NIWA
Taihoro Nukurangi

Biogas for Australian Dairy Farms

An Introduction

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Text books about biogas technology can give the impression that the technology is a silver bullet for a whole range of dairy farming issues. This impression is further reinforced by the glossy brochures handed out by biogas technology suppliers. The potential advantages of biogas technology are indeed numerous, and include: simplifying on-farm waste management (Burke 2001), improving the fertilizer value of manure and other by-products (FNR 2010), reducing farm odour and Greenhouse Gas (GHG) emissions (Schultz et al. 1993, Dalton et al. 1998, Dairy Australia 2008, Heubeck et al. 2014, Laubach et al. 2015), and providing a renewable energy source for on-farm use and even export (Burke 2001, FNR 2010).

However in reality, biogas technology is site specific and has to be selected and tailored carefully to meet the particular needs of each farm. This doesn’t mean that biogas technology has to be complex or cumbersome to manage, but the configuration that is right for each farm needs to be evaluated carefully.

2 Biogas basics

2.1 Biogas formation

Biogas is produced by Anaerobic Digestion (AD), and consists mainly of 50-70% methane and 30-50% carbon dioxide as well as minor gas components, such as water vapour, nitrogen and hydrogen sulphide (Burke 2001, FNR 2010). All organic materials, except woody biomass can be anaerobically digested, and materials including animal manures, wastewater solids, food processing by-products and green waste are good substrates. Despite the fact that the microbial communities involved and the technical configurations employed may vary slightly from substrate to substrate, the core processes of AD remain the same: In the absence of oxygen, organic materials (carbohydrates, fats, proteins, etc.,) are broken down to simple intermediates (such as simple sugars) these are then transformed further to simple organic acids as well as hydrogen and carbon dioxide by various groups of anaerobic bacteria. Methane bacteria then convert the organic acids, hydrogen and carbon dioxide into methane and carbon dioxide (Henze et al. 1995, FNR 2010).

Unlike composting, anaerobic digestion does not generate large amounts of heat, but the rate of digestion generally increases with increasing temperature. There are three different groups of micro-organisms that operate in specific temperature ranges: cryophilic or psychrophilic operating at <30°C; mesophilic operating at 30 - 40°C; and thermophilic operating at 55°C (Henze et al. 1995, Burke 2001, FNR 2010). Psychrophilic systems operate passively at ambient temperature without heating or insulation, so that the operating temperature fluctuates throughout the seasons.

2.2 AD technology

The most common technologies for anaerobic farm waste treatment and recovery of biogas are engineered, heated and completely stirred tank digesters (CSTD), and “passive” Covered Anaerobic Ponds (CAP) (Burke 2001). When considered on an annual basis, the quality and quantity of the recovered biogas are similar for both systems (Craggs et al. 2008, Heubeck et al. 2014).

CSTD have much higher investment costs, require careful management and require more maintenance than CAP systems. Covered Anaerobic Ponds have a larger footprint and more seasonal variation in biogas production. Pond treatment systems are best suited to “fluid” feed stocks such as flush manure, whey or distillery waste - coarser and drier substrates cannot be processed easily.

Covered anaerobic ponds (CAP) have an upper dry matter limit of ~ 5% (total average) for the input substrate and are susceptible to a high proportion of long, fibrous input material i.e., bedding material in the input substrate. CAP are therefore best suited to be added to a “liquid” effluent management system where input and output substrates are handled as liquids already, or where a certain proportion of higher strength waste (i.e., feed pad scrapings) is envisaged to be reliably handled though a liquid management system (i.e., land irrigation).

Mesophilic CSTD have a lower dry matter limit of ~ 4% (total average), which is determined by the amount of biogas generator waste heat obtainable from biogas from a given unit of manure fresh matter and the heat required to bring the input substrate to mesophilic temperatures (~37°C) during the coldest period of the year, considering practical digester insulation properties (Dederer 2012). Heated tank digesters don’t really have an upper dry matter limit in an agricultural context, but it is worth considering that for situations where stackable wastes (i.e., deep litter manure, green waste etc.,) is co-digested with dairy farm manure, the total output will have to be handled as a slurry rather than a stackable manure / compost, which in general is more expensive.

Besides Covered Anaerobic Ponds and CSTD, several other anaerobic digester types have been developed in the past, for the waste water industry in particular, including digester types such as the Up-flow Anaerobic Sludge Blanket (UASB) digester, anaerobic filters or plug flow digesters. For agricultural applications these alternative digester designs have proven to be either not applicable, or as providing few advantages when compared to the simpler and more established technologies.

Numerous attempts to conduct anaerobic digestion in separate stages / phases, i.e., pre-hydrolysis, pre-acidification, thermophile – mesophile sequence, etc. have also yielded few tangible results around the globe in recent years, and are hardly worth the additional effort, in particular when digesting farm wastes.

2.3 Biogas substrates

In an Australian dairy farming context, the main substrates that will be considered for anaerobic digestion are dilute cow shed effluent and more solid manure scrapings / slurries from dairy cow housing systems or feed pads. These wastes are easy to digest and low tech covered pond digesters as well as mesophilic tank digesters can be employed for obtaining biogas from these wastes. Manures are a good biogas substrate due to their pH buffering capability, balanced content of bacteria macro and micro nutrients and the ease of handling with established technology (often pumping). The only major disadvantages of common manures as a biogas substrate is the relatively low specific biogas yield obtainable, which on a fresh matter basis is often aggravated due to the high dilution with wash and flush water commonly used in many field situations (Burke 2001, FNR 2010).

Manures intended for anaerobic digestion should be added to the digester as fresh as possible. Housing systems that store manure in underground bunkers for extended periods of time are less than ideal sources for biogas substrates, since a large proportion of the biogas potential can be lost during storage, and the opportunities to reduce odour and GHG emissions through biogas technology are also reduced in these situations. Large amounts of bedding material in the manure can also complicate anaerobic digestion. While moderate amounts of straw bedding can be processed with tank type digesters in particular, wood based bedding material, such as shavings or saw dust which cannot be broken down anaerobically, do not only not contribute to the overall biogas yield, but can also lead to pipe blockages and the formation of crust layers in the digester, causing operational problems. Carryover of sand bedding material needs to be removed from the manure before it can be digested. While this is possible for dilute flush manures (i.e., by employing sand traps or baffle tanks), more concentrated manure with a high sand content may not be suitable at all for AD, without the use of elaborate and expensive sand and grit removal systems. In general covered anaerobic pond systems tend to be less able to deal with large amounts of bedding material and other course contaminants than tank type digesters.

The amount of manure available for anaerobic digestion on a dairy farm is surprisingly difficult to estimate, since this amount is firstly influenced by the number of cows, their life weight, production level, feed intake and feed composition (digestibility) and secondly by the farming / housing system as well specific animal management. Small management differences can lead to up to ± 50% differences in available manure volume between otherwise identical farms, for example the difference between running the herd on an all pasture farm as one mob or two mobs (effectively halving the time spent on concrete for the average cow) or the difference between once a day and twice a day milking. Therefore daily available manure volumes need to be accurately measured before embarking on any biogas project. However this too is a complex task due to the quite large day to day variability in manure volume (on all pasture farms in particular). At least 5 to 10 individual (composite) samples of manure volume (flow) and solids concentration (total solids (TS) and volatile solids (VS)) are required to compile a reasonably reliable average.

Therefore the manure VS figures given for different farming systems in this section and referenced in the sections below are provided for illustration purposes only, and should not be used as planning basis for any specific anaerobic digestion system. A sensible rule of thumb figures of manure availability for a hypothetical 400 cow all pasture dairy farm without feed pad would be ~ 100 kgVS/day (0.25 kgVS/cow/day) in the form of 0.7 – 1.0% VS cow shed effluent (Vanderholm 1984, DEC 2006, Heubeck et al. 2014). For a 600 cow dairy farm with feed pad the respective number may be 360 kgVS/day (0.6kgVS/cow/day) in the form of a 1.0 – 1.5%VS effluent (Heubeck et al. 2014), if it is assumed that the feed pad manure is scraped and mixed with the cow shed effluent or flushed from the feed pad with recycled cow shed effluent. Manure availability would be much higher for fully housed dairy systems, i.e., a hypothetical 1,000 cow, fully housed dairy farm may produce 5,000 kgVS/day (5kgVS/day) in the form of a 3 – 7% VS slurry (Burke 2001, FNR 2010).

A great range of other wastes and by products can be co-digested with dairy farm manure. These materials may include food processing by-products such as stillage, whey, slaughterhouse wastes, vegetable processing wastes, and urban wastes such as organic supermarket waste, commercial food waste, municipal organic waste or urban green waste.

Many of these wastes have a higher specific biogas yield than manures, and also a higher fertilizer nutrient content. A limited number of these substrates, such as stillage or whey can be co-digested with manure in covered anaerobic pond systems, while the majority of these materials require the use of tank type digesters. Furthermore many wastes require additional processing prior to digestion, such as pasteurisation for most urban wastes, or the removal of foreign objects (waste plastic etc.). The nutrients imported with such materials need to be recognized in farm nutrient budgets, and for many materials elaborate and costly quality assurance, monitoring and specific handling procedures (odour, vermin, biosecurity, etc.,) are required, which may vary greatly between different States in Australia. These points indicate that by and large the co-digestion of outside waste with dairy farm manure is generally not easily facilitated by individual dairy farmers. Larger, stand-alone digestion facilities, with farmer participation, may be a more appropriate option for dealing with off-farm organic wastes. For example in Western Europe the administrative effort and additional level of sophistication required for dealing with many off-farm organic wastes has led to the development of two almost completely independent biogas sectors, one for urban and off-farm organic wastes and one for farm wastes and energy crops.

2.4 Changes to the substrate during digestion

Anaerobic digestion of farm wastes typically reduces the solids content by 50% - 80%, which simplifies handling of the digested waste for uses such as recycled flush water or land irrigation (Heubeck and Craggs 2010, FNR 2010). AD is therefore most useful in situations where cow shed effluent and / or feed pad scrapings are intended to be irrigated to land with existing water irrigation equipment, since AD is very effective in reducing the (coarse) solids content of the wastes making them “blend-able” with irrigation water for many irrigation systems, including centre pivot irrigators. The option of being able to handle digested effluent through existing water irrigation equipment can realize equipment and labour savings and rationalize effluent management.

Efficient anaerobic digestion reduces the bulk of odorous volatile organic compounds (VOCs), in the waste since these (as intermediates) are broken down to biogas. Other odorous compounds, such as hydrogen sulphide (H_2S) are released from the waste during AD, but captured together with the recovered biogas, and ultimately combusted. Consequently odour emissions and the potential for odour impact is substantially reduced for both the handling and storage of farm wastes, as well as during land application or recycling of the digested wastes. Reduction of odour emissions can be a prime driver for the adoption of AD technology, and were for example the key aspect for the adoption of Covered Anaerobic Pond technology by the pork industry in Australia and New Zealand (Heubeck and Craggs 2010, APL 2015).

Anaerobic digestion leaves the fertilizer nutrient content of organic wastes largely unchanged, however a large proportion of nutrients contained in the waste are transformed into simple, more plant-available forms - specifically ammonium-N and soluble phosphate (FNR 2010). These transformations can make the digested waste / manure more usable and help to reduce fertilizer import. Because the overall nutrient content of the substrates is not materially altered during AD, anaerobic digestion is not a tool that can be used to address nutrient surpluses on intensive livestock farms. On the contrary biogas systems that co-digest imported wastes and by-products increase the overall amount of nutrients available to the farm. These changes need to be recognized in the nutrient budgets of farms that choose to import off-farm substrates for AD.

2.5 Rule of thumb biogas yields

The observed biogas yield ($m^3CH_4/kgVS$ = cubic meter methane (standard gas conditions) per kg volatile solids (= kg ash free dry weight) introduced to the digester) of a given substrate is not a fixed number, but is influenced by many factors. Each substrate has a theoretical maximum biological methane (biogas) potential (BMP) that is realized to a varying degree under field conditions. Long retention times at high operating temperatures and a neutral pH level in the digester tend to increase the realization of the BMP, while a deficit of trace nutrients, accumulation of inhibitory substances (free ammonia, salt, etc.,) or digester overloading (resulting in short retention times and VFA accumulation) will decrease the biogas yields achievable in the field (FNR 2010).

The BMP is ultimately determined by substrate composition. A high proportion of fat in the substrate results in a high BMP, whereas the BMP of the most common substrates, which are dominated by protein and carbohydrate components (cellulose, hemicellulose, sugar, starch etc.,) may only be about half as high. Lignin has a BMP of zero under practical field conditions, and as an added disadvantage decreases the methane yield of the components associated with the lignin (such as cellulose and hemicellulose) by shielding these components from microbiological attack.

Under field conditions dairy cow manure has a rather modest methane yield of 0.18 – 0.25 $m^3CH_4/kgVS$, which is mainly a result of its relatively high lignin content (Burke 2001, FNR 2010, Heubeck et al. 2014). The hypothetical dairy farms mentioned above with 400 all pasture fed cows, 600 cows with feed pad and 1,000 fully housed cows would therefore achieve daily biogas yields of 20, 72 and 1,000 m^3 of methane per day (during the milking season) (Heubeck et al. 2014, Laubach et al. 2015).

A very large number of potential biogas substrate that are dominated by carbohydrate components (cellulose, hemicellulose, sugar, starch etc.,) have a methane yield of 0.30 – 0.35 $m^3CH_4/kgVS$ under field conditions, which includes materials such as fruit and vegetable waste, grass clippings, paunch grass, maize straw, most energy crops and also whey. Higher methane yields are generally only achievable with substrates with a substantially higher fat content such as (commercial) kitchen waste

(~ 0.40 m^3CH_4/kgVS), DAF sludge (0.40 – 0.50 m^3CH_4/kgVS) or waste frying fat (~0.55 m^3CH_4/kgVS) (FNR 2010).

2.6 Biogas energy use

In situations where biogas technology is mainly applied to address odour emissions, or where the reduction of fugitive methane GHG emissions is the primary goal of a biogas scheme, biogas flaring without energy utilisation will remain a possible biogas use option, due to its inherent simplicity, low investment costs and very low ongoing operational cost (APL 2015).

However, every flaring situation represents a potential loss of opportunity, which is especially problematic since biogas is without a doubt the most versatile renewable energy resource. Biogas can be used a boiler fuel for hot water and steam raising applications, or as a generator fuel for combined heat and power (CHP) applications. Because raw biogas can be easily stored for short periods of time (hours to days) scheduled and "on-demand" electricity generation based on biogas is feasible. Raw biogas can also be purified to technically pure bio-methane, which can either be injected into existing natural gas grids, or compressed and used as a renewable gaseous vehicle fuel. Theoretically it is also possible to use biogas methane as the basis for the manufacture of a whole range of base chemicals, such as methanol, ammonia or ethylene.

However in the context of dairy farming in Australia, two end uses will be the predominant option for biogas utilisation for the vast majority of possible schemes; combustion for hot water generation and as fuel for CHP generators.

Hot water provision is particularly interesting for small schemes or as an "add-on" for schemes that predominately want to reduce odour and / or methane GHG emissions. Biogas can be combusted in slightly modified standard gas hot water boilers, without the need for substantial biogas quality improvements (i.e., water condensate removal, but H_2S removal only if levels are very high). Such a gas use can often be realized with moderate investment costs of AU$4,000 – 8,000, and does require very little ongoing operating cost and management. The hypothetical 400 cow all pasture farm mentioned above could produce ~ 1,400 L of hot water (85^{o}C) per day with the biogas recovered from the cow shed effluent. These volumes of hot water can easily satisfy all cow shed hot water needs, while substantial volumes of hot water can also be made available for other uses.

The use of biogas as CHP generator fuel is most common around the world, and does require a moderate level of biogas quality improvements (i.e., condensate removal, reduction of H_2S to < 200 ppm, etc.). Electricity generation with a CHP generator can basically fulfil two demands. For smaller schemes a biogas CHP generator can provide electricity to substitute electricity imports and act as a back-up source of electricity for the farm – even in situation where the farm is less than 100% electricity self-sufficient since biogas can be accumulated and stored short term (days) and fuel the CHP generator during power outages for several days. The hypothetical 600 and 1,000 cow dairy farms mentioned above could generate 220 and 1,000 kWh of electricity per day respectively. Entry level biogas generator large enough to power a cow shed (~ 50 kW) cost ~ AU$30,000, more advanced equipment is available for AU$80,000 – 120,000. However since a generator powering a cow shed may only run for 2,000 – 3,000 hours per year, even relatively basic generators may be able to serve the needs of a dairy farm. For the hypothetical 600 cow dairy farm the financial viability of the CHP option will to some extend depend on the ability of the biogas generator to substitute for an alternatively required back-up generator; for the hypothetical 1,000 cow farm the realizable export price for surplus electricity will be paramount for the success of the CHP option. The financial attractiveness of biogas CHP generation will be particularly high for off grid farms and cow sheds that currently rely on diesel generators for electricity provision.

For larger biogas schemes incorporating co-digestion of off-farm wastes electricity export from a biogas fuelled CHP generator can be a substantial source of revenue. However the value of exported electricity will mostly be much lower than the displacement value for electricity imports. Furthermore, appropriate generator sizing can be very problematic in rural Australia. Establishing an electricity export scheme benefits from economies of scale, since the process of obtaining an grid export connection can be drawn out, labour intensive and costly, especially in areas where very sophisticated safety requirements have to be met (i.e., WA). On the other hand, the weak “stringy” electricity distribution networks common in rural Australia can often not accept more than several dozen or a few hundred kW of embedded generation capacity, indicating that for many areas no good compromise for sizing and scoping a biogas based CHP export scheme can be found. An electricity export scheme does in any case require careful and long term planning as well as co-operation with the local lines company, and may in many cases be more difficult to establish and yield poorer financial results than hoped for at first glance.

2.7 GHG implications

The reduction of fugitive methane GHG emissions from manure management should be a very important driver for the establishment of anaerobic digestion systems on dairy farms, however the financial benefit of GHG emission reduction is often hard to realize and is subject to short term decisions in the political field (Laubach et al. 2015, APL 2015).

Methane is a powerful GHG, and the combustion of ~56 m^3 biogas methane that were previously emitted to the atmosphere, represents an abatement of 1t $CO_{2equivalent}$ (IPPC guideline with methane factor 25). On small pasture based dairy farms, like the hypothetical 400 cow farm mentioned above, 0.35 $tCO_{2equivalent}$ per day abatement can be realized through recovery and combustion of the methane from the effluent management system. On larger farms, or where a feed pad contributes to the load of the effluent system, the abatement may be 2 to 3 times higher, i.e., 1.3 $tCO_{2equivalent}$ per day for the hypothetical 600 cow dairy farm. On fully housed dairy farms the GHG benefit may be even higher, i.e., 18 $tCO_{2equivalent}$ per day for the hypothetical 1,000 cow example mentioned above.

However this GHG abatement benefit can only be realized for situations where methane was previously emitted to the atmosphere unabated. In situations where i.e., deep litter manure is anaerobically digested in a new biogas facility, the recovered and combusted methane could not be considered as a contribution to reducing farm GHG emissions. The same applies to methane obtained from co-digesting off-farm substrates or energy crops.

The Emissions Reduction Fund (ERF) offers an opportunity for farmers to earn Australian carbon credit units (ACCUs) for avoidance or sequestration of greenhouse gas emissions. One ACCU is earned for each tonne of carbon dioxide equivalent (tCO_{2-e}) stored or avoided through implementation of an ERF approved project. An ERF method has been approved for destruction of methane generated from dairy manure in covered anaerobic ponds. Information about the method is available from the Clean Energy Regulator website (CER 2015).

The ERF method is used to estimate baseline emissions that would occur without the pond being covered; that estimate sets the upper limit to which greenhouse gas emissions abatement can be claimed. Covered anaerobic ponds are eligible regardless of whether they involve burning off the methane using a flare, or using the methane to generate electricity on site, as both options result in the methane being destroyed. The only difference to the producer is the obvious co-benefits that accrue from generating heat or electricity.

The value of Australian carbon credit units (ACCUs) is unlikely to be high enough to justify installation of an anaerobic digester on Australian dairy farms and any potential income from the ERF should be regarded as a bonus rather than as an incentive to invest in the technology.

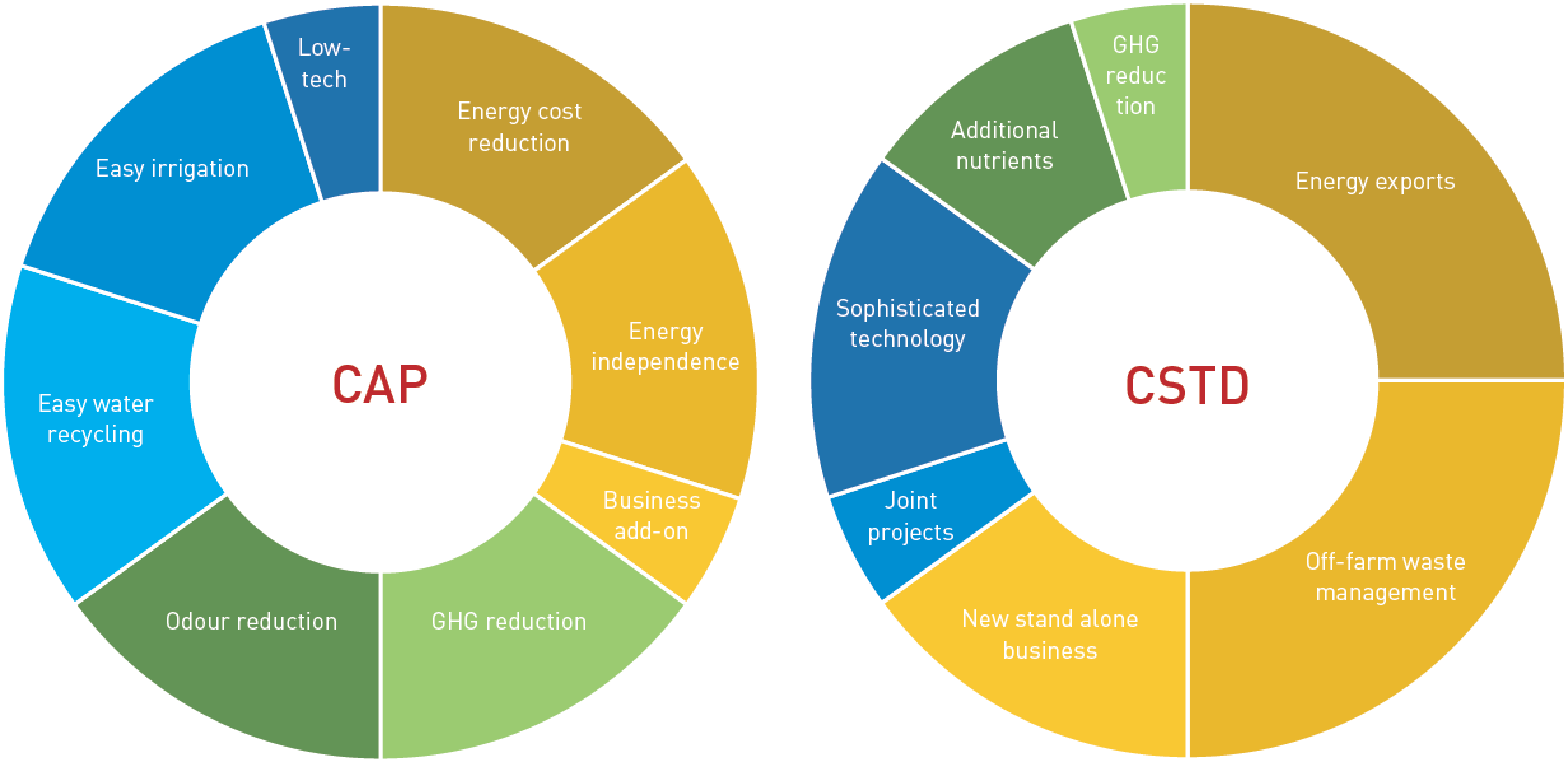
3 Advantages of and drivers for AD on my farm

One of the fundamental dilemmas of anaerobic digestion and biogas technology is that it is addressing a whole range of issues and is so flexible that it is easy to lose focus. However each individual benefit may be not sufficient to justify an AD system or a particular configuration of AD for an individual farm, which is why any AD development should focus on multiple benefits and the most appropriate way of combining these. Among the most important drivers for on-farm AD are;

- Improved waste handling characteristics
  - Reduced waste odour, form waste handling / storage itself as well as during land application.
  - For dilute wastes / effluent AD can be a treatment option that allows for effluent recycling or combined effluent land irrigation with existing water irrigation equipment.
  - Waste nutrients converted into plant available forms, equals more immediate fertilisation response and better plan-ability.
- Reliable, green energy from biogas
  - A potentially cheap source of on-site heat and electricity, particularly for off-grid farms.
  - Renewable energy and image gain.
  - Increased energy supply security, for on-grid farms as a back-up to grid supply or as an enable technology for other renewables like PV on energy self-sufficient farms.
  - Potential earnings from energy exports (large schemes).
- Environmental benefits
  - Reduced odours form waste management: best practice, good neighbours and potentially regulatory requirement.
  - Substantial reduction in farming GHG emission, potential for further earnings through GHG mitigation, however politically uncertain in Australia.
- Business diversification, new business
  - Large biogas schemes that rely on imported wastes and energy exports can develop into larger stand-alone businesses, providing resilience.
  - Co-operative approach between existing dairy farming and land holdings with waste producers and energy users in the food processing industry an interesting approach in intensive dairy regions.

4 Biogas decision support compass

Blue colour represents 'Farms Management drivers', Yellow colour represents 'Monetary Drivers' and Green colour represents 'Environmental Drivers'.



The above compass represents a very simplified, first brush assessment only. In a dairy farming context the technology limitations between covered anaerobic ponds and heated and mixed tank digesters is mainly related to the dry matter content (dilution) at which the dairy farm effluent / manure is available.

While a CAP system can in some cases assist with regulatory problems, such as farm odour emissions or fixed water use reduction targets (via recycling), tank digester systems are generally not able and / or are too expensive and sophisticated to help address such problems. The great strength of tank type digester systems clearly lies with larger systems, that are often developed as stand-alone businesses, which address regional organic waste problems, make available additional fertilizer nutrients for agriculture at low cost and rely on energy export earnings.

Regarding the two aspects with most PR impact – reduction of manure GHG emissions and the generation of green energy – both tank and CAP systems do not differ in principle.

Generalisations in regards to minimum, optimum or most appropriate system size are difficult to make. However CAP systems are applicable to almost any farm size if the goal is to address environmental issues such as odour emissions or improved effluent management.

Biogas CHP generation can be viable even for rather small farms if the biogas generator is capable of replacing an alternatively required back-up generator. However for schemes that focus primarily on the per kWh energy value of the biogas electricity, the aforementioned hypothetical 600 cow farm with feed pad, generating 220 kWh electricity per day represents something of a lower size limit.

For tank based systems overseas practical experience has shown that a minimum CHP electrical output of ~ 150 – 200kW is required to make such systems work (primarily in regards to labour, overheads, and general economies of scale. Also refer to the German experience with the 75 kW CSTD biogas plants below) (FNR 2010, Dederer 2012). Relying on manure only would require 1.5 to 2 of the aforementioned hypothetical 1,000 cow dairy farms using a fully housed system.

These examples indicate that in a dairy farming context mesophilic tank type digester plants will in the foreseeable future only be realized in situations where manure digestion can be combined with industrial organic waste digestion at scales greater than 200kW (CHP equivalent output) requiring investments of > 1 million AU$. This indicates that such undertakings will have to be facilitated as stand-alone businesses rather than add-ons to existing dairy farms.

5 Field examples

Since generalisations about biogas plant construction costs are difficult, particularly in an immature market like Australia, some relevant overseas examples are given below as an indication of costs and benefits. The examples also seek to explain why a specific project has been successful, which should directly lead to the question if similar conditions exist with a prospective Australian biogas opportunity.

CAP biogas system at Lepper piggery, New Zealand
The Lepper Trust piggery in New Zealand opted to build a covered anaerobic pond biogas system in 2009 to primarily address odour emission from the farms effluent management system.

A custom designed 7000m^3 new anaerobic pond was built to digest ~ 70m^3/day of flush manure effluent with a VS concentration of 0.9 – 1.3%. The pond was fitted with an earth sealed, 1.5mm LLDPE cover, complete with rain water removal system and biogas collection ring pipeline. The CAP fulfilled its main task from day 1 – effluent odour emissions from the farm have been reduced markedly, and the piggery has become a much better neighbour.

With the main task achieved, farm management has turned their attention to beneficial use of the ~ 200m^3 biogas methane recovered daily. A 48kW spark ignition CHP unit has subsequently been installed, that operates in grid parallel mode, but can also provide back-up power to the farm during grid outages. As well as providing the majority of the piggery's electricity needs during daytime, waste heat from the generator is used in a reticulated hot water system heating pig sheds.

After 8,000 run hours on the generator and ¼ million kWh electricity generated, the biogas use system and the 7000 m^3 CAP at the piggery have proven reliable. The NZ$120,000 investment had been recouped half way through year 4 of operation. The CAP in particular has proved to work reliable in the moderately temperate NZ climate, and so far has required very little in terms of operational effort and / or maintenance requirements. Of the ~150 h per year labour requirement to manage the biogas system, almost all the time is spent on maintaining the generator, including repetitive supervision task like checking the motor oil level and condensate traps, as well as low level maintenance work, like exchange of motor oil and replacement of spark plugs and air filters. The only negative surprise provided by the system so far were the underestimated costs for consumables, repair and maintenance for the CHP generator, which were slightly higher than the NZ$0.01/kWh initially assumed.

75kW all manure CSTD biogas plants slow to gain prominence in Germany
With over 8,000 biogas plants in operation, Germany is the global leader in the biogas sector. However, while in some states like Thuringia over 40% of all pig and cattle manure is already anaerobically digested, that rate is less than 1/5 in the states with smaller agricultural production structures like Baden-Wuerttemberg (BW). In order to increase the energetic utilisation of manures at smaller scale, regulators designed a generous incentive scheme in 2012. For biogas plants with 75kW power output or less, that digest at least 80% by volume manure, an attractive electricity export rate of 25 Eurocent/kWh is available, fixed for 20 years. Because of the scheme 200 biogas plants of the 75kW class have been built since 2012.

Dr Manfred Dederer (State Biogas Centre Boxberg / BW) has monitored 60 of these new small biogas plants in the southern state of BW and reports less than thrilling results. The plants require the manure from ~500 fully housed dairy cows, indicating that even for those small plants co-operation of several farmers is necessary for success. The new plants also had disappointing own consumption

figures for both heat and electricity, with the electricity own consumption of the CSTD reactors being as high as 6 – 10%, while some plants consumed almost all available generator waste heat to maintain the CSTD temperature in the mesophilic range during the harshest days of winter.
The investment costs for the 75 kW plants ranged from 350,000 to 900,000 Euro, with the median at 570,000 Euro. Consequently, and despite the very attractive electricity export rate of 25 Eurocent/kWh, the 75kW plants with investment costs at the upper range of the investment cost band failed to generate a financial profit. Dr Dederer reports that these small CSTD plants are also relatively labour intensive, requiring 300 – 500 h per year (median 400 h/y) labour for operation, supervision and maintenance. This is quite surprising, considering that many 500 kW CSTD biogas plants (>6 times the size) in Germany are operated with ~ 1,000 hours labour input per year.

According to Dr Dederer, many small improvements need to be made to make the 75kW biogas plant class more financially attractive and enable more widespread uptake, in particular by lowering the upfront investment costs. Alternatively the strategic addition of more bioenergy crop substrate could be an appropriate way to improve biogas plant viability and further the adoption of AD technology at farms with a smaller numbers of housed animals.

Co-operatively operated manure and organic waste biogas plants in Denmark
Denmark was an early pioneer in the area of co-operatively managed biogas plants and the co-digestion of off-farm wastes with animal manures. Many plants have reliably operated for 15 to 20 years. However the information of Al Seadi (2000) is reproduced here mainly to illustrate how different the operating conditions in Denmark are compared to Australia.

For example Nysted biogas plant, built in 1997-98, is a typical co-operatively operated biogas plant owned by farmers. The main interest of the co-operative members in the biogas plant was exploitation of the digestible biomass resources for energy and better manure management, in particular in regards to odour emissions. Biogas from the plant is used in a 2300 kW biogas CHP engine with electricity exported to the grid and generator waste heat exported to the district heating system of the town of Kettinge.

The plant is mesophilic (38°C), with a post-sanitation phase of minimum guaranteed retention time of 8 hours at 55°C. The plant receives slurry and manure from 36 animal farms, consisting of 82 % pig slurry, 17 % cattle slurry and 1% poultry manure. The slurry is mixed and co-digested with organic waste from the sugar industry, medicinal industry and tannery, fat and flotation sludge from abattoir, fruit and vegetable waste and smaller amounts of other organic wastes. The biogas plant with 5,000 m^3 digester capacity processes 180t(FM)/day of manure and 31 t(FM)/day of other organic waste. Substrate logistics are facilitated with two 18 m^3 vacuum tankers that handle materials over an average of only 7 km transport distance. The investment cost for the Nysted cooperative biogas plant was 43.7 million DKK, or roughly AU$ 9 million, which included a ~20% government investment grant.

It is highly doubtful that the electricity and heat produced by the biogas plant can be sold in Australia at terms anywhere near comparable to Denmark, while the 20% government investment grant will not be available. However the biggest difference between this Danish example and the situation in Australia relates to transport distances. It is highly doubtful that 180 t/day animal manure can be sourced with an average transport distance of 7 km anywhere in Australia. As transport distance of the biogas substrate increase, the profitability of the biogas venture will decrease (exponentially). This example clearly indicates that biogas concepts that work in other parts of the world cannot be copied to Australia, since the conditions down under as simply too different.

6 Biogas technology for an Australian dairy farm?

When it comes to biogas technology for Australian dairy farms it is often easier to find out what does not work rather than quickly point to the adequate solution. Simply copying schemes from overseas could well fail since the conditions in Australia are vastly different from those in leading biogas countries in Europe. Large and complex schemes based on co-digestion of off-farm waste have to be developed as a stand-alone business rather than an add-on to an existing dairy operation, because of the large investment, labour and administrative effort involved. With little in terms of government support, relatively low energy prices and a weak position towards established prospective customers in the electricity and gas sector, establishing biogas schemes purely on the value of exported energy will be very difficult, while developing them purely on the basis of their GHG emission reduction benefit is risky in terms of future, politically motivated, changes to current GHG emission reduction programs.

These restrictions and exclusions leave only a relatively narrow scope for the development of biogas schemes within the Australian dairy sector. Sensible anaerobic digestion schemes may be established in areas where AD provides manure management benefits, i.e., reductions in odour emissions or effluent conditioning for improved / simplified land irrigation. Biogas energy use value could be more beneficially realized when substituting existing energy imports, rather than by the export of biogas energy. Off-grid farms and cow sheds, currently supplied by diesel generators, appear to gain the most financially in this regard, and could therefore become early adopters of biogas technology within the Australian dairy industry.

This general area of energy self-sufficiency and only utilising the existing on-farm manure for applying anaerobic digestion schemes in Australia points towards using covered anaerobic pond technology (rather than CSTD technology). Since CAP systems can be applied at smaller scale, require less operational and maintenance effort, and can be constructed much more cost-effectively than completely stirred tank digesters. For these reasons covered anaerobic ponds are the more appropriate solution for the limited amount of anaerobic digestion schemes that are going to be established on Australian Dairy farms in the near to medium future.

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