Effluent Technical Note

Energy Capture Systems from Dairy Effluent

This note gives you a brief overview of energy capture systems (anaerobic digestion and biogas) from dairy effluent. It has been developed for farmers and for companies looking to offer this technology to dairy farmers.

Key points from this note

- Capturing energy is not a solution to dairy effluent, but it can offer some added value.
- Selling electricity to the grid is unlikely to be cost effective due to the way the energy sector operates in New Zealand and the small amount of energy likely to be produced from an average dairy farm. You would need thousands of cows to be able to negotiate a favourable price. It is best to plan to use the electricity generated to power on-farm activities.
- Biogas collection and conversion to heat, fuel or electricity is a specialist area, so experience and expertise are essential.
- The methane in the biogas collected is flammable so all safety regulations must be met and installation on-farm must follow recommended health and safety requirements.

Why the interest?

Over the last decade in particular, there has been a significant shift in the New Zealand dairy sector with an increasing amount of supplementary feed being used in the farm system. Consequently, increased feeding systems such as in-shed feeding, feedpads and covered housing are on the increase. As a result there is increased capture of dairy effluent which means more effluent storage and irrigation, when suitable soil conditions permit, of both solid and liquid effluent. Questions then arise around the practicality and economics of energy capture from this stored effluent.

DairyNZ

Biogas – energy from waste

Biogas is gas produced during the breakdown of biological organic matter into carbon dioxide and methane which can then be used to provide electricity, heat and transport fuel. Biogas can be produced from effluent from farms, crops, crop wastes, fats and oils and sewage or at landfills.

Biogas contains methane (a greenhouse gas), which is the combustible portion of biogas, that can be used for electricity generation, transport fuel and/or heat generation. The most common method of producing biogas is an anaerobic (without air) digestion system. In the case of dairy effluent this would be either a covered effluent pond/tank or by the installation of an enclosed anaerobic digester. Biogas also contains hydrogen sulphide, carbon dioxide and water vapour. The hydrogen sulphide and water vapour need to be removed for the electrical energy generation process. If the biogas is to be used solely for heating, then the gas can be used much as it is produced except for the excess water vapour which should be removed.

What are the drivers for biogas use?

Biogas production from agricultural wastes attracted a lot of interest in the 1970s and 80s over concerns with oils shocks and the cost and supply of crude oil from the Middle East and attention became focused on capturing energy from other more local sources. During that period, biogas was captured from a variety of waste streams for energy and many vehicles were powered by CNG (Compressed natural gas). However, interest has reduced over recent years with the arrival of more energy efficient vehicles, relative stability of oil supplies, reduction in government support and the relatively low cost of energy.

With climate change a global concern and more demanding emissions reduction targets coming, there is increasing interest in using renewable energy sources. New Zealand has the third highest renewable energy supply in the OECD with 38% of total consumer energy met by renewable energy dominated by geothermal, hydro and biomass. More than 75% of New Zealand's electrical supply is from renewable resources.

Attention is also focusing on greenhouse gas emissions on-farm, and the capturing of biogas is receiving some interest from farmers and commercial companies. Biodigesters are widely used in the USA, UK and Europe for a variety of feedstocks and are commonly found on dairy farms there. But as discussed below all these countries have either subsidies, tariffs or other financial support to ensure these systems are economic. On its own, the economic viability of producing biogas may be difficult to justify for an average New Zealand dairy farm.

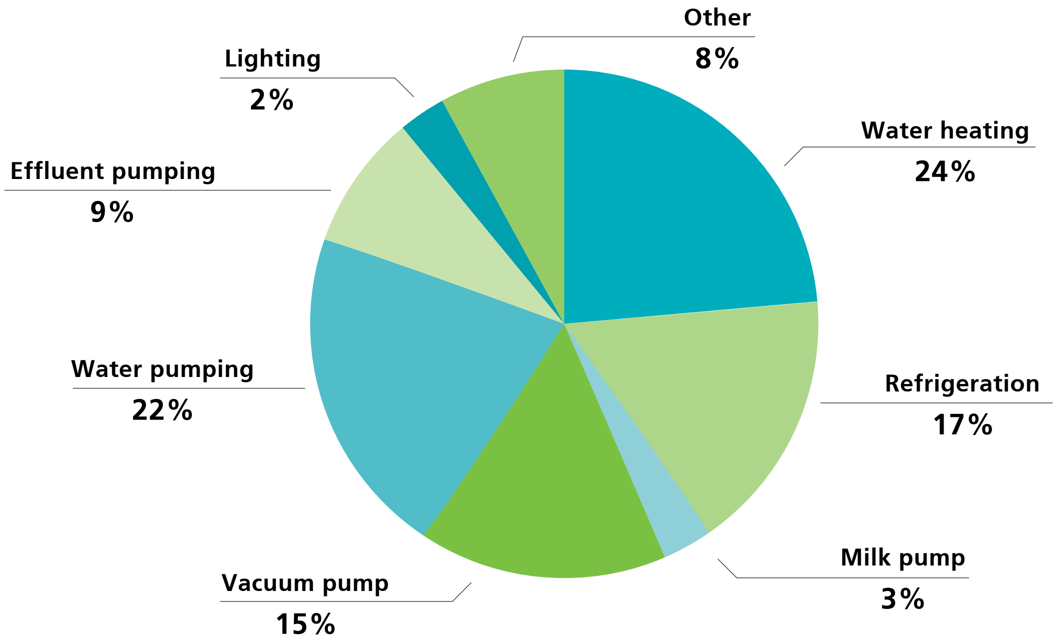
From a farmer's point of view, capturing the methane and using the resulting energy has several advantages subject to an assessment of the economics to:

- Off-set electricity costs on farm
- Provide an energy source in established farming regions with "old" power infrastructure that can struggle with inefficient network capacity at peak demand
- Provide heat for farm operation
- Even out the power load curve which could help a number of farms with peak demand supply issues
- Reduce odour and greenhouse gas emissions.

Energy use on farm

Currently dairy farms spend around $490 million per year on energy (with $250 million on electricity) and with a growing dairy industry this is set to rise. There are opportunities for dairy farms to reduce current energy use by several practical measures.

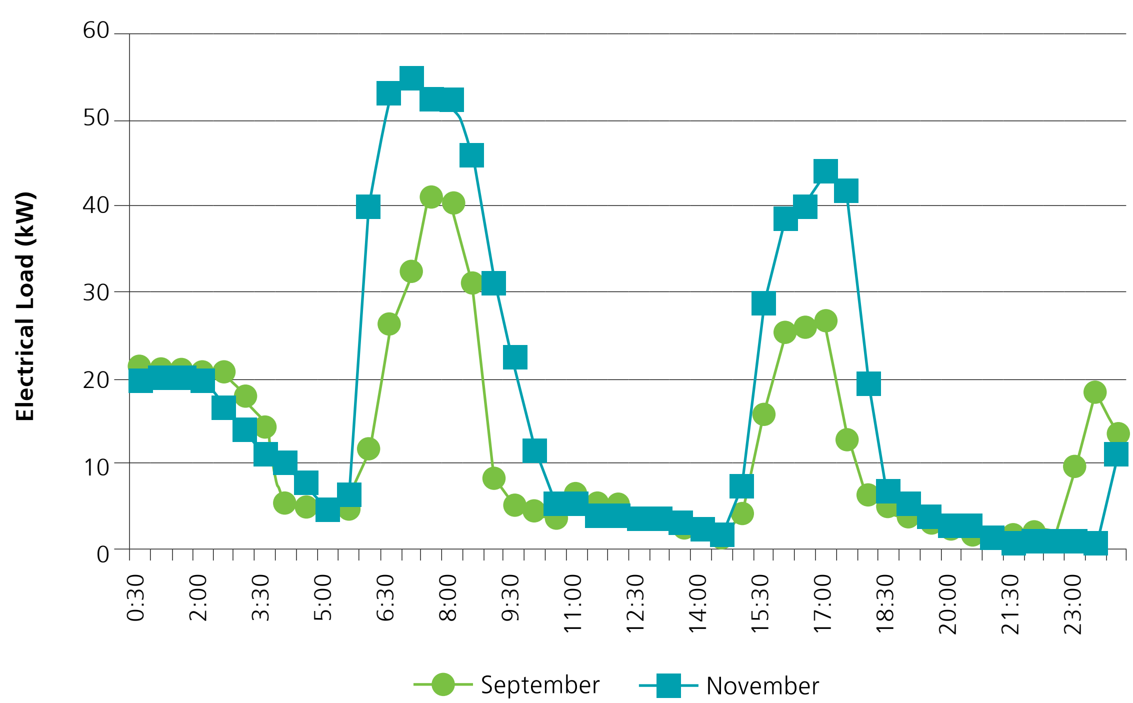
A study undertaken by MAF, EECA and Fonterra on 150 dairy farms analysed historical electricity use data and undertook an energy audit of each farm to identify viable cost savings opportunities. Excluding freshwater irrigation, which is generally separately metered, the average milking operation used 73,900 kWh per year of electricity with the split shown below.



When irrigation use is included, the average farm electricity use increased to 112,100 kWh per year.

Opportunities for savings include reducing hot water use, repairing water and air/vacuum leaks, installing insulation on hot water cylinders, recovering heat from the milk pre-cooler and from the refrigeration plant. Insulation of the milk vat, especially if outside as many are, is another saving that would have a less than five year return on investment.

Energy use on-farm is not spread evenly as a milking shed needs a high volume of electricity for two short periods a day. Shown below is the electrical load pattern for a large operation during a 24-hour period. Farms will still need to be connected to the grid as a reliable supply is always required and this means fixed charges cannot be avoided.

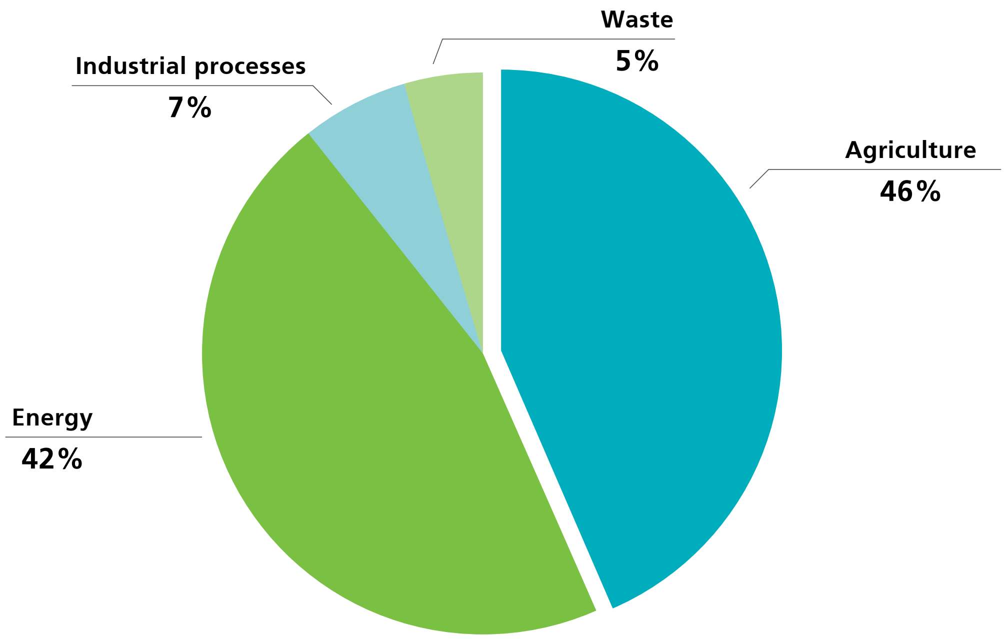


Another factor that needs to be considered with the use of biogas is that within the New Zealand sharemilking system, sharemilkers pay for the electricity costs but the infrastructure is provided by the farm owner. This arrangement therefore provides a disincentive for owners to adopt new technology and make housekeeping improvements.

On-farm GHG emissions

The New Zealand Government has made a commitment to reduce greenhouse gas emissions of which agriculture makes up around 46%. Changes in emissions reflect the changing land use with an increase in dairying from 1990 when there were 3.44 million dairy cows, to around 6.7 million cows in 2015. Even though production has become more efficient with the average emissions per kg milk solids reducing by 19% from 1990, the total emissions have increased due to the significant rise in cow numbers.

NZ GHG Emissions Proportion from each sector (2012)



Agriculture was the largest contributing sector to New Zealand's emissions in 2012. Half of these come from dairying. This is mainly from methane emissions from the rumen of the cow or from nitrous oxide from urine deposits and interaction with the soil.

For methane emissions from the dairy cow, up to 6% may be coming from the storage of dairy effluent (based on the current NZ Greenhouse Gas Inventory). It is likely that these emissions will increase as more effluent is captured from off-pasture infrastructure.

Although a relatively small amount of total greenhouse gas from each dairy farm is coming from the effluent storage system, capturing and using the energy potential from this methane may be of value if other factors are used to advantage. Factors such as solids separation, reduction of odour emitted from effluent ponds and commercial benefit from the reduction in electricity consumption and commercial GHG reduction incentives, like carbon trading, should they become economically viable in the future.

Biogas energy capture systems used in other countries

Anaerobic digestion systems are quite widely used in many countries for methane generation and conversion to energy from dairy effluent. However, in nearly all instances there is some level of government support that ensures they are economically viable. This support ranges from subsidies to install the actual anaerobic digester, guaranteed minimum prices for feeding electricity into the national grid (feed-in tariffs) and other greenhouse gas reduction incentives or pollution abatement schemes. Some countries also assist through subsidies to support crop production which is then used as a digester feedstock. There are no such subsidies available in New Zealand and none are likely to appear in the foreseeable future as New Zealand already has a high percentage of renewable energy technologies compared to other countries.

In most instances overseas, anaerobic digestion systems use feedstocks other than dairy effluent to produce energy. Dairy effluent is regarded more as the inoculum to provide the biological starting microbes for the digestion process. Other types of feedstocks include grains, meat and food wastes, maize, grass silage, fodder beet and chemicals such as glycerol. Two examples of Biodigester systems in the UK are shown in the boxes below.

EXAMPLE 1: 1480 m^3 digester

750 cows housed all year round which produces 17-20,000 T/yr slurry, also use 2,500 T/yr of maize and 450 T/yr of glycerol

Capital cost of £1.2 M (37% covered by grant), sell back to grid as well as use for dairy hot water and 3 on site cottages

EXAMPLE 2: 870 m^3 digester

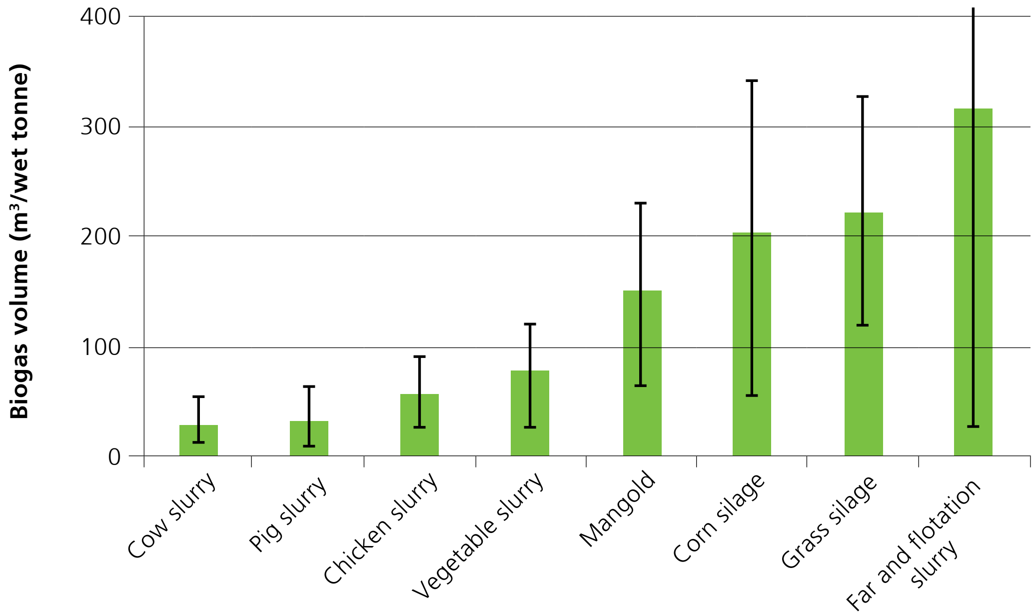
100 Holstein and Brown Swiss cows producing 2,500 T/yr slurry, also use 2,500 T/yr of maize silage or fodder beet, whey from cheese making (210 T/yr)

Claim Feed in Tariffs, extra heat used for grain drying, cheese making dairy hot water and heating the house

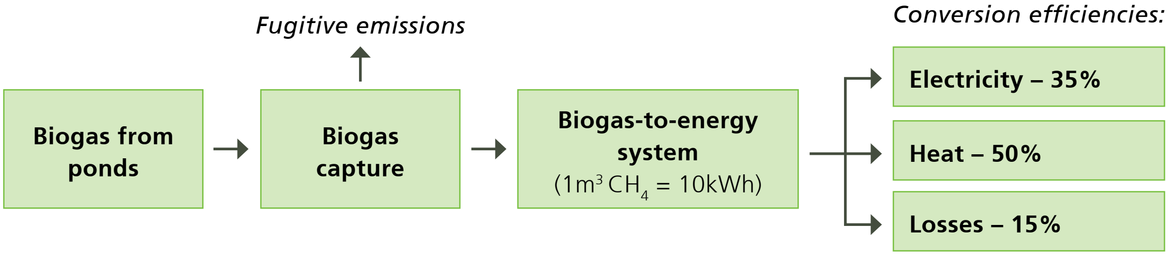
Cost approx. £750,000, self-financed

How much energy can be captured?

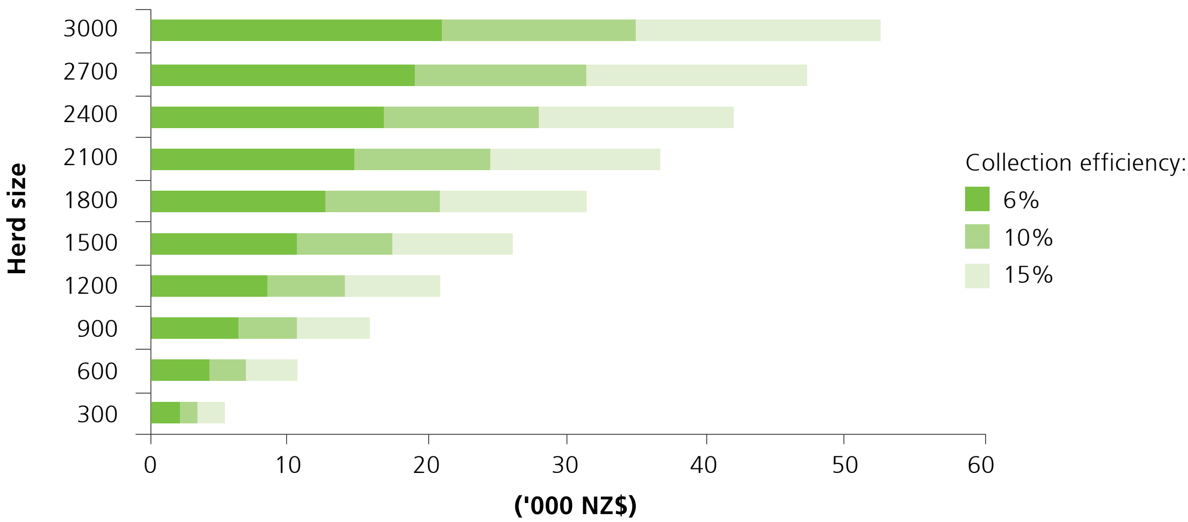
Effluent from the dairy shed is highly variable in nature, being a combination of manure and urine, spilled milk, soil and feed residues, detergents and other chemicals as well as washdown water. This can vary from day to day and depends on individual farm infrastructure, farm system and daily management. Dairy effluent by itself is not a high producer of biogas relative to other feedstocks often used to generate biogas, as shown in this comparative graph below (sourced from UK). It is worth noting that the dairy slurry has already been through one anaerobic digester in the form of the animal rumen before being excreted.



The process to recover energy from biogas typically involves a spark ignition engine to combust the methane gas and drive an alternator. Heat is released during the combustion process and can also be recovered if a co-generation system is implemented. A typical biogas-to-energy flowchart is show below with typical conversion efficiencies.



Based on estimates for a biogas-to-energy potential of 1 m³ ~ 10kWh, an electrical conversion efficiency of 35%, and an assumed energy cost of $0.25 per KWh, the equivalent electricity value produced is shown below.



Note that these electricity numbers are likely to vary considerably between farm systems and may be significantly more or less than quoted here. As there are several technological approaches for anaerobic digestion and gas capture; biogas production capture efficiency varies significantly.

For a 600 cow dairy farm with 6% collection efficiency, the electricity offsetting may only be ~$4,200 per year. However with the growing capture of dairy effluent from feedpads/animal housing and increasing collection efficient to 15%, then this raises the potential electricity value to ~$10,000.

Hot water is used in large quantities on dairy farms to comply with food safety requirements. During biogas-to-energy conversion, up to 50% of potential energy is available for heat production. Therefore to maximise energy recovery, a co-generation process can be implemented where a heat exchanger is used to recover heat that is partly needed to keep the digester at operating temperature and any surplus utilised elsewhere. If the farming enterprise has sufficient demand for heat, the gas can be fired directly in a boiler.

Biodigester systems for dairy effluent in NZ

Anaerobic digestion relies on naturally occurring microorganisms to break down biodegradable material. The process starts with the bacterial hydrolysis of the input materials to simple sugars which are then converted to carbon dioxide, hydrogen, ammonia and organic acids by acidogenic bacteria. Acetogen bacteria convert the organic acids into acetic acid and finally methanogens convert these products into biogas. Digestate is the by-product of anaerobic digestion and can be used as a fertiliser and/or soil conditioner.

There are two main biodigester systems used in New Zealand running as a full energy capture systems. These are the covered effluent storage pond/tank and the purpose built anaerobic biodigester.

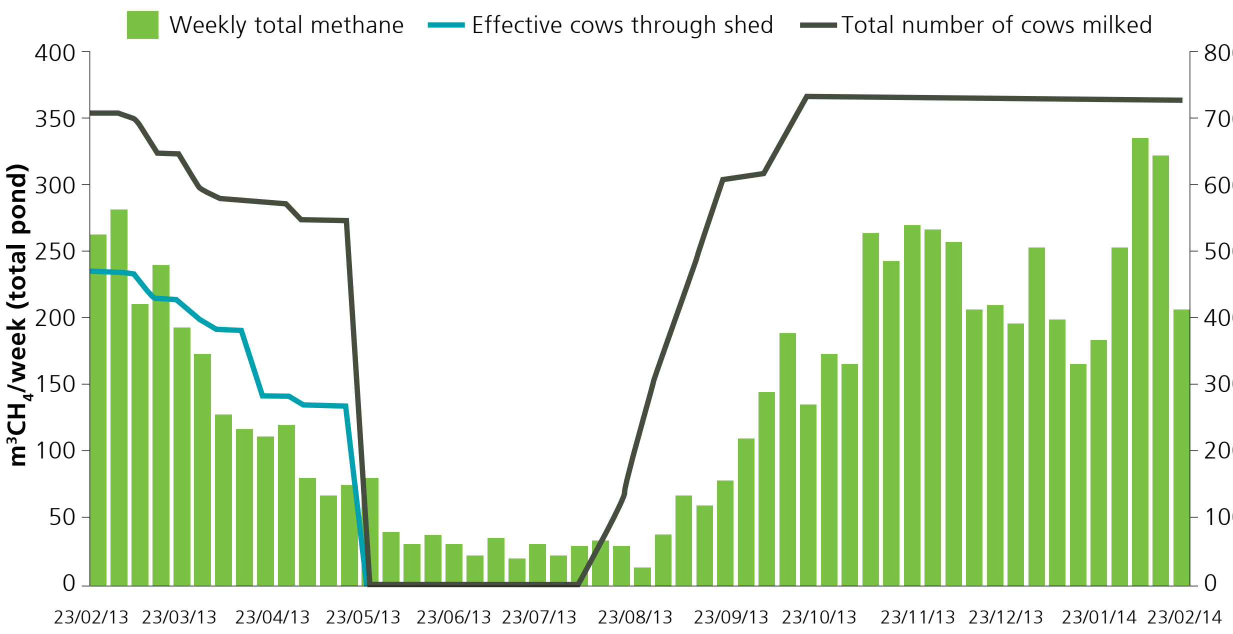
Covered anaerobic pond systems

NIWA has been researching covered anaerobic ponds for a number of years and pond systems are now being installed in a few regions. Based on the research, the methane yield is quite variable. The electricity offsetting is not usually economic in itself, but the cost benefit is improved with the combination as a pond solid separation system. There are a number of solid separation systems used across the country including weeping walls, mechanical separators, and slope screens. These are reasonably costly as most need concrete support structures and/or solids storage bunkers. Lined solids settling ponds, used in combination with a larger storage pond, are also found on dairy farms.

Effluent from the yards and feedpads would first enter this energy capturing/solids separation pond and will then drain to the main storage pond. A main storage pond is still necessary, as farms need to store effluent when soil conditions are unsuitable for irrigation.

If farmers only have one storage retention pond then we do not recommend covering this and capturing the energy. It is important that there is a dedicated storage pond for liquid effluent as this pond needs to be kept low before wet weather periods to ensure adequate storage when conditions are unsuitable for effluent irrigation.

Effluent solids need to continually enter the pond to produce the biogas and in winter if cows are dried off and farm dairy effluent is not produced, the methane yields drop dramatically. However, energy demand is also often low in winter due to the dairy shed not being used. Shown below is data from NIWA research on a pond system in Southland.



When installing a covered anaerobic pond it is recommended that:

- The pond should be deep, narrow and long
- There should be a dedicated pond rather than a retrofitted pond
- Covering a shallow pond is often uneconomic

The pond should be lined depending on regional regulations (synthetic geomembrane, concrete, compacted clay)

The cover is usually a synthetic geomembrane material which is flexible, UV resistant and cost effective. Weight pipes are used for rainwater guidance and an electric rainwater draw-off pump removes built up rainwater. A ring pipeline is used for efficient biogas draw-off.

When planning a compacted clay lined pond, it is important to check with the regional council on their likely requirements. A clay lined pond should be constructed according to the methodology described in the IPENZ Practice Note 21 Farm Dairy Effluent Pond Design and Construction (available on DairyNZ website).

The biogas captured can be flared which will reduce GHG and odour management issues. However, there are no incentives currently to reduce GHG and there are other management and treatment methods available for odour issues. Power is needed to operate the flaring equipment so, if you are covering a pond to reduce odour, it is necessary to factor in power lines to the pond or the use of a solar powered flare system.

Once captured, the biogas is converted to electricity using a Combined Heat and Power (CHP) Units or it can be used as a boiler fuel to heat hot water for use in the farm dairy.

The equipment needed for such a system is shown diagrammatically below.

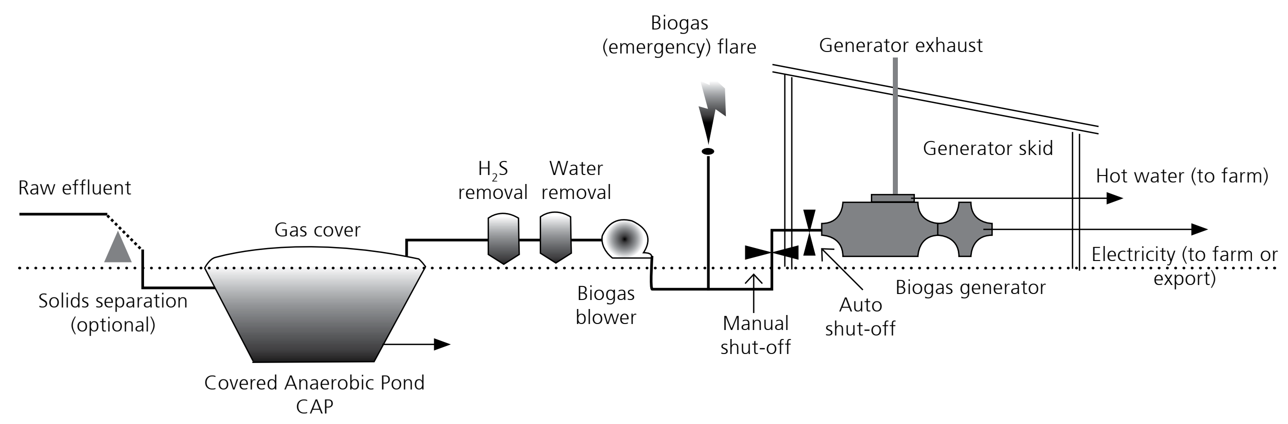


Diagram from Australian Pork Limited (2015) Code of practice for on-farm biogas production and use at piggeries

Anaerobic digesters

Anaerobic digesters can be designed and engineered to operate using a number of different process configurations:

- Batch or continuous
- Temperature Mesophilic (30-38°C) or Thermophilic (49-57°C)
- Solids content (high or low)
- Complexity (single stage or multi stage)

An example of the basic process is shown below

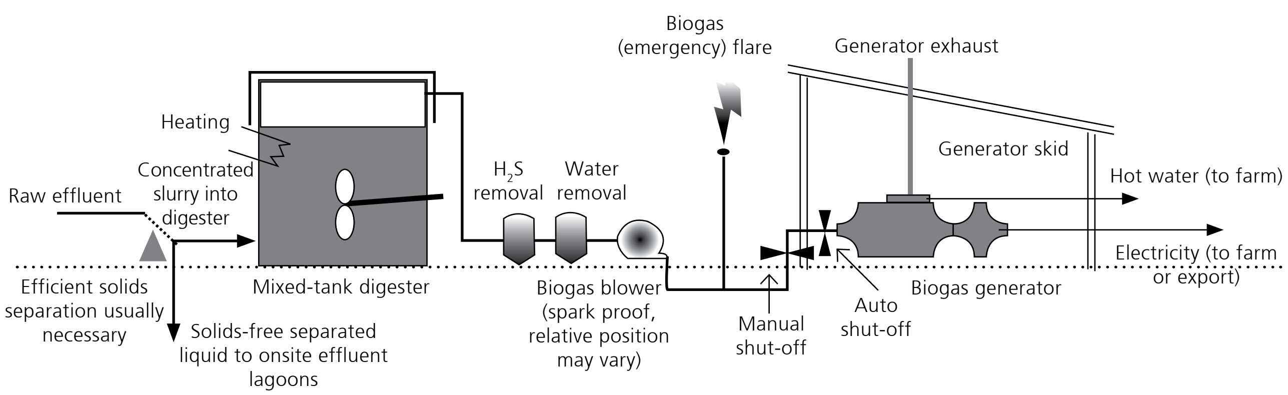


Diagram from Australian Pork Limited (2015) Code of practice for on-farm biogas production and use at piggeries

A wide range of alternative feedstocks (on and off farm) can be co-digested with dairy effluent to increase energy yield such as grass and maize silage, beets, chicken litter and food wastes.

Biodigesters require regular monitoring for temperature, pressure, gas analysis and in terms of management can be compared to looking after another herd of cows. Depending on the scale of the biogas system, an extra staff member may be needed to manage the biodigester; loading the feeder, monitoring operation, managing digestate material (and its storage if soil conditions are unsuitable for land application) and dealing with regulatory compliance requirements (such as discharge consents, Health and Safety requirements and Food Safety).

Depending on feedstock, the anaerobic digestion process can increase nitrogen bioavailability by around 20% over that of the feedstock; the odour level from digestate reduced by 90% to that of stored raw dairy effluent, and the volume of digestate reduced by more than 20% compared to input feedstocks volume depending on moisture content of the feedstock.

Health and Safety – Legislative requirements

There are a number of government agencies relevant to dairy farm biogas operations. The Ministry of Economic Development is responsible for the administration and development of the Gas Act, Regulations and New Zealand Gas Codes of Practice relating to safety, and quality and measurement of gas.

Most recently the Gas (Safety and Measurement) Regulations have included further amendments (July 2013) and information on these can be viewed on the 'Energy Safety' pages of WorkSafeNZ website www.business.govt.nz/worksafe/ More detailed information on the Act can be found on the New Zealand Government Legislation website www.legislation.govt.nz.

Gas (Safety and Measurement) Regulations 2010 is the legal document relating to flammable gas and contains the regulations for gas work.

Of particular interest to prospective farm biogas operations are the following sections:

- (4) Meanings of safe and unsafe.
- (5A) Meanings of low-risk, high-risk, and general gas fitting.
- (9) Requirements to be safe - A person who designs, or supervises the design of, a distribution system, gas installation or part installation, gas appliance, or fitting must ensure that, if the finished design were installed or manufactured as designed, the resulting distribution system, gas installation or part installation, gas appliance, or fitting would be safe when used for its intended purpose and in a lawful manner.
- (10) Obligation to notify WorkSafe of danger.
- (16) General requirement about what gas must be odorised and to what level.
- (30) Who must have a safety management system? (1) Every owner and every operator of a gas supply system must implement and maintain an audited safety management system of the gas supply system.
- (32) What safety management systems must do (1) Every safety management system must comply with either (a) NZS 7901; or (b) Regulations 33 and 34.
- (35) Audit of safety management systems. Every safety management system must be regularly audited.
- (43) Certified designs. A certified design for a gas installation or part installation must be such that, if it is installed, tested, and connected in accordance with the design, the resulting installation or part installation will (a) comply with these regulations; and (b) be safe, as required by Regulation 9 and either AS/NZS5601.1 or 5601.2
- (51) Connecting gas installations to gas supply.
- (52B) Gas safety certification.

- (55) Certification requirements for gas appliances and specified fitting.
- (87) Details to be provided in reporting accidents.

Each year WorkSafeNZ Health and Safety Inspectors carry out thousands of workplace assessments. These are proactive, planned visits and are not usually triggered by a report of serious harm or a health and safety complaint. At least 80% of workplace assessments are targeted to industries identified in the Health and Safety National Action Agenda 2010 – 2013 as high risk, which includes Agriculture, Forestry, Construction and Manufacturing.

Energy Safety is part of WorkSafeNZ which is responsible for providing an effective investigation, compliance, enforcement, and conformance regime for achieving electrical and gas safety outcomes. They work with both the public and industry to create an environment in which:

- People and property are safeguarded from the dangers of electricity and gas.
- Electrical and gas appliances, installations, electricity and gas supply and generating systems are safe.

Standards New Zealand manages standards associated with all the major industries

(www.standards.co.nz). Standards are generally voluntary, but can be mandatory when cited in Acts, regulations, or other legislative instruments. AS/NZS 5601 is the major Standard for all gas installations in NZ with some relevance for farm biogas. NZS 5228 covers the production and use of biogas in farm scale operation (Part 1, Production of biogas, and Part 2, uses of biogas). This standard is however no longer current and has been withdrawn as it is in need of updating to match more recent regulatory changes.

Australian Pork Limited (2015) Code of practice for on-farm biogas production and use at piggeries has excellent information around health and safety requirements and regulations that operate in Australia which is also useful guidance for New Zealand biogas operations.

Any commercial company installing a biogas system on a dairy farm must ensure that they adhere to all relevant New Zealand regulations and install a system that has the health and safety features required for a safe operation. There may also be dairy regulations around application of digestate back onto pasture if external feedstocks are used that include food and animal wastes which may pose a risk unless their origin can be verified.

Selling excess electricity back to the grid

Often claims are made that a dairy farm can sell excess electricity back to the grid and gain extra revenue. Generally though, the price offered is not worth the investment, and even finding a buyer can be challenging in some locations. Based on advice provided to DairyNZ; while any electricity supplier may sell excess generation from on-site generation to electricity retailers, a dairy farm system needs to produce over 1 MW of electricity to be able to fully participate in the electricity market which is approximately equivalent to all the energy captured from the effluent from 3,000 cows housed all-year-round.

The New Zealand electricity market is regulated by the Electricity Authority with the market split into regulation, generation, administration and market clearing, transmission, distribution, metering and retailing. Electricity is traded at a wholesale level in a 'spot' market. Generators submit offers through a Wholesale Information and Trading System, Each offer covers a future half hour period (called a trading period) and is an offer to generate a specified quantity at that time in return for a nominated price. This then enters a contestable trading system. Electricity 'spot' prices can vary significantly across trading periods reflecting changing demand and supply.

The New Zealand electricity market requires skilled and experienced practitioners, so when planning on securing revenue by selling to the grid as part of the cost benefit analysis, we suggest consulting the relevant experts.

The Sustainable Electricity Association of New Zealand (www.seanz.org.nz) although mainly focused on solar and wind generation does have relevant information for further reading as well as the 2014 report 'Energy in New Zealand' on the Ministry for Business, Innovation and Employment website (www.med.govt.nz).

What can go wrong?

Producing methane involves both engineering as well as biological system considerations which mean things can and do go wrong from time to time and it's useful to plan for how issues would be rectified before undertaking a commercial installation.

Issues likely to be encountered are:

- Use of chemicals on-farm that may 'poison' the system
- Seasonal variation in farm dairy effluent and energy demand on the farm
- Shock loading of biological material (rejected milk, large volumes of feedpad scrapings)
- Safety of methane storage (it is flammable)
- Breakdown of equipment

Warning signs may be:

- Drop in Biogas Production
- Low pH
- Change in gas composition
- Increased acid : alkalinity ratio

Expert advice from experienced engineers may be needed to assist with rectifying issues and should be factored into a decision to install a biogas system.

Financial viability

There is some excellent advice offered in the Australian report "Emerging Technologies for Managing Dairy Effluent: Capturing Methane for Bio-energy" around the cost effectiveness of energy capture systems which have been summarised into these bullet points below:

- A digester is treated like another herd of cows.
- Economics of an electricity only enterprise questionable without any financial incentives.
- Economics of a dairy effluent only enterprise questionable (ie need to add other feedstocks)
- Multiple Feedstock – Multiple Product – Better Outcome
- Other revenue streams and farm operational drivers are the key to financial viability (ie sell digestate, use energy captured for other high value on-farm activities)
- Small scale systems that displace retail energy purchased, using the heat recovered and improving the feedstock fertilizer value, may be feasible. Assess each on its own merits.

As mentioned briefly earlier, many countries offer financial incentives to assist with the economics of biogas capture and use. In most cases these systems would be uneconomic without them. New Zealand currently has no incentives to improve the economic viability of this technology; it must stand on its own merits.

Summary of considerations:

Significant effort is required to ensure a New Zealand biogas operation is financially viable for a dairy farm business. Before purchase, the business case should include full disclosure of all the costs to install, on-going operation and maintenance costs, likely yields and best use of the energy captured.

The table below summarise the statements often made around biogas

Statement	**Comment**
Covering the pond or effluent storage reduces odour.	Covering will reduce odour by over 90%, so a significant benefit.
Major reduction in greenhouse gases (GHG) from dairy sector.	The majority of greenhouse gases are from burping cows and urine patches (~94%). However trends are for increasing effluent stored so GHG likely to rise from dairy effluent.
Sell extra electricity to the grid.	Full investigation with relevant experts in the energy sector should be undertaken if this is planned.
Just plug in the digester and it takes care of itself.	An anaerobic biodigester requires feeding and careful monitoring just like a herd of cows. It can get 'sick' and can require additional expertise to resolve.
Because the pond is covered by a synthetic cover no need to worry about explosions.	The methane in the biogas is produced at a relatively low yield and low pressure but there is still a hazard and there are regulations to be followed around biogas storage and electrical equipment used.
Other countries use biogas all the time so it's an established technology and low risk.	Biodigester technology has been used for many years and there are reliable technologies available from experienced companies but it's the economics that should be evaluated before purchasing.
Less hassle than dealing with raw effluent.	The biodigester does not remove the nitrogen or phosphorus from dairy effluent, just converts the carbon material into methane. However, the digestate is reported to have reduced in volume and odour and have some of the nutrients more bioavailable for plant uptake which are all benefits. An effluent storage and irrigation system is still required so there is little cost reduction unless you have a covered pond as a solids separator.

This note concludes that energy capture from dairy effluent may be an option for some dairy farms but we advise caution. Covered pond systems are worth considering but are only economic if factored in as a solids separation system. They do not replace the need for a separate liquid storage system. To improve viability for a stand-alone anaerobic digester, consider other feedstock rather than just relying on dairy effluent (although it is necessary to weigh up the benefits of feeding it to the cow rather than the biodigester) and ensure that the energy generated can be used to offset electricity use on-farm and for other enterprises.

Some extra reading:

Dairy Australia (2008) report *Emerging Technologies for Managing Dairy Effluent: Capturing Methane for Bio-energy* dairy.com.au

Royal Agricultural Society of England report (2010) *A review of anaerobic digestion plants on UK Farms by Angela Bywater* rase.org.uk

Australian Pork Limited (2015) *Code of practice for on-farm biogas production and use at piggeries* australianpork.com.au

Where to go for help and expert advice?

Bioenergy Association website and see members in the Biogas section

www.bioenergy.org.nz

www.biogas.org.nz

DairyNZ acknowledges the technical assistance from the companies listed below in the development of this Effluent Technical Note.

- *ADI Systems*
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