8.1 Production and beneficial use of methane

Biogas is produced during the decomposition of organic matter under anaerobic conditions (see chapter 2.3 'Anaerobic, aerobic and facultative ponds'). It typically contains 60% to 65% methane (CH_4), 35% to 40% carbon dioxide (CO_2) and variable amounts of impurities such as hydrogen sulphide (H_2S) and ammonia (NH_3). Although methane can be flared to reduce greenhouse gas (GHG) impacts (see chapter 8.2 'Greenhouse gas emissions'), it can also be put to beneficial use, offsetting at least some of the farm's electrical and heat energy requirements.

Before you can develop methane capture and use projects, you need to answer the following questions:

- What type of anaerobic digester suits the operation?
- How much biogas will it yield?
- How do the costs and benefits compare with conventional alternatives?

Types of digesters

Large-scale anaerobic digesters in use on dairy farms in the USA and Europe fall into four types:

- Covered anaerobic ponds—traditionally more heavily loaded than conventional anaerobic ponds, with volatile solids (VS) loading rates of up to 170 g m^{-3} and a hydraulic retention time (HRT) of 35 to 60 days (USDA-NRCS 2003). Ponds operate at ambient conditions, so gas yield is reduced in cool seasons (methane production is severely limited in cold climates). Variations incorporating sludge recycling or distributed inflow are referred to as enhanced covered anaerobic ponds.
- Fixed-film digester—a digester, usually heated, containing media that increase the surface area available for bacteria to adhere to, thus preventing washout. As more than 90% of the bacteria are attached to the media, an HRT of days, rather than weeks, is possible. Separation of fixed solids by settling and screening is necessary to prevent fouling.
- Complete-mix digester—sometimes referred to as a continuously stirred tank reactor; usually a circular tank with mixing to prevent solids settling and to maintain contact between bacteria and organic matter. Mixing also maintains a uniform distribution of supplied heat.
- Plug flow digester—a long concrete tank where manure with as-excreted consistency is loaded at one end and flows in a plug to the other end. The digester is heated. Although it can have locally mixed zones, it is not mixed longitudinally.

The total solids content of the effluent stream largely determines the choice between systems. Figure 1 indicates that covered anaerobic ponds and fixed-film digesters suit effluent with up to 3% TS, complete mix-digesters from 3% to 11% TS, and plug flow digesters from 11% to 13% TS. (The term 'digester' is used loosely here to refer to both covered ponds and other types of digesters.)

A number of researchers and commercial developers are currently working on options for recovering energy from manure solids (TS > 20%) using processes such as batch anaerobic digestion, gasification and pyrolysis (GHD 2007b). However, semi-solid material (TS 15%–20% depending on the material) is more problematic as it is too dry to be pumped and agitated but not dry enough to prevent sedimentation and separation of solids and liquids.

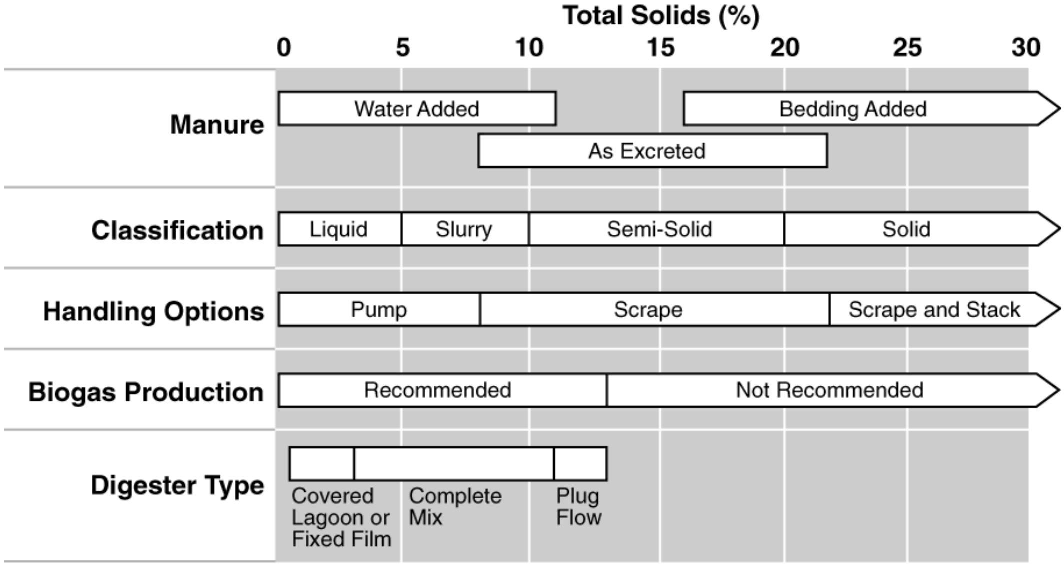

Figure 1. Digester options determined by solids content (source US EPA nd).

Figure 2. Enhanced covered anaerobic pond (photo courtesy of George Western Foods).

With a typical solids content of <2% TS, the effluent from most Australian dairies will not be suitable for digestion in complete-mix or plug flow digesters without concentration in a solid–liquid separator (see chapter 2.1 'Solid–liquid separation systems'). Most mechanical separators leave most of the volatile solids in the liquid fraction. Improved performance via chemically enhanced separation (see chapter 5 'Odour emissions and control') is an option, but a thorough cost–benefit analysis is necessary.

Biogas yield

In absolute terms, the amount of biogas produced can be calculated from stoichiometrics given that 0.3495 m^3 of methane is produced for each 1 kg of COD destroyed at standard conditions of 0 °C and 101.3 kPa (ASERTTI 2007) or, converted using the Ideal Gas Law, 0.375 m^3 at 20 °C and 101.3 kPa.

Note that although 'methane yield per amount of VS added to the digester' (L CH_4 [kg VS]$^{-1}$) appears to be the most commonly reported measure of methane productivity, it varies with the chemical composition of the VS added. That is, the relative concentrations of carbohydrates, proteins and lipids composing the VS determine the methane productivity. For example, the theoretical methane yield is 415 L CH_4 [kg VS]$^{-1}$ from a carbohydrate but 1014 L CH_4 [kg VS]$^{-1}$ from a lipid (Moller *et al.* 2004). As dairy cattle are fed diets with a higher proportion of poorly digestible lignin and cellulose than pigs, it follows that the methane potential of dairy manure is lower than that from pig manure. In addition, rumen activity results in digestion of the easily degraded materials before excretion. Methane productivity based on the amount of COD added should be therefore be used where possible, or in conjunction with VS (ASERTTI 2007).

In a covered anaerobic pond, the amount of undigested COD (or VS) settling as sludge cannot easily be determined, so $COD_{destroyed} \neq COD_{influent} - COD_{effluent}$. But collection and measurement of methane yield allows the VS degradability to be determined; this information can be used in planning other similar digesters.

Impact of temperature

Although methane can be produced over a wide range of temperatures, microorganisms grow best over a narrower range, so most digesters are designed to operate in the mesophilic temperature range (20–50 °C). Unheated or ambient-temperature digesters in Australia usually operate within the psychrophilic temperature range (10–30 °C). Unfortunately, the ultimate gas yield of psychrophilic digestion (of cattle manure) is, on average, 30% lower than that of mesophilic digestion (Burton and Turner 2003).

In uncovered lagoons, the average water temperature in the upper layer (0–2 m) follows average monthly air temperature, with a slight time lag, but lower layers show a reduced thermal cycle centred on the mean annual air temperature (Hamilton and Cumba 2000). Smith and Franco (1985) describe a model for predicting pond temperatures.

In general, the rate of anaerobic degradation increases at higher temperatures; these reactions follow the Arrhenius temperature-dependence equation:

$$k = A \cdot e^{-Ea/RT} \qquad (1)$$

where k = reaction rate constant

A = proportional factor

E_a = activation energy

T = temperature (K)

R = gas constant.

The E_a of most biological reactions is approximately the same (within an order of magnitude); that is, as a simple rule of thumb, the reaction rate doubles with each 10 °C of temperature increase. Therefore, anaerobic degradation at 25 °C should proceed half as fast as at 35 °C. In general, therefore, at lower operating temperatures the hydraulic retention time should be increased in line with the equation above: thus, at a comparable loading rate, the 25-°C digester should have twice the hydraulic retention time of the 35-°C digester.

In reality this applies only to small temperature differences, as other parameters may intensify or diminish the effect. For example, at lower temperatures ammonia is less inhibitory, allowing a faster reaction rate (GHD 2007b). Anecdotal evidence suggests that increased mixing reduces some of the loss in performance at lower temperatures. However, anaerobic degradation is a very complex process and requires complex models to predict digester behaviour accurately.

The lower temperature limit for the methanogens is generally thought to be around 13 to 15 °C, but low activity has been observed at 7 to 9 °C (Shilton 2005). The proportion of methane in the biogas may be low at such low temperatures.

Methane concentration

The theoretical concentration of methane in biogas is:

$$\%CH_4 = 19 \times COD/TOC \quad (2)$$

At typical COD:TOC ratios of 3 to 3.5 in dairy effluent, biogas typically contains 60% to 65% methane (up to 85%). The biogas is usually saturated, and the higher the temperature, the greater is the absolute amount of water vapour held.

Reported yields

The methane productivity of dairy effluent is summarised in Table 1.

Table 1. Reported methane productivity by psychrophilic digestion of dairy effluent.

Methane productivity ($L\ CH_4$ [kg VS added]$^{-1}$)	Details	Source
390[a]	2-ML lagoon, av. 18–19 °C, HRT 67 days, 1.1% TS, loading rate 0.12 kg VS $m^{-3}\cdot day^{-1}$	Safley and Westerman (1992)
194	Laboratory digester, 15 °C, HRT 170 days, loading rate 0.1 kg VS $m^{-3}\cdot day^{-1}$	Safley and Westerman (1994)
103 (128 with recycling of digester contents)	Laboratory digester (fixed-film), 23–24 °C, HRT 2.3 days, 1.3% TS	Powers *et al.* (1997)
70	Laboratory digester (control), 10 °C, HRT 33 days, 0.4% VS, loading rate 0.12 kg VS $m^{-3}\cdot day^{-1}$	Vartak *et al.* (1997)
210[b]	4.6-ML lagoon, av. annual temp. and HRT not specified, loading rate 0.05 kg VS $m^{-3}\cdot day^{-1}$	Craggs *et al.* (2008)
($L\ CH_4$ [kg COD added]$^{-1}$)		
45	14-ML lagoon, 15 °C, HRT 40 days, 0.5% TS, loading rate 0.07 kg VS $m^{-3}\cdot day^{-1}$; only 90% of pond covered	Williams and Gould-Wells (2004)

a: The ultimate methane productivity was 530 $L\ CH_4$ [kg VS destroyed]$^{-1}$—much higher than typical.
b: VS added was estimated, not measured.

Where productivity is measured in terms of the amounts of VS added and destroyed, the ratio of the two represents the biodegradability of the VS in the effluent. At a COD:VS ratio of 1.1 in dairy manure (ASAE 1999), the ultimate methane productivity should be approximately 390 $L\ CH_4$ [kg VS destroyed]$^{-1}$ (at standard conditions of 0 °C and 101.3 kPa). Although Barth and Kroes (1985) suggest that anaerobic ponds achieve degradation (not removal) of 55% of VS added in dairy effluent, the methane productivity implied by that would be 210 $L\ CH_4$ [kg VS added]$^{-1}$, which is at the high end of the reported range. This suggests that VS destruction in ponds is probably lower than 50%.

Beneficial use of biogas

Biogas can simply be flared so that instead of methane (with a GHG equivalence 21 times that of CO_2), the combustion products—CO_2 and H_2O—are discharged. Wotton et al. (2007) reported on the types of flares suitable for biogas and their requirements under Australian regulations.

Alternatively, the biogas could be discharged through a biofilter, where some of the methane will be oxidised by aerobic bacteria (see chapters 5 'Odour emissions and control' and 8.2 'Greenhouse gas emissions').

Unless odour control is a specific aim, it is unlikely that either option will be adopted, as the costs (pond cover, gas collection and flare or biofilter) are not offset by a use with monetary return. In the event of monetary incentives or carbon credits aimed at reducing GHG emissions from manure management systems, the biofilter option may not qualify owing to variable performance and difficulties in measuring reductions.

Hot water

Boilers developed for the combustion of biogas are commercially available. Existing natural-gas-fired boilers can be modified to run on biogas with the following provisions:

- Commercial gas boilers are certified to meet Australian Standards, so modifications will require approval from the Australian Gas Association.
- Boilers containing a copper heat exchanger or fittings will suffer from corrosion unless the biogas is scrubbed to reduce H_2S concentrations. (H_2S in water forms an acid that corrodes metal, especially copper and bronze. Frequent starting and stopping of the boiler intensify this problem.)

Boiler efficiency is typically 80% to 90% (Van Haren and Flemming 2005).

Milk cooling with absorption chillers

Absorption chillers are heat-driven refrigerators relying on heat for energy supply rather than electricity. They are not new technology but have typically been used to supply much larger cooling capacities than are needed for on-farm milk cooling. More recently, the use of absorption chillers for air conditioning has led to the development and commercialisation of smaller units. However, the small, low-temperature units required for on-farm milk cooling to <4 °C are still at the pre-commercial stage and require further development.

Generation of electricity

Systems that generate electricity from biogas consist of:

- an internal combustion engine (compression or spark ignition) or a gas micro-turbine
- an optional heat recovery system
- a generator
- a control system.

Compression (converted diesel) internal combustion engine—Compression engines are also known as dual-fuel engines, as a small amount of diesel (10%–20% of the amount needed for diesel operation alone) is mixed with the biogas before combustion. Dual-fuel engines offer an advantage during start-up and downtime as they can run on anywhere from 0% to 85% biogas (Van Haren and Flemming 2005).

Spark-ignition internal combustion engine—Natural gas or propane engines are easily converted to burn biogas by modifying the carburetion and ignition systems. With

60% methane, biogas reduces engine power by approximately 20%, compared with 10% by natural gas and 5% by LPG (Van Haren and Flemming 2005).

Converted petrol engines offer efficiencies of 18% to 28%, but gas engines and compression (converted diesel) engines offer efficiencies at up to 42%. In general, the small spark-ignition engines (converted petrol engines) cover the range from 10 to 60 kW, dual fuel engines from 40 to 200 kW, and gas engines from 150 to 500 kW (up to 3 MW is possible). An additional 40% of the biogas energy can be captured from engine jacket water and exhaust gases by a heat recovery system (see below).

Gas micro-turbines—These are essentially internal combustion engines with a rotary action instead of reciprocating. Although gas turbines are typically much larger than needed for biogas (e.g. >800 kW), suitably sized micro-turbines have been developed but are currently difficult to source and service in Australia.

A 30-kW (nominal) micro-turbine running on biogas from a covered anaerobic lagoon at California Polytechnic State University (400 cows intensively housed) powered a generator producing 15 to 25 kW at 20% to 25% efficiency (Williams and Gould-Wells 2004). NO_x emissions were 3 ppm (low NO_x emissions are an advantage of micro-turbines over internal combustion engines).

Heat recovery systems—Commercially available heat exchangers can recover heat from the engine water cooling system and exhaust. Typically, heat exchangers will recover around 0.8 kWh of heat per kWh of electrical output from the engine jacket and 0.75 kWh from the exhaust, increasing total (electrical plus thermal) energy efficiency to 45% to 65% (up to 80% in larger installations).

Generators fall into two types: induction (or asynchronous) and synchronous. An induction generator operates in parallel with the mains supply, deriving phase, frequency and voltage from it, and cannot stand alone. Synchronous generators can operate in parallel with the mains or, in the event of supply interruption, without it. Synchronous parallel generation requires a sophisticated interconnection to match generator output to mains phase, frequency and voltage. This is typically more expensive than controls for an induction generation and will attract more scrutiny from the electricity supplier.

A generator may operate without exporting electricity to the distribution grid. Electrical interlocks are used to prevent export and avoid the need for supplier approval (local electrical contractors are capable of installing interlocks, and commonly do so for backup generators).

Common problems with using biogas

Water vapour can interfere with pressure reducers, boiler orifices and other devices, and reduce the energy value of the biogas. Condensate traps offer an effective way of removing moisture (Van Haren and Flemming 2005).

H_2S is corrosive even in small concentrations. To avoid corrosion, H_2S levels should not exceed 500 ppm for use in conventional internal combustion engines (Van Haren and Flemming 2005), although manufacturers may accept up to 1000 ppm (Harding and Olliff 2007). However, reported H_2S concentrations in biogas from dairy digesters have been as high as 6000 ppm, so H_2S removal may be required. The cost of H_2S removal is up to 20% of generation plant cost (Harding and Olliff 2007), but must be considered in conjunction with the proposed maintenance schedule.

Biogas is not easily compressed. Therefore, it is difficult to use the biogas for anything but (nearly) continuous on-site consumption.

Back-up gas supply

Contingency plans must be developed for systems reliant on continuous biogas supply. Generators isolated from the grid, biogas-fired boilers for hot water and, in the future, absorption chillers for milk cooling will require alternative gas sources when the system is off-line for maintenance. It is inadvisable to select equipment reliant on biogas where winter yields are unable to meet expected energy needs.

Energy budgets for large- to medium-sized dairies

For medium- to large-scale dairies where cows are not housed intensively, the energy content of the collected manure may not be sufficient to justify the costs incurred to generate electricity. These farms may prefer to focus on offsetting the energy requirements for hot water and, if suitable absorption chillers become available, milk cooling. The energy use of these two activities accounts for three-quarters of a dairy's energy bill: 43% for milk cooling and 33% for hot water (Rogers and Alexander 2000).

To show the feasibility of offsetting energy requirements, Table 2 compares energy yield following methane capture with typical requirements for hot water alone, or for hot water and milk cooling, under the following assumptions:

- 4.7 kg VS per cow day^{-1} (derived from Nennich *et al.* (2005) in chapter 1.2 'Characteristics of effluent and manure' and reduced by a safety factor of 20%)
- 20% of VS removed by pre-treatment
- boiler efficiency 80%, chiller COP 0.6
- hot water use of 3 L per cow day^{-1} (input at 15 °C, output at 90 °C)
- milk yield of 20 L per cow day^{-1} cooled from 17 °C (after platecooler) to 4 °C
- sufficient gas storage available to supply gas to appliances whenever needed (i.e. no loss of gas to a flare).

Table 2. Percentage of daily manure output that must be collected to satisfy use.

Use	Assumed average annual methane productivity (L CH_4 [kg VS added]$^{-1}$)						
	50	**75**	**100**	**125**	**150**	**175**	**200**
Hot water only	18	12	9	7	6	5	5
Hot water + milk cooling	40	27	20	16	14	12	10

As the energy requirements are modelled on a per-head basis, the results in Table 2 are independent of herd size. However, system cost and payback period will vary with herd size, and economies of scale are expected.

Methane productivity is a critical determinant of whether sufficient biogas is available to meet energy requirements for hot water and milk cooling. Although the yields in Table 1 suggest that Australian covered ponds operate somewhere within the range assumed in Table 2, further research is required to more accurately determine the methane productivity expected over the range of climatic conditions in each dairy region.

As the values of methane productivity in Table 2 are annual averages, actual productivity will vary significantly from summer to winter. As mentioned above (see section 'Impact of temperature'), a 15-°C drop in monthly average temperature from summer to winter could more than halve the methane productivity. Winter operation must be investigated to ensure that sufficient energy is available to supply biogas-reliant equipment. Further research is required to identify this productivity–temperature dependence in order to avoid overuse of the back-up gas supply.

After sufficient biogas is generated to meet the requirements for hot water (and milk cooling), additional biogas is likely to be flared. Alternatively, it can be burned in the boiler, and a heat exchanger can be used to transfer the heat to the covered pond, although it may have a negligible impact on pond temperature.

Considerations for the overall effluent management system

Solids separation before digester

Digester function will be compromised by indigestible solids, so the use of a shallow trafficable solids trap or sand trap to remove large material is wise. Sand-bedded freestalls will require significant investment in solids separation equipment (see chapter 2.1 ‘Solid–liquid separation systems’). However, the removal of volatile solids along with the fixed solids will reduce the potential methane yield, so a trade-off is necessary.

Waste feed and organic bedding may be (slowly) biodegradable, but long straw and floatable material should be held back from the digester. Rundown screens with a large orifice size (see chapter 2.1 ‘Solid–liquid separation systems’) may be useful in this regard, as typical VS removal is low.

The effluent stream must be free of extraneous objects that could cause blockages, as a covered pond is not accessible without significant disruption and downtime.

Desludging and crust management

Once a pond is covered, there is no easy way to gain access for maintenance activities such as desludging. Some manufacturers include a ‘zippered’ opening at intervals around the pond perimeter, into which a sludge agitator and pump can be inserted when necessary. This is, at best, only a back-up option, and the design of the digester and its crust- or sludge-handling systems must be robust and reliable.

It is not economically feasible to cover a pond with enough ‘dead’ space for sludge accumulation to match the design life of the cover material. Indeed, there is significant economic advantage in minimising sludge accumulation as much as possible. Regular sludge harvesting or removal via a network of pipes across the pond base is an option in some enhanced covered anaerobic ponds and covered in-ground anaerobic reactors (see chapter 2.8 ‘Desludging and pond closure’). Anecdotal evidence suggests that the recirculation of the collected sludge increases biogas production (by improving contact between bacteria and substrate).

Unfortunately, much of the design information relating to sludge and crust management is proprietary and tightly held by digester companies.

Storage

Effluent storage and reuse are still required, as pollutant concentrations after digestion can exceed the standards for discharge.

Safety precautions

Methane is odourless and colourless and is explosive when mixed with air at 5% to 15% by volume. Be aware that whereas methane is lighter than air and will disperse, CO_2 and H_2S are heavier than air and can collect in confined spaces (see chapter 6 ‘Occupational health and safety’). Biogas equipment areas should be open or well ventilated to disperse fugitive gases. Safety precautions must be considered during design and maintenance. Procedures and equipment for a ‘hazardous area’ classification might have to comply with AS 2430.3.7 (Standards Australia 2004). Specific safety procedures are beyond the scope of this document; seek specialist advice.

Design criteria and selecting a designer

USDA-NRCS (2003) provides basic design criteria (HRT and VS loading rate) for locations across the USA, but no comparable guidelines exist for Australia. Further research is needed to develop similar tools for local conditions.

Specialist knowledge and experience in the design of anaerobic digesters are essential for a successful outcome. Early adopters (before 1982) in the USA experienced a 75% failure rate in plug flow and complete-mix digesters and a 30% failure rate in covered ponds (US Department of Energy 1995). Inadequate design was cited as one of the main reasons for failure. Other reasons varied but included shutdown due to declining energy prices and sale of the farm.

Although the skills and experience needed to develop a biogas project are slowly becoming more accessible, the technological and financial risks resulting from poor advice are still significant. Refer to published information including (but not limited to) US EPA (nd.) and ASERTTI (2007) when comparing proposals.

Current research

Given the concerns regarding climate change (see chapter 8.2 'Greenhouse gas emissions'), anaerobic digesters are attracting significant research and commercial interest. Magma (2007) reviewed R&D activities for the Rural Industries Research and Development Corporation's 'Methane to Markets in Australian Agriculture' program. The review includes details of previous studies of the feasibility of installing covers on piggery anaerobic ponds, flares, scrubbers, porous burners and fuel cells.

Additional information is provided in a report by GHD (2007a) that reviews options for methane capture and use in Australian intensive livestock industries. The report considers the viable project scale for dairy farms, using European and US data from Mehta (2002), who assumed digester and engine costs of $\$6250 \cdot kW^{-1}$ and 0.15 kW per animal or $1000 per animal. Although the results suggest a payback period of 6 years, the 'power generation potential' seems to be based on heated (mesophilic) digesters. Covered anaerobic ponds (the most appropriate approach for dilute effluents in Australia) are typically psychrophilic and will have much lower gas yields. Predictions by RCM Digesters (2003) for a covered pond (see 'Case studies' below) suggest a power generation potential of 0.05 kW per animal from an ambient-temperature pond in northern Victoria.

GHD (2007a) concluded that the economic viability of methane projects is highly variable and requires site-specific analysis. In general, sites that currently use gas (natural or LPG), or could, will more likely be feasible and require less investment. Electrical generation may not be feasible for smaller sites.

Case studies

1—2200-cow freestall northern Victoria

(RCM Digesters Inc. 2003) studied four options to produce and use methane at a proposed 2200-cow freestall dairy in northern Victoria:

- Option 1—Covered anaerobic pond, freestalls bedded with sand, floodwashed
- Option 2—Option 1 with organic matter bedding replacing sand
- Option 3—Option 2 plus cheese whey from local factory
- Option 4—Plug flow digester using scraped manure.

Although the initial motivation to investigate biogas production was odour control, the proponent liked the opportunity to offset energy consumption. The financial analysis of the four options showed negative net present values (NPV) with low internal rates of return (IRR) for Options 1, 2 and 3, but Option 4 was profitable. The proponent chose not to adopt Option 4 owing to an aversion to scraped manure systems. Of the flushed manure options, Option 3 returned the best NPV at –$58 860.

Table 3. Analysis of digester options (RCM Digesters Inc. 2003).

	Option 1	Option 2	Option 3	Option 4
Av. gas production ($m^3·day^{-1}$)	695	1 580	1 711	3 388
Av. electrical output (kWh)	51	116	126	214
Electrical offsets (% of bill)	36	81	88	154
Max. heat recovery (MJ)	320	910	1 095	807
Min. heat recovery (MJ)	248	416	502	179
Capital cost ($)	626 609	796 569	797 193	1 201 228
NPV ($)	–280 860	–105 466	–58 860	391 973
IRR (%)	0.0	2.7	6.0	42
Simple payback period (y)	20	11	10	6.5

The analysis used the following assumptions:

- Costs of anaerobic pond earthworks were not included in the capital cost.
- $61 870 was subtracted from the capital cost as a result of avoiding a permeable cover required for odour control.
- Electrical consumption offset was valued at $0.102·kWh^{-1}; excess was sold at $0.075·kWh^{-1}. Both values include renewable energy certificates of $0.04·kWh^{-1}.
- Operation and maintenance costs were $0.017·kWh^{-1}; energy costs increased at 3% p.a.
- 100% finance, 10-year loan period, 8% loan interest rate.
- Discount rate of 11%.
- 15-year project life; system downtime 10%.
- Exchange rate of A$0.658 per USD.
- The financial benefit resulting from the reuse of treated water was not included. For Option 4, the sale of digested solids was estimated at $49 924 and included in the financial analysis.

The proposed loading rate for the anaerobic pond was low (even after 10 years' sludge accumulation), and the resulting large surface area would incur unnecessarily high cover costs.

The predicted gas yield exhibited a seasonal trend. Electrical output met anticipated consumption during summer but fell to around two-thirds of consumption over winter. The project has been given planning approval but construction has been delayed.

2—US feasibility study

Although the nature of the Australian dairy industry is different from that of the USA, a report by the (US Department of Energy 1995) provides an insight into the effect of scale and the proportion of manure collected on economic viability. The report analysed the feasibility of methane recovery at three different sized farms, each collecting either 15% or 55% of the manure generated. Table 4 shows the results for covered lagoons.

Table 4. Impact of scale on economic feasibility of methane recovery (US Department of Energy 1995).

Herd size (head)	Proportion collected (%)	NPV ($US)	IRR (%)	SPP (y)
250	15	–16 545	1.1	13.3
500	15	–7 744	6.0	8.5
1000	15	11 253	10.8	6.4
250	55	–7 912	6.2	8.3
500	55	12 507	10.8	6.4
1000	55	49 891	13.9	5.6

The analysis used the following assumptions:

- Revenue was based only on savings from offset electrical and heating use, and surplus electricity sales (if available).
- Biogas yields were not specified but were calculated for central Texas.
- 15-year project life.
- O&M costs increased at 1.5% p.a.; energy cost did not increase.

The study concluded that the minimum herd size required to achieve an IRR of 8.5% was 780 to 890 head if 15% of manure is collected, decreasing to 400 to 560 head if 55% is collected.

3—Mobile fixed-film digester

Active Research (Active Research 2007) used effluent from the Victorian DPI's Ellinbank farm to investigate methane production from a mobile fixed-film digester. The 2220-L digester operated at 38 °C, had a hydraulic residence time of between 15 and 100 h, and used ultrasound to 'disintegrate floc'.

The 1-kW, 24-kHz ultrasound unit resulted in a 30% increase in gas production. Unfortunately, incomplete data prevented verification of this result and the methane productivity results.

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8.1 Production and beneficial use of methane