fall well within horses' hearing range of 55 – 33,000Hz [12]. The use of sonication was deemed to be potentially disruptive and dangerous in an equestrian centre where the noise of the system could startle or agitate the horses and cause injuries in horses or people who may be around them.

The chemical process of digestion occurs in four main phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis. During treatment, water is added to the material and hydrolysis begins. During hydrolysis, the particulate matter in the material begins to break down into fatty acids and enzymes. Saccharification will also occur, whereby carbohydrates in the mix will break down into sugars and polymers; these sugars will break down further in the fermentation process. During acidogenesis, the fatty acids and sugars are broken down into various other acids, hydrogen and also ammonia, a weak base. In acetogenesis, the products of acidogenesis are broken down to form acetic acid, carbon dioxide and some hydrogen. In the final step of methanogenesis, acetic acid is broken down to form methane and carbon dioxide [3].

The temperature during a biogas digestion process impacts the type of bacteria that will be dominant in the process. This will have a flow-on effect to the retention time required to digest the majority of the VS, which in turn will have an impact on the size of the digestion chamber that needs to be designed. There are three types of bacteria commonly found in biogas digestion: psychrophilic, most active at 5°C to 20°C; mesophilic, most active between 30°C and 40°C; and thermophilic, which prefer temperatures between 60°C and 75°C [13]. Psychrophilic bacteria have the lowest output over a given time period, while the cost and complexity of maintaining a large system at appropriate temperatures for thermophilic bacteria make them unviable. Australian technology most commonly uses mesophilic bacteria, so this bacteria type has been the chosen for further investigation.

In designing the system, it was essential to work out an appropriate hydraulic retention time (HRT). The digestion process will continue as long as there is material to be digested, but the rate of biogas production tapers off over time. Kusch et al performed an experiment to estimate the digestion rate of horse manure using mesophilic bacteria. Out of all the VS that could be digested, 52% were consumed in the first 4 weeks, 62% were digested in 6 weeks but only 74% of the VS were digested at the end of 10 weeks [6]. There is a 20% improvement in the cumulative output between 4 weeks and 6 weeks, but after that point in time the rate of digestion slows considerably. Six weeks can therefore be considered as the limit of useful digestion time for mesophilic bacteria. This sets the upper limit on the HRT and hence the maximum useful capacity of the tank required for the material. Beyond this point, the economics of constructing a large enough tank are likely to outweigh any potential benefits in output.

Table 2: Volume of digestate assuming dilution of 2.5 water: 1 manure and digestion at ideal temperature.

Retention Time	Volume of digestate material	Daily volume of biogas produced	Total Volume required	Recommended tank diameter
4 weeks	175m^3	188 m^3	363 m^3	9.6m
6 weeks	262.5 m^3	244 m^3	506.5 m^3	11.4m
10 weeks	437.5 m^3	267 m^3	704.5 m^3	13.4m

Diameter is based on a 5m tank height, recommended by Clarke Energy[3]. Space on the site is limited but the tanks described would fit in the available area.

4. Potential Benefits from a Horse Manure Biomass-Fuelled Cogeneration System

4.1. Energy

Given that the main energy demands of the case study equestrian centre are relatively evenly split between heat and electricity (Figure 2) a cogeneration system is a good fit to supply the energy needs. Using what would otherwise be waste heat from a gas turbine generating electricity boosts the overall efficiency of the system, although the efficiency is dependent on how much heat can be recovered and used. The Clean Energy Council estimates efficiencies as high as 70-90% for CHP systems compared to 35% for separate heat or power generation [14]. The heat energy can be used for water heating, in steam turbines or in adsorption chilling to provide cooling. A cogeneration system will produce roughly equal amounts of heat and electrical energy, but the proportions of each will be strongly dependent on the set-up of the cogeneration system [15]. A topping system will prioritise the electrical output, a bottoming system will maximise the heat energy output and then the electrical output. Given that the electrical energy demand is larger than the heat demand [1], a topping cogeneration system was selected for this study.

There are 200 horse stalls at CPEC [16], with an occupancy rate of over 95% for most of the year. According to CPEC records, an average of 2.55t of manure is collected for disposal every day [17]. At a rate of 170L CH_4/kg.VS and 31% VS for horse manure, this will yield about 134,000L of methane per day. The estimated amount of methane generated on a daily basis has an energy content of 4900MJ. In a cogeneration system of 60% efficiency with equal outputs of heat and electricity, this would yield at least 410kWh/day of each. Based on the estimated volume of fuel material, the biogas digester should produce enough methane to yield well over 100MWh of heat energy and 100MWh of electrical energy per year. Based on information received from Utilitas, 18MWh pa will be consumed in system operation, leaving 82MWh of useable electrical energy,[4]. These figures are confirmed by industry estimates.

A biogas cogeneration system with six weeks retention would be able to supply the majority of the heat and electricity needs of CPEC. This takes into account the expected doubling of heat energy demand that would be consumed by an adequately sized hot water system. To confirm this, it would be necessary to perform bio-methane potential (BMP) testing on the material from CPEC to make sure that the expected yield is accurate [4]. It may also be possible to use tri-generation to extract further value from the material [18].

4.2. Avoided Waste Disposal Costs

The economic viability of horse manure as a fuel heavily depends on the avoided transportation and disposal costs. The primary issue is the cost associated with manure disposal, which is currently over $140,000pa [17], and is projected to rise by up to 50% over the next 10 years due to landfill constraints [19]. By processing the manure in a biogas digester, the by-products of the process can be used as fertilisers or other horticultural products. This transforms the waste material into a product with commercial value, creating a revenue stream for CP. The projected value of the product is beyond the scope of this study, but would be expected to eliminate the costs of waste disposal as a minimum. The digestate also has economic value as a fuel source for pyrolysis. Pyrolysis combined with biogas digestion could potentially supply more electrical power or export energy to the grid [20], and this would also be worth further investigation.

4.3. Emissions Abatement

The waste manure from CPEC causes another issue for Centennial Parklands, namely that of CO_2-e emissions due to the methane emitted as the manure decomposes. Methane has a global warming potential of at least 21 times that of CO_2 [21]. The 134000L of methane that could be captured and used by the biogas cogeneration system each day has a weight of 88.7kg. In a year, this adds up to 32.4t of methane, which is equivalent to 680t CO_2-e pa and this far outweighs the CO_2-e emissions due to electricity consumption at the equestrian centre. In NSW, every kWh of purchased energy has an emission factor of 0.88kg CO_2-e/kWh.[22] For the annual load of 141MWh at CPEC [1], the emissions due to electricity demand work out to be 124.3t CO_2-e pa. In previous reviews of CO_2-e emissions at CP, the value of the methane from the manure has not been taken into account, despite its magnitude in comparison to the emissions caused by electricity generation. By using the methane from the manure in a small gas turbine, these emissions can be reduced by 709.2t CO_2-e pa.

Table 3: Emissions according to technology in use

	Hot Water	Other electrical	CO_2 from generated energy	Methane from Manure	Total CO_2-e
Current Load	33,250kWh	108,000kWh	124.3t CO_2-e	32.4t CH_4 or 680t CO_2-e	804.3t CO_2-e
Biogas and Cogeneration	75,000kWh	108,000kWh	95.1t CO_2-e from cogeneration	Captured, used in cogeneration	95.1t CO_2-e

4.4. Economic Assessment

The combined savings from waste disposal costs and electricity costs would allow this system to achieve full payback in approximately 4 years. This is based on the following: 1) an initial cost of $883,000[2], 2) a rate of inflation of 2.8%pa [23], 3) a projected increase in electricity costs of 7%pa [24], 4) first year savings of $160,000, 5) O&M costs of $15,000pa[3] and 6) an expected increase in disposal costs of 50% over the next 10 years [19]. As Centennial Parklands is a NSW

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[2] $883,000 was the CAPEX quoted by Utilitas for component cost and installation.

[3] O&M costs were based on 25% of a single APS 4 public servant's wage of $60,000pa

Government agency,[25] it has been assumed that it would be able to obtain finance at low cost and the discount rate was set at CPI: 2.8%pa. It is assumed that all savings would be directed to repay capital costs. This does not take into account any commercial benefit that might be derived from selling the de-watered digestate as a horticultural product, which would accelerate the payback.

In a business as usual case, the costs over 10 years would be $2.6m ($2013) to CPEC. If the biogas digester solution were implemented, CP would benefit to the net present value of $1.69m ($2013) over 10 years compared to business as usual.

5. Conclusions

For Centennial Parklands, the 2.5t/day of manure collected at CPEC could be utilised in a biogas digestion powered cogeneration system. The system is predicted to produce 82MWh of useable electrical energy, meeting the majority of CPEC electrical demand and approximately 100MWh of heat energy, more than enough to meet the needs of the hot water system, even with the expected increase in the amount of hot water used. The economic viability is largely dependent on the savings on waste disposal, with additional economic benefit derived from savings on purchased energy.

In conclusion, horse manure is a viable fuel source for biogas digestion where there are a large number of horses housed in close proximity. The CO_2-e emissions from the methane produced as the manure breaks down can be captured by using the manure in biogas digestion. While the actual amount of methane produced from the manure will vary according to the quality of the material, it is reasonable to expect between 150L-200L CH_4/kg.VS, or about 22L-30L per kg of manure. This methane can be used to power a gas turbine or cogeneration system, supplying power to the facility in which the horses are housed.

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