

Biogas recovery from a temperate climate covered anaerobic pond

S. Heubeck and R. J. Craggs

ABSTRACT

New Zealand has over 1000 anaerobic waste stabilisation ponds treating wastewater from farms and industry. Traditional anaerobic ponds were not designed to optimise anaerobic digestion to produce biogas and are therefore uncovered, releasing biogas to the atmosphere, which can cause odour problems and contributes to GHG emissions. The biogas production and treatment performance of an anaerobic piggery pond retrofitted with a perimeter cover working under field conditions was monitored over a 14 month period. The cover design proved successful in capturing biogas, mitigating odour and GHG issues and coping with New Zealand weather conditions. High solids removal rates (73% and 86% for TS and VS respectively) were achieved. An annual average biogas methane production rate of $0.263 \text{ m}^3 \text{ CH}_4/\text{kgVS}_{\text{added}}$ was observed, which is similar to gas production rates of mesophilic farm waste digesters, and indicates that the prolonged hydraulic and solids retention times of covered anaerobic ponds can fully compensate for lower operating temperatures. These results suggest that covered anaerobic ponds treating agricultural wastes in New Zealand have great potential to reduce odour and GHG emissions and recover renewable energy, while producing an easy to handle effluent for land irrigation or further treatment.

Key words | anaerobic pond, biogas, energy recovery, methane production, WSP

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INTRODUCTION

Anaerobic waste stabilization ponds are widely used for the treatment of agricultural, industrial and municipal wastewaters (McGrath & Mason 2004; Park & Craggs 2007). Anaerobic ponds are simple, usually unheated anaerobic digesters operating in the psychrophilic temperature range (below 35°C), with operating temperatures varying with ambient temperature. Volatile solid (VS) reduction and biogas production rates below 35°C decrease almost linearly with decreasing temperature (Henze 1995), thus psychrophilic ponds require a longer solids retention time than mesophilic digesters to achieve the same volatile solids reduction (Stevens & Schulte 1977). Methanogenesis occurs at temperatures as low as 3–9°C, but the minimum temperature has been found to decrease as the pond ages (Stevens & Schulte 1977; Cullimore *et al.* 1985).

Anaerobic waste stabilization ponds in New Zealand (NZ) have been primarily designed for VS and BOD₅ reduction through sedimentation of wastewater solids, rather than for efficient anaerobic digestion and biogas recovery. Therefore anaerobic ponds are uncovered, allowing biogas (comprising primarily of CH₄ and CO₂) to escape to the atmosphere, contributing to greenhouse gas (GHG) and odour emissions. Previous monitoring of biogas emissions from anaerobic waste stabilisation ponds using 25 m² floating covers (Park & Craggs 2007; Craggs *et al.* 2008) indicated that under New Zealand temperate climate conditions anaerobic pig and dairy farm ponds produce similar annual average biogas methane volumes based on the volatile solids (VS) loading as more sophisticated mesophilic digesters, although a pronounced seasonal

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variation in gas production was observed. Since the New Zealand agricultural sector may soon require mitigation options for its increasing GHG emissions, there was a need to verify our previous observations at full-scale by developing and demonstrating a practical cover design for biogas capture from ponds in New Zealand. This paper presents monitoring data (organic loading and removal, and biogas production and composition) of an anaerobic piggery pond, which was retrofitted with a full perimeter cover to gain a more accurate understanding of the GHG emission reduction and energy recovery potential of covered anaerobic ponds.

METHODS

Location and description of the monitoring site

The anaerobic pond was located at the Waratah Farms Roto-o-rangi piggery near Cambridge (−37.9S, 175.5E) in the Waikato region of New Zealand. The site experiences a moderate maritime climate (annual average air temperature: 13.5°C; annual average rainfall: 1,183 mm). The opportunity to cover the existing anaerobic waste stabilisation pond, primarily to mitigate odour concerns, arose as part of an intensive farm redevelopment, during 2007/2008. The existing pond was originally constructed in 1973 and clay lined, with dimensions at the water surface of 28 m by 90 m. The pond was 3 m deep with a steep bund slope of approximately 3:1 (vertical: horizontal), giving a total pond volume of 7,200 m³. Flush manure from the pig sheds is washed into a collection sump and passed through a solids separator to remove fibrous material before being pumped into the anaerobic pond. Effluent from the anaerobic pond flowed by gravity to a facultative storage pond, before being irrigated to land. Ultimately the pond will receive flush manure from 1,500 grower pigs (average weight 50 kg); however during the redevelopment phase the number of pigs varied between 1,200 and 700. Following thorough desludging the existing anaerobic pond was covered with a 0.75 mm polypropylene (PP) earth sealed perimeter cover. The cover had no in-built flotation, but included an array of weight pipes for rainwater guidance. Rain water was removed from the cover by a float switch

operated submersible pump. Biogas draw-off from the cover was accomplished using a 100 mm perforated PVC pipeline around the pond perimeter under the cover, connected to a centrifugal gas blower.

Monitoring

Biogas flow was continually monitored using a domestic gas flow meter (Email Industries (NZ) Ltd) connected to the gas blower. A telemetry data acquisition system was installed to log biogas flow at 15 minute intervals. This consisted of a magnetic event sensor fitted within the gas flow meter that generated a pulse output for every 2 litres of biogas flow. Biogas flow data was logged at 15 minute intervals (Campbell Scientific CR10 data logger, Campbell Scientific Inc, UT, USA) and was downloaded daily through a cell phone modem. All biogas production data was corrected to standard temperature and pressure (20°C; 1,013 mbar). Biogas and pond water temperatures were measured at 15 minute intervals using temperature loggers (HOBO Water Temp Pro, Onset Computer Corporation). Biogas temperatures were measured at the biogas draw-off point from the cover. Pond water temperature was measured in the pond effluent taken from 1 m below the pond water surface. Wastewater flow was measured by monitoring the flow of effluent from the covered anaerobic pond in the transfer pipe to the facultative storage pond, using an ultrasonic flow meter (PCS-MWA-M Prosol Process Solutions Ltd. Auckland NZ) strapped to the outside of the pipe. Wastewater flow data was logged at 15 minute intervals by a Campbell data logger and downloaded via a cell phone modem.

Biogas composition (CH₄, CO₂, O₂, NH₃ and H₂S) was determined weekly using a portable gas analyser (GA2000 plus Landfill Gas Analyser, Geotechnical Instruments (UK) Ltd, Leamington Spa, England). The gas analyser was calibrated biannually with certified standard gases. Pond influent and effluent grab samples were taken at weekly intervals. Pond effluent samples were obtained at the transfer pipeline between the anaerobic pond and the facultative holding pond, influent samples were taken downstream from the solids separator. The water quality of the influent and effluent of the anaerobic pond was analysed using standard methods (APHA 1998) for

the following parameters: total solids (TS), volatile solids (VS), total Kjeldahl nitrogen (TKN) and ammoniacal nitrogen ($\text{NH}_4\text{-N}$).

RESULTS AND DISCUSSION

Cover performance

The perimeter cover was easily installed from 3 sections that were welded together on-site. The cover performed well throughout the monitoring period, with satisfactory guidance of rainwater to the removal pump. The only operational issue was the accumulation of leaves from nearby trees on the cover in autumn which required occasional unclogging of the rainwater draw-off pump. No build up of a crust of organic material underneath the cover was detected over the monitoring period. Billowing of the cover material between the rainwater guidance pipes created gas storage capacity. As demonstrated during a power outage which prevented the gas blower from operating, the cover could store up to 500 m^3 of biogas. This inbuilt gas storage capacity of the anaerobic pond cover is a valuable feature, as it enables, and gives flexibility to, intermittent biogas use.

Wastewater flow and pond loading

Since the anaerobic pond cover prevents evaporation losses and rainwater incursion, and the pond has been sealed for many years, it was assumed that the effluent flow equalled the pond influent flow, which was used to calculate pond loading rates. The low hydraulic head ($\sim 0.5\text{ m}$) between the

covered anaerobic pond and the facultative holding pond, and the potential for magnesium-ammonium-phosphate (struvite) build-up meant that the wastewater flow had to be measured with an ultra sonic flow meter (attached to the outside of the pipe) rather than an impeller type flow meter (within the pipe). For this reason reliable flow data was only recorded from May 2008 onwards. Pond effluent flows varied strongly; both daily and monthly (Figure 1). Daily variation in pond effluent flow was influenced by daily precipitation, since firstly some stormwater entered the flush manure collection system and diluted the pond influent, and secondly rainwater accumulating on the pond cover, displaced pond water below the cover at times when rainfall exceeded the capacity of the rainwater draw-off pump. Since all rainwater was eventually removed from the pond cover by the pump, spikes in pond water flow caused by heavy rain events were usually followed by days of low pond water flow (Figure 1).

While the monthly variation in pond water flow may also have been influenced by rainfall, a large proportion of the variation can be attributed to the ongoing redevelopment of the farm, resulting in changes in both the number of pigs onsite and the area of shed that was flushed. The pond loading rates ($\text{kgVS}_{\text{added}}/\text{d}$ & $\text{kgVS}_{\text{added}}/\text{pig}/\text{day}$) were calculated by multiplying the total weekly pond water flow with pond influent VS measurements from grab samples taken at weekly intervals (Table 1). The pond loading averages for the period May to November 2008 were calculated as $90\text{ kgVS}/\text{day}$ and $0.127\text{ kgVS}/\text{pig}/\text{day}$.

Since the pond loading rates calculated for each week varied widely (Table 1), they were also calculated using an alternative approach based on feed utilisation (Table 2).

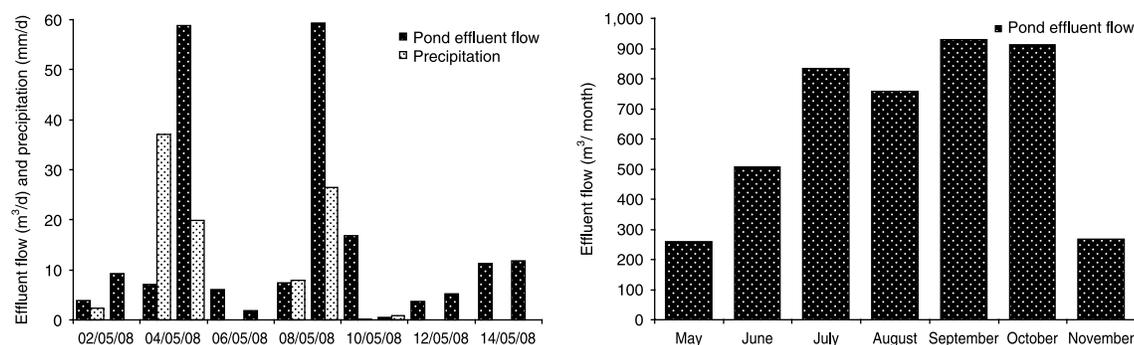


Figure 1 | Example of daily variation in pond effluent flow and precipitation (2–15th May 08), and monthly variation in pond effluent flow (May to November 2008).

Table 1 | Weekly pond water flow and influent versus concentrations

Week	Sampling date (grab sample)	Weekly flow (m ³ /week)	VS con. (g/m ³)	VS loading (kg/week)	VS loading (kg/day)	Number of pigs	VS loading (kg/pig/day)
1	8/05/2008	95	6,008	568	81	900	0.090
2	16/05/2008	109	6,734	732	105	900	0.116
4	28/05/2008	20	1,518	30	4	900	0.005
5	5/06/2008	69	8,154	561	80	670	0.120
6	12/06/2008	108	8,694	942	135	670	0.201
7	19/06/2008	114	6,678	764	109	670	0.163
8	26/06/2008	135	6,406	863	123	670	0.184
11	18/07/2008	246	2,000	493	70	700	0.101
13	31/07/2008	139	2,600	362	52	700	0.074
14	7/08/2008	146	3,900	570	81	700	0.116
15	14/08/2008	153	2,600	397	57	700	0.081
16	21/08/2008	214	3,700	790	113	700	0.161
18	4/09/2008	75	6,300	475	68	700	0.097
19	11/09/2008	165	1,200	198	28	700	0.041
20	18/09/2008	220	4,700	1,036	148	700	0.211
23	8/10/2008	314	4,100	1,288	184	700	0.263
24	16/10/2008	192	3,700	709	101	700	0.145
27	6/11/2008	132	4,600	606	87	700	0.124
	Average	147	4,644	632	90	727	0.127

The dry matter excreted by the pigs each day was calculated based on the known amount of feed consumed at the farm (typically 2.2 kg/pig/d), and standard literature figures for dry matter (DM) and digestibility (VQ) of the

various feeds used. The solids separator removal rates were assumptions based on industry information, which take into account different concentrations of easy to separate (fibrous and inorganic) compounds in various feeds, while the VS

Table 2 | Calculation of pond loading rate based on feed utilisation

Pond VS input calculation

Number of pigs	670
Total feed consumed daily	1,492 kg/d
Feed consumption per pig	2.2 kg/d

Composition	(kg/d)	DM (%) [*]	DM intake (kg/d)	VQ (%) [*]	Excreted DM (kg/d)	Separator removal [†] (%)	DM post separator (kg/d)	VS ratio [‡] (%)	VS pond loading (kg/d)
Barley	550	86	473	83	80	50	40	65	26
Maize	550	86	473	90	47	20	38	65	25
Meat & bone	184	95	175	70	52	25	39	65	26
Soy cake	208	89	185	92	15	15	13	65	8
Total	1,492		1,306		195		130		84
Per pig/day	2.23		1.95		0.29		0.19		0.126

^{*}Dry matter (DM) and digestibility (VQ) data from Kirchgessner (1997).

[†]Estimated separator removal rates of various manure components base on industry information.

[‡]Monitored average TS/VS ratio of post separator wastewater Sep 2007–Apr 2008.

ratio (TS/VS ratio) was an average figure from the weekly monitoring. The calculations (Table 2) indicated pond loading rates of 84 kgVS/d and 0.126 kgVS/pig/day, which were very similar to the values calculated based on pond water flow and influent VS data.

Wastewater treatment performance

The water quality of the pond influent varied widely, in a similar way to the pond flow (Table 3). The covered anaerobic pond provided excellent TS and VS removal (73% and 86% reduction respectively), through sedimentation and anaerobic digestion. These figures are similar to a solids reduction in a temperate climate dairy manure anaerobic lagoon (82.2% and 86.7% for TS and VS respectively) reported by Safley & Westerman (1992). These high removal rates are probably a reflection of the low volumetric loading rate and long retention time the pond was operated with. The $\text{NH}_4\text{-N}$ concentration of the pond effluent was higher than in the pond influent (Table 3) since ammoniacal nitrogen is released during the anaerobic breakdown of wastewater solids (Henze 1995; Burke 2001). Comparison of pond influent and effluent TKN data shows only a minor reduction of 15% in Total Kjeldahl Nitrogen. Since gaseous (NH_3) ammoniacal nitrogen losses from the pond in the biogas were calculated to be less than 4 kg $\text{NH}_4\text{-N}$ for the entire monitoring period, this indicated that the majority of the TKN removal was through sludge accumulation within the pond. Some of this accumulated TKN will probably be released over time by bacterial

degradation of more recalcitrant organic compounds. Sedimentation and thorough anaerobic digestion in the covered anaerobic pond created a relatively homogenous and inert effluent, which was easy to pump and handle, provided struvite build up was monitored. This effluent could be irrigated to land without the odour and clogging issues commonly encountered with raw effluent.

Biogas production and quality

Biogas production from the covered anaerobic pond was monitored from September 2007 to November 2008 and the biogas composition analysed at weekly intervals. The annual average biogas composition was 66.7% methane (CH_4), 30.4% carbon dioxide (CO_2), 0.2% oxygen (O_2), 2.8% other gases (N_2 etc.), 252 ppm ammonia (NH_3) and 612 ppm hydrogen sulphide (H_2S) (Table 4). These figures are in line with literature values for the quality of biogas from heated and mixed farm waste digesters (Safley & Westerman 1988; Burke 2001), but the CH_4 concentration was lower than 74% reported by Craggs *et al.* (2008) and 80.4% reported by Safley & Westerman (1992) for small scale floating cover experiments on a piggery and dairy anaerobic pond, respectively. This difference is probably due to less scrubbing of CO_2 from the biogas in the pond water of completely covered anaerobic ponds compared with open pond systems (Green *et al.* 1995). Monthly biogas methane production ($\text{m}^3\text{CH}_4/\text{month}$) and monthly biogas methane production per pig ($\text{LCH}_4/\text{pig}/\text{month}$) for the period September 2007 to November 2008 are shown in

Table 3 | Annual average pond influent and effluent water quality parameters and pond treatment performance

Parameter	Pond influent			Pond effluent		
	Average	n	S.D.	Average	n	S.D.
Total Solids (TS) concentration (g/m^3)	14,234	33	7,974	3,904	33	538
Volatile Solids (VS) concentration (g/m^3)	7,859	33	5,756	1,110	33	335
Ammoniacal nitrogen ($\text{NH}_4\text{-N}$) concentration (g/m^3)	838	33	396	1,076	33	231
Total Kjeldahl Nitrogen (TKN) concentration (g/m^3)	1,544	37	547	1,311	37	246
<i>Pond treatment performance</i>						
TS reduction (influent/effluent)	73%					
VS reduction (influent/effluent)	86%					
Ammoniacal nitrogen reduction (influent/effluent)	– 28%					
Total Kjeldahl Nitrogen reduction (influent/effluent)	15%					

Table 4 | Average biogas composition and methane production rates from the piggery anaerobic pond for the monitoring period September 2007 to November 2008

Parameter	Sep 07	–	Nov 08
Monitoring period:	Sep 07	–	Nov 08
Number of pigs:	670	–	1,200
<i>Biogas composition</i>			
CH ₄ (%)	66.7%		
CO ₂ (%)	30.4%		
O ₂ (%)	0.2%		
Other gases (%)	2.8%		
NH ₃ (ppm)	252		
H ₂ S(ppm)	612		
<i>Biogas production:</i>			
VS production per pig (kgVS/pig/d)	0.127		
Total VS production monitoring period(kg)	53,645		
Total biogas methane production (m ³)	14,086		
Biogas methane production rate (m ³ CH ₄ /kg VS _{added})	0.263		
Daily average biogas methane production (m ³ CH ₄ /d)	32		

Figure 2 along with values of mean pond water and air temperature. Monthly biogas methane production varied greatly, and a general trend between biogas methane production and mean pond water and/or air temperature can be seen. However, the clear seasonal relationship between biogas methane production and pond water temperature identified in experimental cover studies (Safley & Westerman 1989, Craggs *et al.* 2008) could not be confirmed. The lack of a clear correlation between biogas methane productivity and temperature may be due to the very low volumetric loading of this pond (~ 0.0125 kgVS/m³/d) and the variation in manure quantity and quality added to the pond (as a result of construction work at the piggery during the study). Covering the pond probably promotes more stable conditions within the pond by: (1) preventing wind mixing of the pond water; (2) preventing evaporative cooling; (3) providing an insulating layer of biogas above the water surface; (4) absorption of solar heat collected by the black cover. As a result, the temperature of pond water in a covered anaerobic pond would be expected

to have less diurnal and seasonal variation than that of an open pond, and result in more consistent biogas production.

The average biogas methane production value for the monitoring period based on VS loading was calculated to be $0.263 \text{ m}^3 \text{ CH}_4/\text{kg VS}_{\text{added}}$ (Table 4). This value is similar to the methane production values of more sophisticated heated and mixed farm waste digesters (e.g. Hill 1984; Safley & Westerman 1988, Cobb & Hill 1990; Burke 2001). This indicates that unheated covered anaerobic ponds in temperate climates like New Zealand can fully compensate the disadvantage of lower operating temperatures through extended hydraulic retention time. The hydraulic retention time of the covered anaerobic pond in this study was long (343 days), however, the retention time of the settleable solids would be much longer, as they accumulate and remain on the pond bottom until they are anaerobically degraded or eventually removed by desludging.

The methane production value of $0.263 \text{ m}^3 \text{ CH}_4/\text{kg VS}_{\text{added}}$ is also similar to that ($0.279 \text{ m}^3 \text{ CH}_4/\text{kg VS}_{\text{added}}$) determined in earlier studies on anaerobic piggery ponds (Craggs *et al.* 2008). A likely explanation for the slightly lower value in the present study is that biogas production does not occur evenly across the pond area (Safley & Westerman 1988), particularly around the pond edges and our earlier study extrapolated methane production under a small cover to the whole pond area.

The capacity of the pond cover to store biogas can compensate for some of the observed variation in biogas production, and also provides flexibility for potential intermittent biogas uses (e.g. peak load generation). Therefore covered anaerobic ponds not only have a great potential for reducing odour and GHG emissions produced by New Zealand's expanding agricultural sector, but also provide a flexible and versatile source of renewable energy that can help farms and rural communities to achieve a higher level of energy self-sufficiency. As demonstrated, covered anaerobic ponds can retrofit existing pond infrastructure, and purpose built installations are cost competitive with heated and mixed tank digesters. Moves by a number of NZ Regional Councils to mandate deferred irrigation storage for dairy farm effluent in order to mitigate nutrient leaching and run-off concerns, could provide an opportunity for covered anaerobic pond technology, since newly installed uncovered storage ponds will be additional

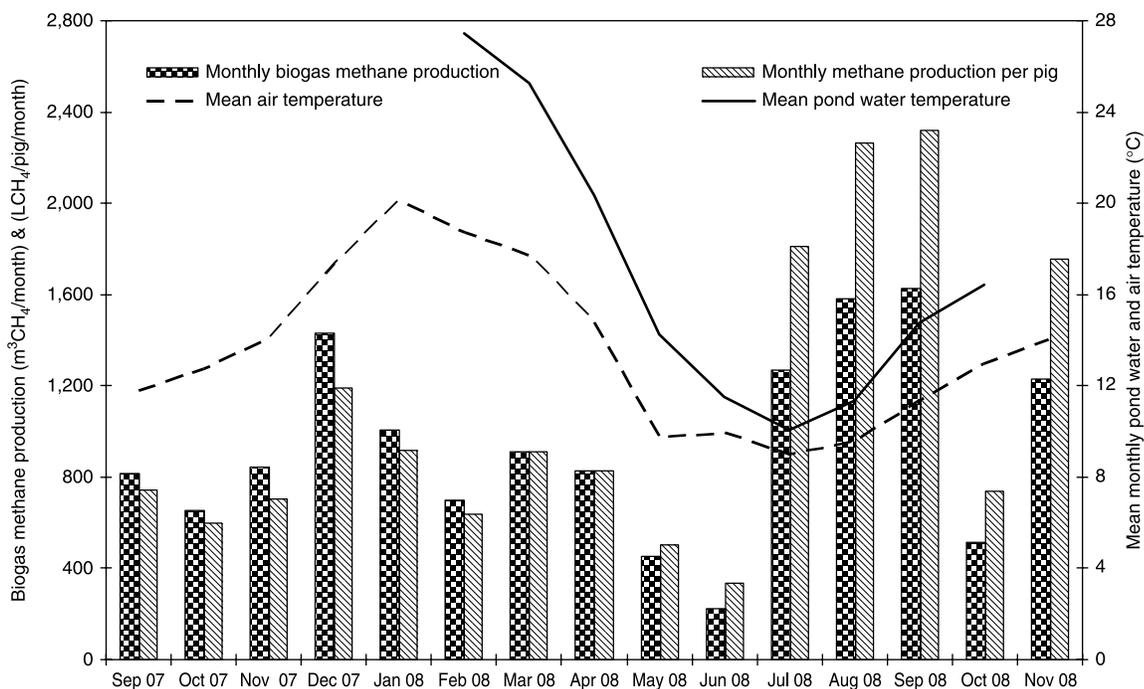


Figure 2 | Total monthly biogas methane production ($\text{m}^3\text{CH}_4/\text{month}$), monthly methane production per pig ($\text{LCH}_4/\text{pig}/\text{month}$) and mean air and pond water temperatures for the monitoring period. (Pond water data for period Sep 07 to Feb 08 not available).

sources of odour and GHG emissions. Further research is required to establish cost effective and reliable biogas utilisation at small scale to realise the distributed energy value of agricultural effluent, for heating, electricity generation and transport applications.

CONCLUSIONS

A simple, easy to retrofit pond cover has proven successful in capturing biogas from an existing anaerobic pond, to address odour and GHG concerns, and provided options for energy recovery through biogas use. The major findings of this field-scale demonstration were:

- The durable cover was capable of handling New Zealand's climate conditions and provided biogas storage to compensate for production variation or enable intermittent biogas use.
- High wastewater solids removal rates (73% and 86% for TS and VS respectively) were achieved within the covered anaerobic pond.

- The similarity of the biogas methane production rate ($0.263 \text{ m}^3 \text{ CH}_4/\text{kg VS}_{\text{added}}$) of the covered anaerobic pond to that of more sophisticated mesophilic farm waste digesters indicates that prolonged hydraulic and solids retention times in covered anaerobic ponds can fully compensate for lower operating temperatures.

Covered anaerobic ponds have great potential to reduce odour and GHG emissions produced by New Zealand's expanding agricultural sector. As they can retrofit existing pond infrastructure, and are cost competitive with heated and mixed tank digesters, they provide opportunities for farms and rural communities to achieve a higher level of energy self-sufficiency.

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