Australian Government
Department of Agriculture

AUSTRALIAN Pork™

Exploration of the Opportunities to Establish Anaerobic Digestion for the Generation of Biogas

Final Report
APL Project 2009/2293

June 2010

FSA Consulting
Glenn Poad & Eugene McGahan
PO Box 2175
Toowoomba Qld 4350

Executive Summary

What the Report is About

Anaerobic digestion of animal manure and organic waste is well established overseas but is still developing in Australia. The Australian biogas plants installed so far predominately operate on gas produced from sewage waste, food and abattoir waste. Berrybank pig farm in Victoria is perhaps the best-known local example of a successful anaerobic digestion based farm.

The biogas industry is well developed in Europe and is developing in the United Kingdom and North America. This project reviews the international developments and investigates the feasibility of applying the process in Australia.

Who is the Report Targeted at?

This report has been developed for Australian Pork Limited. Dissemination of the results to secondary target audiences (i.e. pork producers or the general public) will be at the discretion of the funding body.

Background

Commercial scale anaerobic digestion started in Northern Europe in 1984 and developed in two directions over the next decade. In Denmark the move was towards large centralised anaerobic digestion plants where the manure is transported from up to 80 farms to the plant and the digestate is returned back to the farm or sold. Electricity that is generated in the plant is sold to the local grid and generated heat is normally sold to local community heating schemes. As the first Danish biogas plants began to operate and a better understanding of the biogas process was achieved, other advantages in using this technology emerged. These advantages include methods of recycling manure waste, improved environmental performance through nutrient recovery, reductions in odour emissions from raw manure spreading, heat recovery and improved GHG performance.

In Germany the system design is much smaller and is suited to the waste produced from one farm or several local farms. The German biogas industry is significantly larger than any other country and is growing at a faster rate. The German Government has introduced legislation, which guarantees power pricing from renewable energy sources and provides a reliable income for the 20-year term of the contract. Significant areas of land are made available to grow energy crops, which are supplied to the biogas plants specifically to produce electricity. Finding a way to use the heat generated from the Biogas plants is always a challenge to convert it into a revenue stream. Some of the new German biogas projects are looking at novel ways of using the biogas by purifying it with carbon dioxide removal and injection into the local gas network or transporting biogas produced from a collection of biogas plants over 20 km to a centralised power generation plant that supplies heat to the adjacent community.

The Biogas industry in North America and the United Kingdom is developing but the progress to date is slower than Europe and the level of Government support is significantly less than some European nations.

Aims/Objectives

This project aimed to search and identify biogas plant installations worldwide and examine the successful outcomes and problems experienced. The project identified the areas of biogas development and different outcomes achieved from taking each path.

Methods Used

The project conducted a comprehensive literature review to investigate the reported biogas plant installations worldwide and provided case studies where appropriate.

Results/Key Findings

The economic balance of biogas plants is tenuous and to achieve a long-term positive outcome, the plant must have all revenue streams in place. In the majority of cases in Europe and North America, a financial grant ranging from 20 to 40% of the capital cost has been provided through Government assistance programs to reduce the financial burden of debt servicing. Even with this level of assistance, there are still cases of some plants struggling to achieve a positive cash flow.

The Danish biogas industry developed first and now has the largest scale centralised biogas plants, but there has been little development since the1990s.

The German biogas industry is the world leader with by far the highest number of installed plants and the highest number of anticipated new installations. The success of the German biogas industry is largely due to guaranteed long-term power prices for renewable energy and simple plant design with good technical support.

In Europe, the key driver behind the biogas development is establishing an alternative renewable energy source to fuel oil.

Having observed the progress in Europe, the United Kingdom and North America are developing their respective biogas industries with mainly farm based systems and a small number of larger centralised plants. The Government from each country provides some form of support to develop the local biogas industry through a variety of funding schemes and legislation.

Australian Government commitments have been designed to achieve GHG emission targets and this has focused interest in increasing renewable energy production. Biogas generation plays a part in this, but it appears to be behind solar energy and heat pumps as the more favoured choices.

The biogas industry in Australia has developed in a similar way to the countries outside Europe. Landfill gas and biogas from sewage plants are developed first; digestion of manure waste and mixed wastes follows.

Australia has a low population density, large land mass and a warm to hot climate; almost completely opposite to Northern Europe conditions. To establish a centralised digestion plant in Australia that is economically successful will be challenging. The long distances between significant sources of organic waste will result in high transport costs to and from the plant. To be economic the plant would also have to have a demand for the heat generated that either offsets costs or provides a sales return. Community heating schemes, which are a convenient heat demand for the European biogas plants do not exist in Australia. Apart from the spot price electricity market and RECs system, there is no incentive to sell electricity that is generated from a renewable energy source on the Australian market.

The German farm based system may be a better option to match the Australian conditions. For farm scaled systems the transport costs can be eliminated and potentially the heat generated could be used on farm to provide heat to a pig-breeding unit in a similar way to the anaerobic digestion system at Berrybank.

For the smaller farm the costs of installing a farm based tank digestion system is likely to be prohibitive. The covered anaerobic lagoon with gas flaring or energy recovery is a more practical option.

For any of the options considered, the economic viability will only be achieved if all of the potential sales returns actually generate an income or significantly offset costs. This includes the sale of digestate and electrical power and use of heat and electrical power on site. The economic feasibility of establishing a biogas industry in Australia will be improved through increased levels of Government support and attractive renewable energy pricing to the generator.

Recommendations

Further research is recommended to quantify the costs and benefits of establishing a covered pond digestion system with flaring and with energy recovery for the small and medium sized piggery. This should include the cost of covering the existing pond providing a new smaller covered pond with higher solids loading.

Further research is recommended to quantify the costs and benefits for a farm-based system using the German model to determine the economic lower limit and potential for receiving mixed waste streams, which can be locally sourced.

Investigation of the feasibility of the larger centralised plant should be completed and based upon selecting an area with high pig animal density to determine if the economics associated with transport and digestate sales are likely to provide a viable revenue stream, along with electricity and heat sales.

Acknowledgements

This project is supported by funding from Australian Pork Limited and the Department of Agriculture.

Table of Contents

List of Figures

List of Tables

Abbreviations

ABS	Australian Bureau of Statistics
AEMO	Australian Energy Market Operator
CAD	Centralised anaerobic digestion plant
CH_4	Methane
CHP	Combined heat and power plant
C:N	Carbon to nitrogen ratio
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
CPRS	Australian Government Department of Climate Change's Carbon Pollution Reduction Scheme
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSTR	Continuous stirred tank reactor
db	Dry basis
DKK	Danish krone (currency)
DM	Dry matter
FIT	Feed in tariff
GHG	Greenhouse gas
GIS	Geographical Information System
GWh	Gigawatt hours
HDPE	High density polyethylene plastic
KJ	Kilojoules
kW	Kilowatt
kWh	kilowatt hour
kWhr/yr	Kilowatt hours per year
LATS	Landfill Allowance Trading Scheme
ML	Megalitre
MJ	megajoule
MW	Megawatt
MWh	Megawatt hour
NEM	National Electricity Market
NH_3	Ammonia normally a gas at standard temperature and pressure
NH_4^+	Ammonium ion normally present in liquid form
N_2O	Nitrous Oxide
OBSFA	Ontario Biogas Systems Financial Assistance Program
pH	A measure of a solutions acidity or basicity
RECs	Renewable energy certificates
RIRDC	Rural Industries Research and Development Corportation

RRP	Regional Reference Price
SLA	Statistical local area
SPU	Standard pig unit
TS	Total solids
UASB	Up flow anaerobic sludge blanket digester
USDA	United States Department of Agriculture
VFA	Volatile fatty acid
VS	Volatile solids

1. Background to Research

Anaerobic digestion is a naturally occurring process and has been used by humankind for centuries to convert organic waste material into useful by products such as biogas. On the small farm scale, converting cow dung into biogas is commonly used for cooking throughout India and China. Farm scale and larger commercial biogas plants are now well established in Europe and to a lesser extent in North America.

Anaerobic digestion of animal manure has the potential to provide a range of benefits to the agricultural industry, such as producing renewable energy, producing a high value soil conditioner, reducing greenhouse gas impact and potentially reducing odour problems, which are traditionally associated with manure waste disposal.

One of the many challenges for the agricultural industry is handling the farm waste stream in an economic and environmentally responsible way. This project initially investigates farm scale and large centralised biogas plants, which are currently in operation. The project specifically focuses on plants which process piggery waste. The project then assesses the preliminary feasibility of establishing a farm scale or large centralised biogas plant in Australia.

Australian agriculture will likely experience serious impacts from climate change (Gunasekera D et al. 2008). By undertaking research projects such as this, the Australian Pig Industry is exploring the options available towards "Managing Risk for Sustainability". Global warming is being driven by manufactured emissions of greenhouse gases (GHG), like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). While pig production represented only 0.4% of the national GHG emissions, the Australian Government Department of Climate Change's Carbon Pollution Reduction Scheme (CPRS) Green Paper reports that the Australian pork industry is the seventh biggest GHG emitter per unit of revenue. Most of the pork-related on-farm GHG emissions result from CH_4 emissions from effluent lagoons.

Mitigation of GHG emissions, or carbon abatement, needs to be broadly adopted to address effects of climate change in the long term. At present, emissions from agricultural sources are excluded from the proposed CPRS. There is also a community expectation that industries will act to mitigate GHG emission, whether the CPRS applies directly to them or not. The adoption of GHG mitigation measures has serious implications for environmental sustainability and the environmental credibility of the Australian pork industry. Hence, there is a need to identify practical ways the Australian pork industry can reduce its emissions in a cost effective way. Anaerobic digestion for the generation of biogas is one potential option.

It is reasonable to expect that in the future, energy costs will increase. Methane capture and conversion into energy is a way of offsetting the effects of increasing energy costs for agricultural industries.

2. Objectives of the Research Project

The initial objective of this project is to review current and proposed developments in the field of biogas production using anaerobic digestion of piggery and other organic by-products both in Australia and overseas.

A further objective is to undertake a preliminary assessment of state-of-the-art technology, practices, regulation and economics of biogas production through anaerobic digestion of piggery by-products.

Finally, the project will analyse the potential for applying biogas in the Australian pork industry.

3. Research Methodology

Stage 1 - Current Anaerobic Energy Developments

A review of the current and proposed energy production developments in anaerobic digestion from piggery waste and other organic by products was completed for Australia and overseas.

This included documenting the available information and related information sources, on the size, location and planned development of bio-energy facilities in Australia. This covered all industries that produce organic by-products.

The review provides current information on:

- The size, location and operational status of anaerobic digestion facilities currently operating in Australia, with Geographical Information System (GIS) mapping of sites.
- Future proposed developments.
- Size requirements (waste volume) for economic feasibility.
- Construction and operating costs (where available).
- Form of energy produced (electricity, heat) and end use for this energy.

This review focuses on energy production from organic by-products using anaerobic digestion internationally with focus on current developments in a broad-scale. The biogas from anaerobic digestion process is well developed in Europe, case study examples have been provided for some farm based biogas plants, and larger centralised biogas plants. Where possible the case studies include construction cost, funding structure, operating cost and sales to provide an indication of how the plants are performing.

The review includes an extensive desktop search to identify developments in other regions of the world. This search focused on by-product sources most closely related to by-products from the pork industry.

Stage 2 - Current Technologies for Energy Production

A literature review of the publicly available research on the technical aspects of energy generation from piggery and other organic by-products streams was completed. This review was a desk-top study, with electronic communication with Australian and International research groups.

The review included:

- Current and potential anaerobic digestion technologies for biogas production focussed on piggery by-product streams.
- Technical requirements and constraints for operation.
- Economic feasibility of anaerobic digestion.
- Quantities of material required to ensure viability of plants.
- Primary information requirements such as potential energy yield of different organic by-products and research requirements to collect this information.

Stage 3 - Potential for Biogas Production in the Australian Pork Industry

Section 3 of the proposal has been excluded from the initial stages of the project scope by APL.

3a Location of Piggeries and Potential Sites for Development

This will address the following issues:

- amount of material available
- biosecurity
- required transport distances
- risks and opportunities
- type of energy produced
- potential environmental benefits and limitations of centralised or local facilities versus individual operations
- identification of ideal locations for developing farm scaled and CAD plant.

This will involve the mapping of piggeries and pork processing plants using a GIS, as well as estimated volumes of production now and in the short term future (to 2015). Although FSA Consulting has worked very extensively within the pork industry, our database of piggery and processing works locations is incomplete. Where we have data, we are mapping the location and size of piggeries as part of a recently contracted GRDC project entitled “Fertiliser from Waste”. We would be reliant on APL to supply location and size information for the Australian industry to produce better maps for the industry. We understand the sensitivity of this data and the need to ensure it is not released in a form that identifies the location of individual piggeries either as a result of this project or independently. To protect the privacy issues around specific locations of facilities, the project team will only present aggregated data on volumes of waste stream products from regions. Other data sources we will use will include but not be limited to Australian Bureau of Statistics (ABS), Google Earth™, National Pollutant Inventory (NPI) database and state EPA licensing.

3b Legislative Constraints and Economic Incentives Available

We would provide a review of legislation relating to the siting, design, operation and monitoring of energy production facilities in Australia. We will examine both State and local government regulations and planning schemes to identify current legislative barriers to gaining development approval. In some cases, approval for energy production facilities depends upon the capacity of the applicant to demonstrate high environmental performance and economic contribution to the region.

3c Technical Requirements for the Development of Bio-energy/Nutrient Recovery Facilities

Technical requirements to be addressed include:

- Requirements for further research / information capture on promising anaerobic digestion technologies for bio-energy production and nutrient recovery.
- Feedstock requirements and assessment of piggery by-products and piggery by-product blends for various bio-energy production systems.
- Minimum size requirements for an economically feasible plant (this will be informed by the GIS mapping component outlined above).
- Legislative requirements for development approval.
- Facility management – by processors or a third party company.

3d Economic Analysis

Based on the findings in the other stages of the project, the economics of converting piggery waste into energy will be evaluated. We will estimate the operating costs of two such systems. Following this, the capital development expenses and annual ownership costs required to establish the new technologies would be undertaken and included in the total assessment. We will also identify likely income. The potential economic incentives will be included to identify changes in the analyses and improved economic viability.

This assessment and detailed expenses modelling will enable the industry to determine if the development of farm scaled plants or larger CAD plants for processing piggery by-products is likely to be viable in Australian conditions after considering Australian operating parameters, constraints and incentives.

4. Anaerobic Digestion

4.1. The Anaerobic Digestion Process

Anaerobic digestion is a biological mechanism that converts organic material, into methane, and carbon dioxide. The energy in the material being digested is retained in the produced gas as methane. Anaerobic digestion is a natural process that takes place in the absence of external electron acceptors such as oxygen. The digestion process occurs in several steps. **Error! Reference source not found.** shows an overview of the process (Pavlostathis & Giraldo-Gomez 1991).

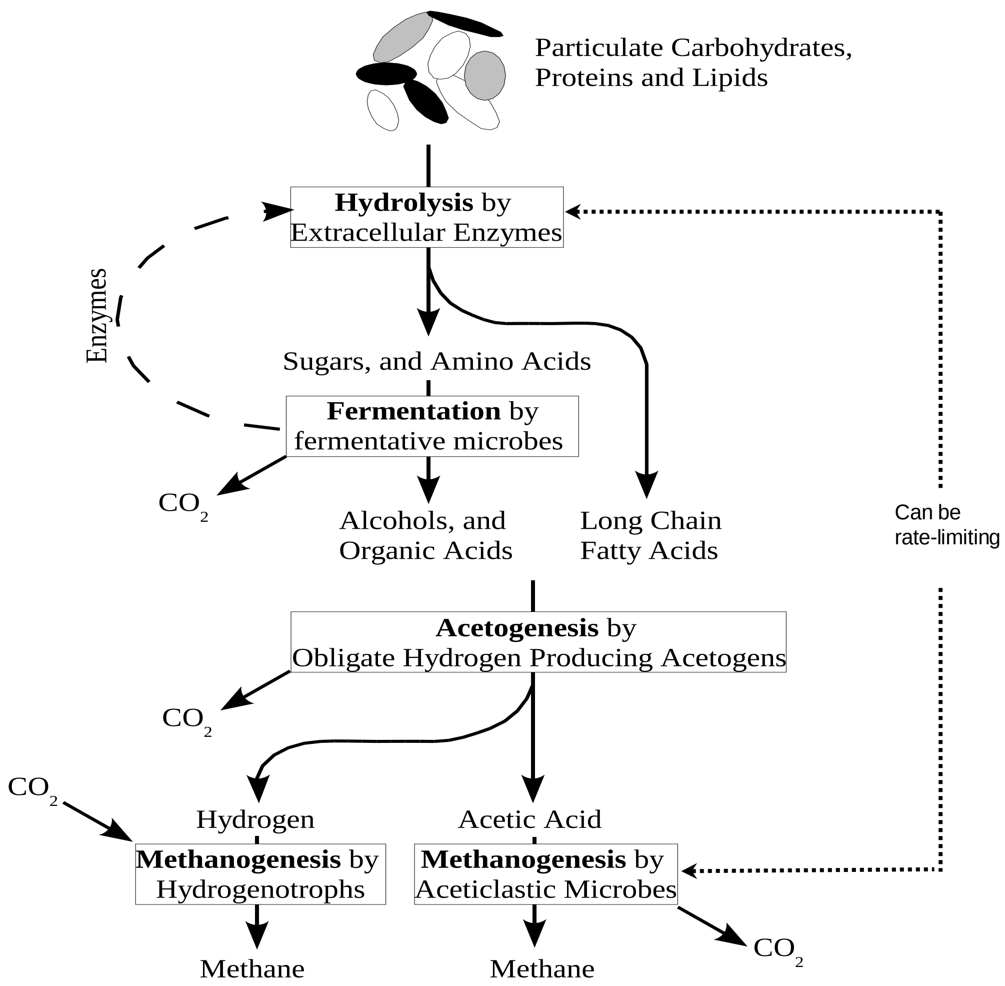

Figure 1: Anaerobic digestion process

Source: Pavlostathis & Giraldo-Gomez (1991)

The key steps involved in Anaerobic Digestion include (Monnet 2003, Pavlostathis & Giraldo-Gomez 1991):

a. Hydrolysis – This is a chemical process where hydroxyl groups break down complex organic molecules into sugars, amino acids and fatty acids. This step can often limit the rate of the digestion process due to the nature of the feed stream. To reduce the possibility of rate limitation the feedstock should be reduced to small particulate size. Significant rate limitation in this step will lead to an overall poor digester performance. This would be evident with undegraded material being washed out.
b. Acidogenesis / Fermentation – This is a biological process in which sugars and amino acids a converted into volatile fatty acids, alcohols, and carbon dioxide. It is almost never rate-limiting, but will decrease pH, and may inhibit other steps.
c. Acetogenesis – Organic acids and alcohols are converted to acetic acid, and hydrogen in this biological process. It is generally only rate-limiting in very high rate processes.
d. Methanogenesis – There are two different biological processes occurring in which (i) acetate is converted to methane (aceticlastic methanogenesis - 70% of methane produced), and (ii) hydrogen and carbon dioxide is converted to methane. The first process is highly impacted by potential inhibitors, including ammonia, pH (stops at <7.0), and specific issues. Normally reactor failure is initiated by failure of process (i) (Batstone et al. 2002). Aceticlastic methanogens are the organisms, which contribute to the majority of methane production and are also the slowest growing. These organisms can be washed out of the digestion system if retention times are below approx. 10 days.

4.2. Digester Operating Conditions

4.2.1. Digestion Temperature

The performance of the anaerobic digestion process is strongly temperature dependant. Biological methanogenesis has been reported to operate in the range of 2°C in marine sediments to above 100°C in geothermal areas (Chynoweth et al. 1998). Applications of the process can occur at ambient temperatures also known as psychrophilic (15-20°C), mesophilic (30-40°C), or thermophilic temperatures (50-60°C). Typically, most digesters are designed for either mesophilic or thermophilic conditions. In general, with increasing temperature the digester performance improves, comparable digester size is reduced due to higher loading rates but the thermophilic digesters are regarded as being less stable (Batstone 2006). There appears to be an upper temperature limit of around 60°C above which there is a rapid reduction in microbial activity (Chynoweth et al. 1998).

Sudden changes in reactor temperature of (+2°C) can lead to the last stage of digestion (methanogenesis) to fail. Sufficient energy is normally available from the gas engine system to heat the digester to at least mesophilic temperatures without an external heat source (Batstone 2006).

4.2.2. *Ammonia Content*

Ammonia inhibition is caused by the free form of ammonia (i.e., NH_3, not the ammonium ion NH_4^+). Inhibition by ammonia is strongly influenced by pH and is also temperature dependent, as demonstrated in **Error! Reference source not found.** (Batstone et al. 2002, Siegrist et al. 2002).

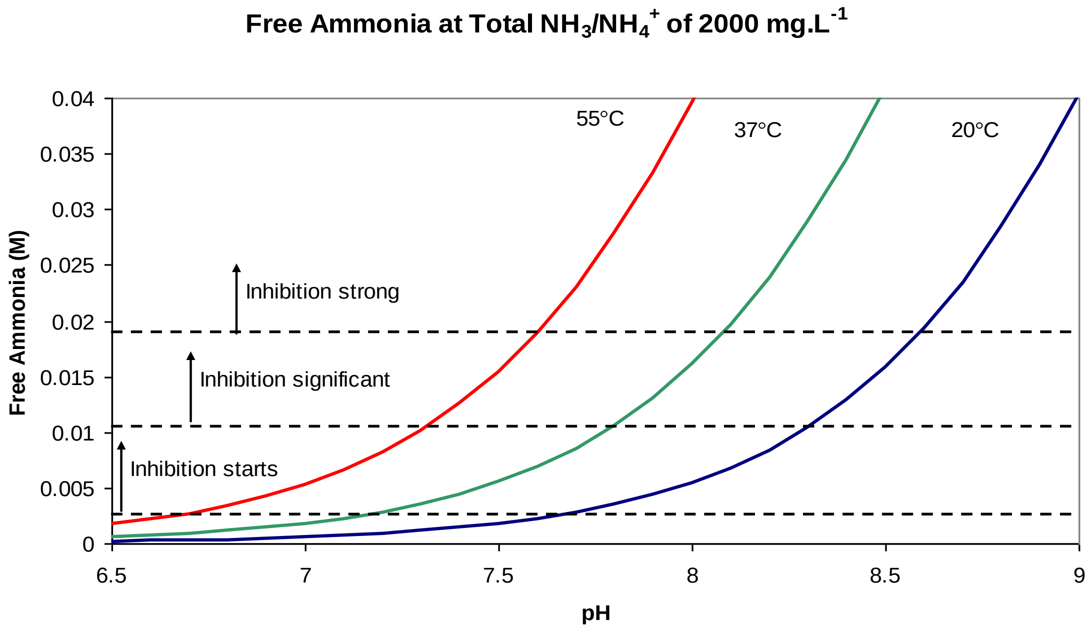

Figure 2: Free ammonia levels, and ammonia inhibition

Source: Batestone D (2009) Pers-Coms

Ammonia inhibition has a strong impact on the final step of aceticlastic methanogenesis, and in the short term, will cause inhibition. In the long term, it will cause a fundamental change in microbiology that causes the system to operate in a sub-standard way (Karakashev et al. 2006).

Despite its negative impacts, ammonia can also have a positive impact in that its presence maintains a pH of >7, which is vitally important for anaerobic digesters. The fermentation step produces acids, which lowers the pH and the presence of ammonia helps maintain the pH at a higher level. At a pH of below approx. 6.5-7.0, methanogenesis stops (Batstone et al. 2002), fermentation continues, and the system enters an acid overload from which it is very difficult to recover (caustic dosing is required). Ammonia acts as a base, and keeps the pH at a high level.

4.3. *Types of Anaerobic Digestion*

The design of the anaerobic digester needs to provide sufficient retention time to allow for hydrolysis of particulate substrates, and provide beneficial conditions for methanogenesis where acetate is converted to methane. This also includes maintaining the digester pH above 7.0.

Anaerobic digestion technologies have developed into two broad areas. Long hydraulic retention times with extended sludge retention, such as anaerobic lagoons, liquid mixed digesters, plug flow digesters and leach bed digesters, provide beneficial conditions for the methanogenesis step where acetate is converted to methane. A short hydraulic retention time with extended solids retention to promote hydrolysis of the feed stream is a feature of the high rate digester. **Error! Reference source not found.** shows the grouping of the anaerobic digestion technologies in two broad areas. The split between the two groups of groups should be read as the four upper technologies in a group and the single technology in the lower group.

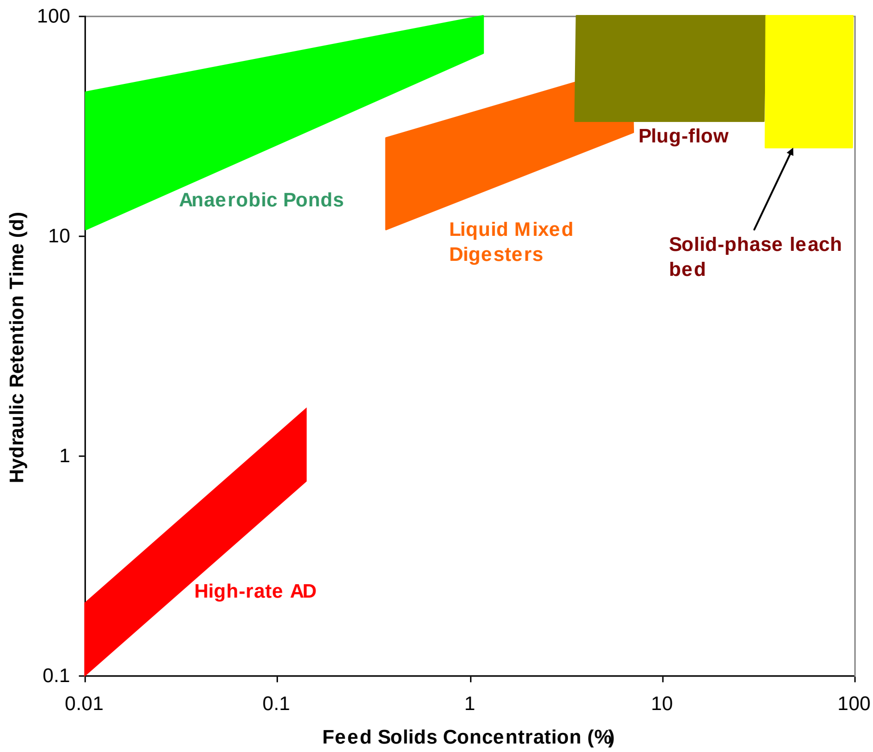

Figure 3: Operating conditions (HRT and feed solids concentration)

Source: Batestone D (2009) Pers-Coms.

4.3.1. Anaerobic Ponds

Ponds provide a long retention time and are perceived as a low capital cost option. Large ponds tie up land and can be a source of odour problems and require desludging approximately every 10 years. Desludging can be extremely expensive and may require a plant shut down or alternative waste handling system in operation while desludging occurs. Methane capture requires an impermeable cover and collection system. Methane capture from covered ponds has generally been reported as relatively poor, however recent work by NIWA demonstrates that biogas availability from a well designed covered pond system is similar to the biogas availability from heated tank reactors (Craggs et al. 2008).

Solids loading heavily drive overall costs. The concentration of the waste stream to the pond is relatively low at around 1% for piggery effluent. Because of the large pond volumes, correction under failure can be extremely expensive or impractical.

4.3.2. Liquid Mixed Digester

The mixed digester operates at a concentration range of 3-6%. The digester is operated as a fully mixed system, with either gas recirculation, or mechanical mixers incorporated in the design. The feedstock can be continuous or batch fed with retention times of approximately 20 days. This is established technology and is used across many industries. The costs are relatively high to establish the plant and the tanks provide poor volumetric loading. The mixed digester produces a liquid digestate.

4.3.3. Liquid Plug Flow

Material is loaded at the front of the digester, and passes through the digester to become a product at the end. As the materials are not mixed, intimate contact between the bugs and the biomass is poor. The liquid plug flow digester operates at semi-solid liquid (10-20%) conditions in a long polyethylene tube. The plug flow digester has a very high loading rate.

4.3.4. Solid Phase (Leach Bed)

This is similar to an engineered, high-rate landfill, where material is loaded into a digester, tumbler, or baskets, and leachate or inoculum liquid is circulated through the solids in the digester. Very high loading rates are possible with very high feed solids concentrations between 50-100%. Good gas conversion is possible due to retention of the active biomass. The digesters can be difficult to effectively seal.

4.3.4.1. Batch Solid Phase Digester

The batch solid phase digester is operated until methane production stops and the digester is unloaded and reloaded. The biogas quality and quantity is variable, however the batch plant can be relatively inexpensive.

4.3.4.2. Continuous Solid Phase Digester

For the continuous solid phase digester, material is continually added and spent material removed. The digester produces a continuous biogas supply but is considerably more expensive than the batch process. The continuous process is only practical at a very large scale and is extremely expensive.

4.3.5. High-Rate Anaerobic Digestion

High rate anaerobic digesters normally operate with extended solids retention time, and short liquid retention times, by integrating solids retention within the main digester. The most common type is an up flow anaerobic sludge blanket (UASB) reactor, which relies on a naturally forming granular sludge blanket (particle size 1mm), through which the liquid percolates. They require a low solids feed, with relatively high amounts of soluble feed material, and are most often used for domestic sewage treatment, as well as industrial wastewaters (van Lier 2008). Hydraulic retention times are normally short, typically less than 48 hours, while solids retention times can be very long. The digester has a low footprint, relatively low capital cost and the digester operation is very stable.

4.4. Scale of Anaerobic Digestion Plants

4.4.1. Farm Based Systems

The farm based system is typically designed for one farms manure or manure collected from small farms nearby. Depending upon the availability of local organic waste material it is possible to mix the feedstock used in the digester.

A well-known farm based anaerobic digestion system in Australia is located at Berrybank farm, Victoria. The anaerobic digestion process at Berrybank farm produces electricity and heat from biogas produced from piggery waste. Farm based systems have been successfully implemented throughout Europe. In Germany there are in excess of 2700 farm based anaerobic digestion systems (Scholwin 2006) and standardised equipment packages are available from a range of equipment suppliers.

The farm-based system has the advantage of short transport distances from the source of feed waste to the digestion plant, hence transport costs can be minimised. In Europe, the heat energy produced by the plant can be used to heat the digester or alternatively provide heat to a local community. Community heating schemes are common in Europe and provide a continuous heat demand for a significant period of the year during the cooler months. The heat generated from the biogas process can often be easily tapped into an existing community heating system. This is an attractive arrangement as the cost to establish the reticulation system around the community is not borne by the biogas plant and the opportunity to replace expensive petroleum based heating fuel with an environmentally friendly and inexpensive heat source is appealing.

In Australia, the position is slightly different. The heat generated by the plant could be used to heat the digester or provide heat to pig breeder units. Pig grower units generally do not require significant quantities of heat. It is possible to use the heat generated by the biogas process to provide heat during the cool months and cooling during the warmer months through the tri-generation process, which uses absorption chillers. The Australian climate is significantly warmer than the mid to northern European climate and community heating schemes are not common in Australia and as a result, it is more difficult to establish a use or revenue source for the heat generated.

The electrical power generated by the biogas plant can be sold to the local grid or partially used to run the digestion process. In Europe, it is common for biogas plants to export electrical power to a local grid under a contractual agreement and receive fixed premium rates for the power generated. The contracts are typically established for long periods, often 10-20 years. A similar long-term contractually based system is not yet operating in Australia; price differential between renewable and non-renewable energy was established in 2001 with the renewable energy certificate scheme.

Electrical power that is generated in Australia from a renewable energy source such as wind, hydro or a biogas plant is sold onto the local grid at spot market rates, which vary significantly depending upon the time of day and retail demand. The renewable energy generator is also issued with renewable energy certificates (RECs) based upon quantities of power generated. The RECs are tradeable and attract a payment when surrendered to the governing body. The retail consumer can also choose to receive part or all of their electrical power from a renewable energy source, which attracts a premium price.

The feasibility to supply electrical power into a local grid must be investigated on a case-by-case basis as the local grid may require significant modifications to allow power injection to occur. The supply of power into the local network would require coordination with the local power company to insure power surges and power fluctuations are avoided.

4.4.2. Industrial or Municipal Anaerobic Digestion Systems

With these systems, the anaerobic digestion plant is located close to the food processing factory or municipal sewage works. The principle reason for the digestion plant is to reduce the organic load of the waste stream and recover energy and heat. Generally, the industrial plants are energy intensive and the energy produced is consumed within the plant. The municipal systems could use the heat energy produced, but potentially export the power to the local grid.

4.4.3. Centralised Anaerobic Digestion (CAD)

Waste streams from a variety of farms and processing plants are transported to a centrally located anaerobic digestion plant. The first CAD plant was established in Denmark and began operation in 1984. Prior to 1984, several farm-based plants were established in Denmark on an experimental basis. The majority of these have been shut down due to technical or economic problems (Hjort-Gregersen 1999). The number of CAD plants worldwide is approximately 50 and they are all located in Europe. There are 18 CAD plants in Denmark (California Energy Commission 2008).

The feedstocks to the CAD plants in Demark are normally mixed. The feed stocks are sourced from a range of locally available waste streams and can include cattle, pig and poultry manure, organic waste from meat processing, fish processing, dairy and tannery waste, medical and sewage waste (Hjort-Gregersen 1999).

Typically, the CAD plant has a larger feedstock capacity and energy production capacity than the farm-based plant. Demark continue to be the world leaders in energy generation from Centralised Anaerobic Digestion plants.

5. Feedstock to the Anaerobic Digester

5.1. Pig Waste Characterisation

In 2005-06 Australia had a pig herd of 2.7 million pigs or 301,000 sows (ABS 2006). The industry is highly dispersed throughout the grain growing areas of Australia (ABARE 2006). Figure 1 shows the numbers of pigs reported to the Australian Bureau of Statistics grouped into SLA areas (statistical local area). This data is provided by the Australian Bureau of Statistics (ABS 2006).

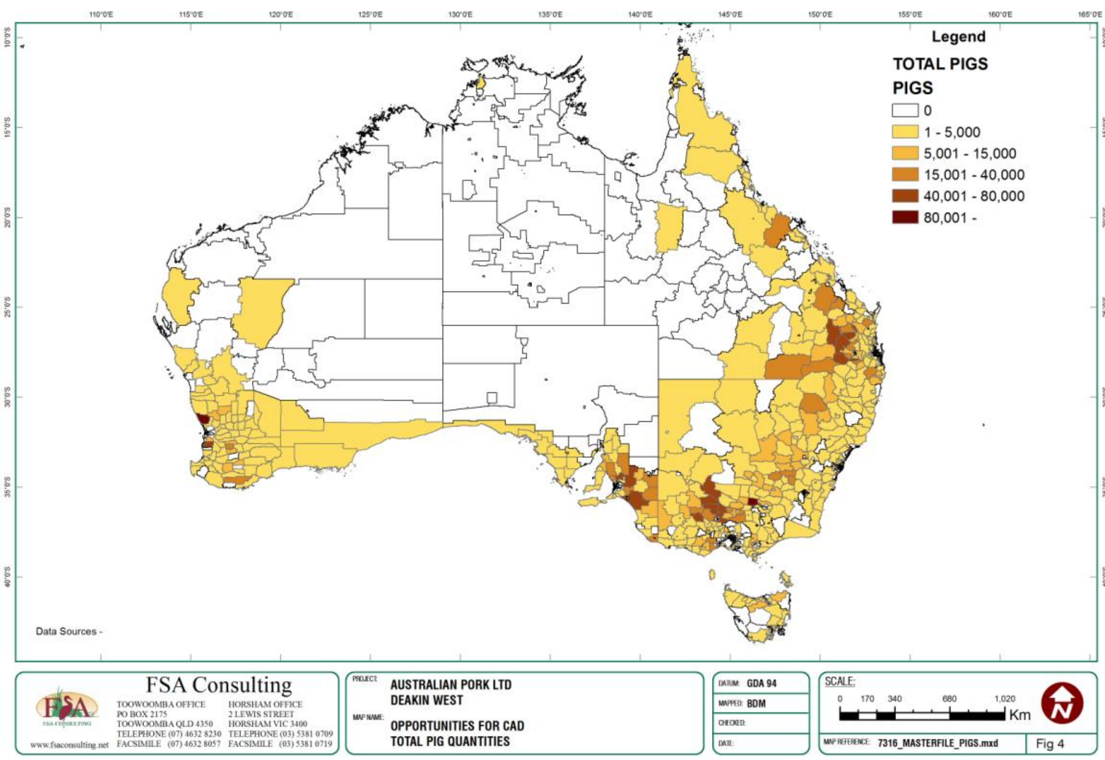

Figure 1: Location of piggeries by SLA (ABS 2006)

The data presented in Figure 1 shows a high concentration of pig numbers in South East Queensland and northern Victoria. There is also an apparent high concentration of pig numbers in the statistical local areas in South Australia however, the data in South Australia is unreliable and pig numbers are estimated in this state.

There are two main types of piggery operating systems; each produce very different waste streams. The two main types of piggery accommodation are described as:

1. Conventional flushing piggery

   The conventional flushing piggery typically house pigs within sheds. The shed flooring is usually partly or fully slatted and spilt feed and water, urine and faeces fall through the slats into the underfloor channels or pits. The channels are regularly flushed or drained to remove effluent from the sheds. The effluent is generally treated and stored in a pond system prior to irrigation on-farm or evaporation. The by-products of these systems are:

- Solids (e.g. screenings) that are removed from the effluent stream pre-treatment – these represent a relatively small mass of material and are not considered further here.
- Liquid effluent, which is generally treated and stored in a pond system prior to irrigation on-farm or evaporation.
- Sludge that represents settled solids that are removed from the pond system periodically (typically every 1-10 years).

Table **1** shows the typical characteristics of fresh manure from a piggery running 1000 grower pigs on a range of diets. This data has been generated using feed input diet and feed conversion calculations using PIGBAL.

Table 1: Characteristics of 1000 grower pigs waste stream

All data tonne/ 1000 grower pig/yr	Total Solids	Volatile Solids	Nitrogen	Phosphorus	Potassium
Barley/Lupin/Canola Meal	165	134	11.9	2.7	5.1
Sorghum/Barley Wheat/ Millrun/Canola Meal	148	120	12.6	4.0	3.3
Sorghum/Maize/Mung Beans/ Canola Meal	120	100	11.4	2.4	2.8
Sorghum/Soybean-Solvent/ Canola Meal	114	97	11.7	2.9	3.4
Sorghum/Wheat Diet/Soybean-Solvent	110	89	11.3	3.4	2.9

Source : Poad et al. (2010).

Effluent from conventional piggeries typically has a solids concentration between 0.5 and 2.0%.

2. Deep litter piggery

Deep litter piggeries typically accommodate pigs within a series of hooped metal frames covered in a waterproof fabric, similar to the plastic greenhouses used in horticulture. Pigs are bedded on straw, sawdust, rice hulls or similar loose material that absorbs manure, eliminating the need to use water for cleaning. The by-product of this system is used bedding that is generally removed and replaced when the batch of the pigs are removed, or on a regular basis. Table 2 shows the typical characteristics of spent bedding from a range of fresh bedding materials.

Table 2: Nutrient content of spent bedding from deep litter piggeries

	Unit	Straw	Rice Hulls	Sawdust
Moisture	% wb	41.6 (18 - 64)	36 (21 - 53)	40.8 (21 - 50)
pH		6.8 (5.7 - 8.5)	7.1 (7 - 7.3)	6.3 (6.2 - 6.3)
Total Nitrogen	% db	0.8 (0.2 - 1.3)	0.7 (0.1 - 1.6)	0.9 (0.6 - 1.3)
Ammonium Nitrogen	% db	0.5 (0 - 1.2)	0.3 (0.1 - 0.5)	0.6 (0.4 - 1)
Total Phosphorus	% db	1.1 (0.2 - 2.5)	0.9 (0.6 - 1.3)	1 (0.4 - 1.3)
Ortho-Phosphorus	% db	0.4 (0.2 - 0.6)	0.4 (0.3 - 0.6)	0.4 (0.2 - 0.5)
Potassium	% db	1.8 (0.6 - 2.8)	1.8 (1.2 - 2.1)	1.8 (1.6 - 1.9)
Sulphur	% db	0.4 (0.1 - 0.7)	0.4 (0.3 - 0.5)	0.5 (0.4 - 0.5)
Copper	% db	0 (0 - 0.1)	0 (0 - 0)	0 (0 - 0)
Iron	% db	1.3 (0.1 - 3.2)	1 (0.7 - 1.6)	1.1 (0.5 - 1.6)
Manganese	% db	0.1 (0 - 0.8)	0.2 (0 - 0.8)	0.3 (0 - 0.8)
Zinc	% db	0.2 (0 - 0.4)	0.1 (0 - 0.3)	0.1 (0.1 - 0.2)
Calcium	% db	1.9 (0.4 - 3.1)	1.4 (1 - 2.1)	2.4 (2.1 - 2.7)
Magnesium	% db	0.7 (0 - 1.8)	0.4 (0 - 0.6)	0.4 (0 - 0.7)
Sodium	% db	0.4 (0.1 - 0.7)	0.3 (0.1 - 0.4)	0.4 (0.4 - 0.5)
Chloride	% db	0.8 (0.3 - 1.3)	0.6 (0.4 - 0.8)	0.7 (0.4 - 1.1)
Conductivity	dS/m	11.7 (6.6 - 15.6)	9.6 (9.2 - 10)	13 (12.6 - 13.4)

Source: Black (2000); and Nicholas et al. (2006).

Notes: Data provided as average and range (in brackets).

Nutrient contents based on a combination of fresh, stockpiled and composted spent bedding

Fresh excreted pig manure is high in nitrogen. In the conventional flushing shed, it is estimated that up to 10% of the nitrogen is lost through volatilisation while in the deep litter system the volatilisation losses are expected to be 10-20%. Table 3 shows characteristics of piggery waste compared to cattle and poultry.

Table 3: Average characteristics of pig, cattle and poultry excrement

All data expressed as a percentage of total solids

Component	Grower Pigs	Cattle	Poultry
Volatile Solids (VS)	82	84	75
COD	133	140	135
BOD_5	35	20	35
Total Nitrogen	8.5	8.5	7.0
Ammonia Nitrogen	4.0	1.2	4.5
Phosphorus	2.8	1.2	2.0
Potassium	2.2	4.0	2.0
Volatile Fatty Acids	0.7	0.2	na

Source :Svoboda (2003)

The organic matter in the piggery streams comprises volatile solids (VS) and fixed solids (FS) or ash. The VS concentration is a measure of the potential for methane generation. Estimating the actual methane yield based upon volatile solids concentration is not necessarily accurate. This is due to the variation in the composition of volatile solids, which originates from the feed composition. Organic compounds such as lipids proteins and carbohydrates degrade readily. Some fibrous materials such as straw and wood that is found in deep litter are composed of lignin cellulose material and will not decompose readily.

Fibrous solids have a low biogas potential due to low rates of biodegradation. Chemical Oxygen Demand (COD) reduction is linked to methane generation. For every kg of COD destroyed there will be 0.35 m^3 of methane produced (Metcalf & Eddy Inc. 2003) at standard temperature and pressure conditions.

The reductions in COD for pig, cattle and poultry waste during anaerobic digestion have been reported by Hobson et al (1977) and cited by Svoboda (2003). The data was obtained from pilot plant trials and farm based anaerobic digesters and is shown in Table 4.

Table 4: Reduction in organic components of pig, cattle and poultry slurry from mesophilic anaerobic digestion

Parameter		Pig	Cattle	Poultry
Total Solids (TS)	%	40	30	60
BOD_5	%	75	55	80
COD	%	50	35	50
Volatile Fatty Acids	%	73	70	80

Source : Svoboda (2003).

One of the by products of anaerobic digestion is the remaining solid digestate. The remaining organic material is less likely to decompose and hence the digestate is more stable. The digestion process also has the effect of increasing the level of nutrients in the digestate. The digestate is normally in the form of slurry and can be directly transported to farm areas, for land spreading or thickened and sold as a soil conditioner.

Svoboda (2003) identified that the digestate can produce low level residual odour which originate from low concentrations of VFA's and hydrogen sulphide and cites a field study (Pain et al. 1984) where a five-fold reduction in odour concentration was measured from field application of raw pig slurry and anaerobically digested pig slurry.

5.2. Issues with Anaerobic Digestion of Pig Waste

5.2.1. pH and Volatile Fatty Acids

Conn (2007) reports the pH of pig manure typically ranges from 6.5–8.6 and low or high ph will result in changes in the chemical composition of the waste stream. The amount of VFA's and

ammonia that are volatilised from manure mainly depends on manure pH and concentrations of VFA's and ammonium nitrogen. As the pH is reduced the proportion of VFA's in the volatile form increases. At higher pH levels the ammonium nitrogen equilibrium moves towards to ammonia, which is more readily volatilised.
Volatile fatty acids found in pig manure include acetic, propionic, butyric, valeric and caproic acids. Acetic acid normally comprises 60-70% of the total VFA's and propionic acid 10%-20%. The remaining longer chain VFA's typically comprise 10-20%. Volatile fatty acids may be reduced by 93% and phenols and p-cresol virtually eliminated (Svoboda 2003).

In general, the optimum pH for anaerobic digestion is 6.5-7.5. The conversion rate of organic compounds to VFAs is faster than the conversion rate of VFAs to methane. At concentrations above 1000 mg/L VFAs can be toxic to methanogenic bacteria. Significant toxic problems are unlikely to occur if the digestion process is operated in the pH range 6.5-7.5 with VFA concentrations below 1000 mg/L (Svoboda 2003).

5.2.2. Ammonia Inhibition

Pig and poultry manure contain high levels of ammoniacal nitrogen. The ammoniacal nitrogen concentrations can reach levels of 2-6 g/L NH_4^+-N, and this can increase the pH level towards and over 8 (Svoboda 2003). At this pH, level free ammonia is released which has a strong impact on the final step of aceticlastic methanogenesis. Svoboda (2003) suggests that free ammonia levels should be maintained below 80 mg/L while ammonium ions can be tolerated up to 1500 mg/L as NH_4^+-N. Svoboda cites a study by van Velsen (1979) where stable operation was achieved by the bacteria acclimatising to ammonia nitrogen concentrations up to 8000 mg/L.

5.2.3. Solids Concentration

Waste streams from conventional sheds are typically in the range of 1-2% total solids concentration. This concentration range suits the direct supply to a covered anaerobic pond system.

An increase in solids concentration from 3-6% is required to supply the waste stream to a liquid mixed digester. Increased concentrations provide improvements in the digesters hydraulic capacity, but there is an upper limit of approximately 6-8% where pumping equipment cannot efficiently pump the slurry. Solids separation technology or dissolved air flotation is normally used to achieve the required solids concentrations.

5.2.4. Methane Inhibitors

Sulphides are produced during anaerobic digestion by the reduction of sulphates and degradation of proteins (Svoboda 2003). The metabolic activity of then methane producing bacteria will be strongly inhibited in soluble sulphides exceed 200 mg/L. The addition of a heavy metal such as iron will result in the formation of an insoluble precipitate, which effectively removes sulphide from the liquid stream.

Lignin found in spent deep litter will not decompose readily. Cellulose is resistant to degradation when bound in a tight complex (e.g. pine wood) or contained in biomass that contains methanogenic inhibitors (e.g. eucalyptus wood) (Chynoweth et al. 1998).

Mixed feedstocks, which contain easily degraded organic material (such as animal manure) and materials that are resistant to degradation (such as deep litter straw and sawdust) will result in partially digested litter material remaining in the digestate. Low levels of methane will be produced from the digestate as the remaining litter material decomposes.

5.2.5. Antibiotics and Feed Additives

Lallai (2002) has investigated the effects of commonly used antibiotics for the treatment of pigs on methane production from the anaerobic digestion of slurry. The antibiotics tested were amoxicillin trihydrate, oxytetrcycline hydrochloride and thiamphenicol. Different concentrations of each antibiotic were tested with pig manure slurry and anaerobic sludge to determine biogas production and methane concentration. Significant differences in methane production were found with the addition of thiamphenicol to the slurry at concentrations of 80 mg/L and 160 mg/L. Only minor differences in methane gas production were observed with amoxicillin addition and no difference was observed with oxytetrcycline addition.

5.2.6. Uneven Loading

Biological activity in anaerobic pond systems suffers from uneven loading of organic waste streams. Good conventional shed management practice involves shed flushing on alternate days to even out the quantities of organic waste streams entering to the pond.

Digester loading for a farm based system or a central anaerobic digestion system can be well controlled as the waste streams can be received in sumps and pumped into the digestion vessel. The larger systems that take mixed streams of manure waste and food waste and silage crops require careful control to ensure good mixing and consistent feedstock mixes.

6. Process Outputs

6.1. Biogas Yield

Biogas produced anaerobically is primarily composed of methane (CH_4) and carbon dioxide (CO_2). The gas may also contain smaller amounts hydrogen sulphide, ammonia and trace elements of hydrogen, nitrogen, carbon monoxide. The gas is usually saturated with water vapour and can also contain dust particles.

Table 5 shows the typical range of biogas components. The actual content of a particular component will depend upon the feedstock mix.

Table 5: Typical range of biogas components

Component	Content range[a]	Content range[b]
Methane	55 – 80%	63.2%
Carbon dioxide	15 – 45%	18.8%
Hydrogen Sulphide	0 – 5000 mg	
Ammonia	0 – 450 mg/m^3	
Humidity	Saturated	
Calorific Value	20 – 25 MJ/m^3	

Source: a) Navickas (2007).

b) Birchall (2009).

Note: Methane content ranged from 54% to 70.4%

Biogas is classed as a medium grade energy fuel. The calorific value of biogas is approximately 21.5 MJ/m^3, as compared to 36.1 MJ/m^3 for natural gas (Monnet 2003).

Biogas yield from anaerobic digestion of organic material is determined by the feedstock composition. Table 6 shows the wide range of biogas yields for different feedstocks. The reported yields for pig manure appear lower than expected and this is possibly due to the data originating from European systems, where pig manure is stored in pits over winter for approximately six months. There is no published Australian data, which can provide a reliable comparison at this stage. Table 6 shows the biogas yield from different feedstocks and provides volumetric biogas yield per tonne of wet biomass. The quantity of volatile solids in the wet biomass is not specified and this introduces a degree of uncertainty in the actual biogas yield from each biomass source but the intention of the data presented in this table is to show the range of biogas yields possible from different feedstocks. An additional column has been included in Table 6, which provides the maximum methane producing capacity of the manure from different species (B_o values). This data is sourced from the IPCC (2006) and is country specific but there is still potential variation possible from diet and species. The IPCC data presented for the Oceania region.

Table 6: Biogas yield from different feedstocks

Biomass	IEA Bioenergy[a] (m^3 biogas/ wet t biomass)	Bioplin Technology[b] (m^3 biogas/ t biomass)	B_o Maximum methane producing capacity[c] (m^3 CH4/kg VS)
Pig Manure	18	25	0.45
Fattening Cattle Manure	34	30	0.17
Dairy Manure	20	55	0.24
Poultry Manure	93	35	0.36-0.39
Distillery Waste	35 (Potato)	80	
Vegetable Processing	35		
Rape Seed Cake	612		
Canteen Waste (high fat)	90		
Canteen Waste (low fat)	44		
Fat	108 (flotation fat)	800 (used fats)	
Fatty Waste		400	
Vegetable Oil		350	
Sewage Waste		80	
Meadow Grass	98		
Maize Silage	190	200	
Grass Silage	183	110	
Milled Grain	597		
Corn Crop Mix (5.3% fibre)	391		
Total Plant Grain Silage	195		

Source: a) IEA Bioenergy 15th European Biomass Conference & Exhibition.
b) Navickas (2007).
c) IPCC (2006).

The production of methane from organic carbon in the feedstock depends upon the availability of carbon in the feedstock. The typical carbon to nitrogen (C:N) ratio for piggery waste ranges from 6:1–8:1. The ideal C:N ratio range for optimum anaerobic digestion is 16:1–25:1 (Zhu 2010). A lower C:N ratio can lead to ammonia accumulation and pH values exceeding 8.5, which is detrimental to the methanogenic bacteria (Monnet 2003).

Zhu (2010) suggests that increasing the C:N content of the piggery waste stream by the addition of waste streams with a high C:N ratio will increase the volume of biogas produced. It is suggested that it is also possible to increase the methane content of the biogas by the addition of certain feedstocks to the piggery waste stream, for example oat straw and corn stalks. An increase in both the volume of gas produced and methane content of the gas per tonne of feedstock results in an increased energy generation potential. This will have a significant impact on the economic viability of the plant. However, further research would be required to determine the biodegradability of potential additional organic materials available in Australia. Materials containing lignin are known to be more resistant to anaerobic degradation (such as sawdust and to a lesser extent straw) than animal manure.

Biogas can be used in a number of ways, including powering a conventional boiler to generate steam, powering a fleet of vehicles, disposal through a flare stack burner with no energy recovery or powering a gas engine or gas turbine for energy recovery in a cogeneration plant. Developments that are more recent include supplying biogas to a microturbine for the generation of small electrical and heat loads. Another recent technology is supplying biogas to a fuel cell where electricity is directly generated through an electrochemical process.

6.2. Cogeneration and CHP Plant

Cogeneration is also known as a combined heat and power (CHP) plant. Biogas is burnt with oxygen in a reciprocating gas engine to produce mechanical energy. A variety of reciprocating gas engines have been used, including spark ignition and compression ignition. The gas engine drives an alternator, which generates electrical energy. To enable heat recovery, the radiator on a standard engine is replaced with a heat exchanger. Additional heat can be recovered from the engine exhaust gas.

The conversion of biogas energy into electrical energy is approximately 30-35%. An additional 57% of biogas energy can be converted into heat energy if the gas engine is fitted with an efficient heat exchanger and heat from the flue gas is recovered (Navickas 2007). Approximately 8% of the energy contained in biogas is lost through system losses. The efficient conversion of the energy available in biogas will depend largely on the CHP plant design.

In the larger European biogas plants, the generated electricity is sold at a premium price and the generated heat is supplied to a local residential community scheme.

The CHP technology is well developed and there is a range of European suppliers with equipment to offer. The European equipment is also available in Australia. Some CHP plants do not run continuously and operate for 16–20 h/day. The generated electrical and heat energy can be directed back into the digestion process to replace or supplement the energy requirements to reduce the operating costs.

6.3. Digestate

Anaerobic digestion produces digestate, which is a mixture of liquid and solid residue. The quality of the digestate will vary according to the feedstock processed. As the organic material passes through the anaerobic digestion process, the digested material becomes stable, with the majority of the organic material decomposed. This will produce higher concentrations of nutrients.

The availability of the nutrients is higher in digestate than in untreated organic waste. The nutrients are mineralised to allow for improved plant uptake. Digestate has approximately 25% more available NH_4-N and a higher pH than untreated liquid manure (Danish Biogas Association 2010).

Digestate originating from agricultural manure may contain antibiotics, pesticide residues and metals, which originate from animal feed additives. The European Commission is in the process of establishing policy in a "Green Paper" which is expected to regulate the level of contaminates in composts and digestate.

6.4. Pathogen Treatment and Biosecurity

The operation of the digester at mesophilic temperatures is not regarded in Europe as providing enough sterilisation treatment to remove pathogens. The centralised AD plants include a pasteurisation stage in the process and this enables the safe distribution of digestate from the centralised plant to any of the feed stock supply farms, without the risk of spreading disease.

A Danish monitoring programme reports that maintaining a thermophilic processing temperature for 53.5°C for eight hours has the same effect as pasteurising the mixture at 70°C for one hour (Danish Biogas Association 2010).

6.5. Odour Mitigation

Digestate odour is significantly reduced compared to untreated liquid manure. The volatile fatty acids and mercaptans that are largely responsible for odour generation from animal manure are consumed during anaerobic digestion.

7. Anaerobic Digestion Plants in Australia

7.1. Renewable Energy Plants in Australia

Table 7 shows the current number and capacity of operating and proposed renewable energy plants in Australia,

Table 7: Renewable energy plants in Australia

State	Sites	Status	Electrical energy Capacity (kW)
Biomass and biogas	146 sites	Operating	867
Biomass and biogas	44 sites	Proposed	1,188
Total renewable	605 sites	Operating	11,460
Total renewable	294 sites	Proposed	17,276

Source : DEWHA (2009).

A proportion of the 867 MW of reported electrical energy capacity presented in Table 7 will be consumed on site hence there will be significant disagreement between what is generated nationally and what is injected into the national grid.

7.2. Anaerobic Digestion Plants in Australia

Table 8 shows a detailed survey of the Australian biogas installations and proposed projects, which produce energy from anaerobic digested feedstock.

Table 8: Australian biogas plants operating and proposed 2010

Company	State	Waste Stream Feedstock	Electrical energy Capacity (kW)	Installation Date
QAF Meat Industries - Corowa	NSW	Piggery waste	240	Proposed
AJ Bush & Sons	NSW	Abattoir	85	Proposed
Charles IFE Pty Ltd - Berrybank	VIC	Piggery waste	180	1990
Burrangong Meat Processors	NSW	Abattoir	600	Reopening
AJ Bush & Sons	QLD	Abattoir	1000	Developing
Rockdale Beef	NSW	Abattoir	920	Unknown
Westside Meat Works	VIC	Abattoir	100	Unknown
EarthPower Technologies	NSW	Food waste	3500	2003
McCain's Foods	VIC	Food waste	3000	Unknown
Werribee AGL	VIC	Sewage methane	10000	1996
Werribee Melbourne Water	VIC	Sewage methane	1300	1995
Werribee 2 Melbourne Water	VIC	Sewage methane	7000	1998
Diamond Energy - Shepparton	VIC	Sewage methane	1100	2007
Diamond Energy - Tatura	VIC	Sewage methane	1100	2009
Carrum Downs 1 & 2	VIC	Sewage methane	17000	1975
WA Water Woodman Point	WA	Sewage methane	1200	1998
Water Corp WA	WA	Sewage methane	1200	1999
Brisbane CC – Luggage Point	QLD	Sewage methane	3200	1979
Stanwell Corp - Townsville	QLD	Sewage methane	270	2000

Brisbane CC – Oxley Creek	QLD	Sewage methane	1030	2003
Gold Coast CC - Elanora	QLD	Sewage methane	230	2005
Veolia Water - Ti Tree	QLD	Biomass	2200	2008
Sydney Water – North Harbour	NSW	Sewage methane	1400	2008
Sydney Water – Malabar	NSW	Sewage methane	3000	1999
Sydney Water – Cronulla	NSW	Sewage methane	497	2001
Sydney Water – Bondi	NSW	Sewage methane	970	2008
Sydney Water – Glenfield	NSW	Sewage methane	400	2008
Sydney Water – Liverpool	NSW	Sewage methane	230	2008
Sydney Water – Warriewood	NSW	Sewage methane	150	2008
Sydney Water – Wollongong	NSW	Sewage methane	400	2008
Carbon Partners - Scencorp Group	VIC	Greenwaste and food waste	6800	Proposed
AnaeCo	WA	Municipal waste	Unknown	Demo plant in operation
Victorian Farmers Federation / Bio-cogen	VIC	Agricultural waste	2000	Proposed

Source: Geoscience Australia (2010).

The location of the existing and proposed biogas plants is Australia is shown in Figure 2.

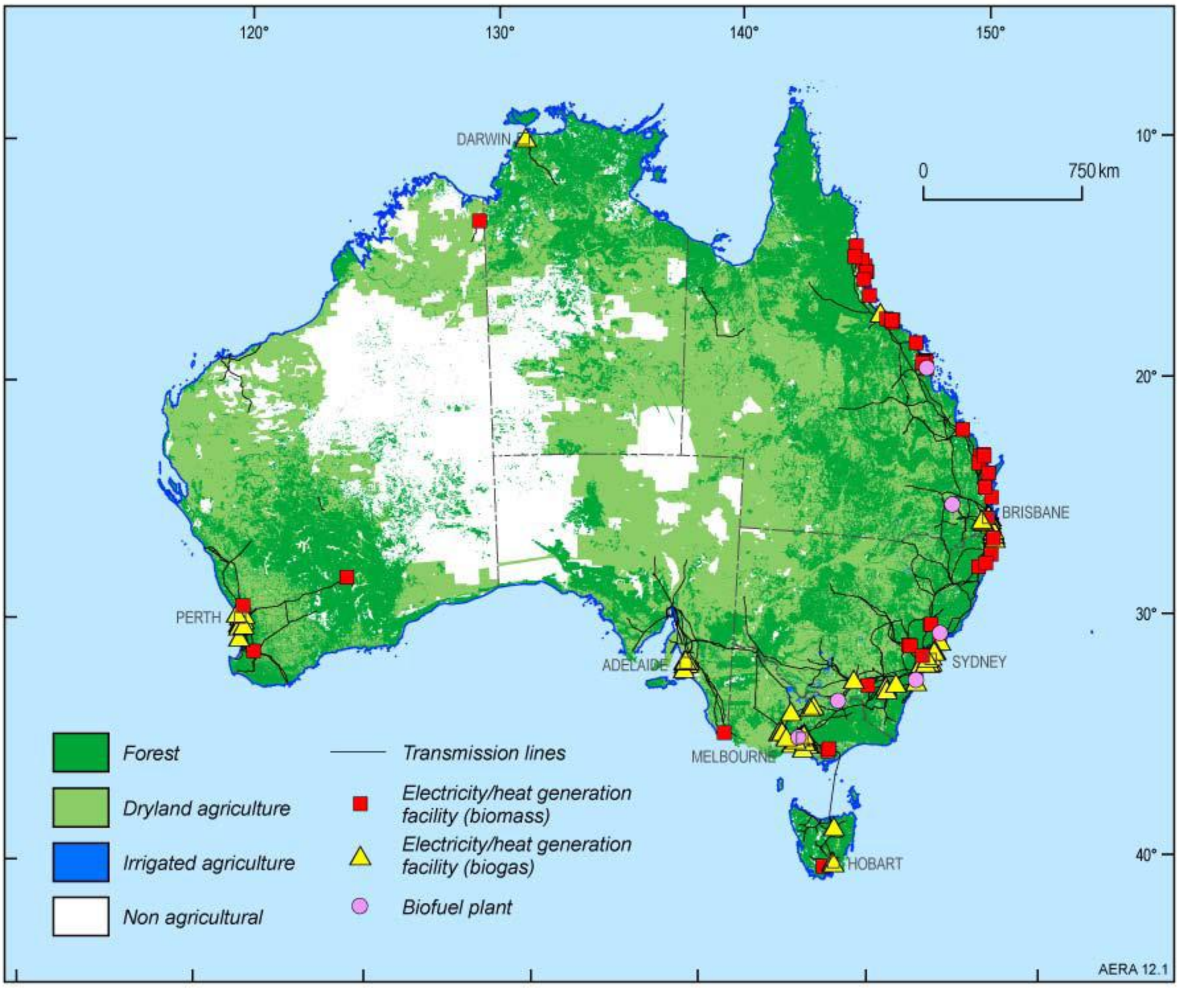

Figure 2: Location of Australian biogas plants 2010

Source: Geoscience Australia & ABARE (2009)

7.3. Case Studies of Australian Biogas Plants

7.3.1. Berrybank Farm

The first commercial scale anaerobic digestion plant in Australia for processing pig manure operates at Berrybank Farm, Victoria. At the time of the plant installation in 1991, the farm capacity was 14,730 SPU (standard pig unit) and the digestion system was designed to process all of the liquid manure.

The process system comprises automatic flushing valve collection, grit and bone meal removal, slurry thickening by dissolved air flotation to 4-5% consistency and then primary and secondary digestion. The first anaerobic stage is mesophilic, operating at 37°C and the second stage operates at ambient temperatures. The digestate is separated and thickened into 7 t/day of fertiliser, at a moisture content of 25%. Two streams of recycled water (100,000 L/day) and mineralised water (100,000 L/day) are produced, along with 1700 Nm^3 of biogas. The biogas is scrubbed to remove hydrogen sulphide and condensate and then supplied to the CHP energy production plant. The CHP plant generates 120 kW of electrical power for 16 hours per day and the heat produced is used to heat the primary digester. The generated electricity that is not used on the farm is sold to the local grid in Victoria.

An audit in 2001 by the Australian Centre for Cleaner Production and cited by Birchall (2009) reports the following information:

- The capital cost of the facility in 1991 was $2.3 million (equivalent to approximately $4 million in 2009).
- 320,000 L/day of liquid manure is processed at TS 1.6%.
- 7200 kg/day of digestate is produced at 25% solids, which are sold as a fertilizer.
- 1,700 Nm3/day of biogas is produced.
- 120 kW of electricity is produced.

The financial payback period is estimated to be six years based upon an annual saving of $425,000. The annual returns are $250,000 from the sale of digestate fertiliser, $125,000 from electricity savings on site and sales to the grid and $50,000 from water savings.

The digestion plant also improves the environmental performance by reductions in GHG emissions and reductions in odour from the sheds and anaerobic pond.

7.3.2. Bears Lagoon piggery

A 12 month study ending May 2009, was commissioned by the Rural Industries Research and Development Corporation (RIRDC) and conducted at Bears Lagoon piggery to document the performance of a covered anaerobic lagoon (Birchall 2009). The project collected monthly operating parameters and determined the methane yield. The Bears Lagoon Piggery is a commercial grow out operation and is located near Bendigo, Victoria. During the study, the pig capacity averaged 23,000 SPU. The piggery comprises a 14 shed nursery unit where 18-day-old pigs are grown to weaner and grower pigs. A separate 12 shed finishing unit houses the pigs from 17-24 weeks. All sheds have flushed drains with bore water used for drinking and flushing.

The separate piggery waste streams are combined in a collection sump equipped with an agitator, and then pumped to two run down screens. The run down screens were removed from the process, one month before the end of the trial. The total flow was measured daily from the sump. The screen liquid was then transferred to an 18 ML covered anaerobic pond, which overflows to a 9 ML aerated pond. Treated effluent is transferred from the aerated pond to a 120 ML winter storage pond.

As gas production commenced the anaerobic lagoon cover partially inflated and gas was supplied to a blower, gas flow meter and flare stack.

The results were collected over 12 months and showed that the anaerobic lagoon temperature was approximately 5°C warmer than the surroundings with a mean of 19.9°C in the lagoon discharge pit and 20.6°C at 3.5 m depth below the surface. There was a wide temperature range measured in the discharge pit from a summer peak (29°C) to a winter minimum (12°C). The temperature measurements at 3.5 m depth were within 1-2°C of the discharge pit temperatures.

The monitoring project reports a median hydraulic flow to the covered lagoon of 493,000 L/day. A review of the reported results suggests that the data could instead be interpreted as an average winter flowrate of approximately 400,000 L/day and a summer flowrate of approximately 700,000 kL/day (December to March). The increase in flow was reported to be due to pig cooling during the summer months.

Table 9 shows a summary of the characteristics of the unscreened effluent to the covered lagoon.

Table 9: Bears lagoon piggery characteristics of screened wastewater

Parameter	Units	Before digestion[a]	After digestion[a]	Reduction
Hydraulic flow	L/day	493,000		
Total solids	mg/L	12,220		
Volatile solids	mg/L	8,210	3,230	64%
COD total	mg/L	15,650	4,350	71%
VFA	mg/L	2,650		
VS/TS ratio		0.67		
COD/VS ratio		1.9		

Source : a) Birchall (2009).

For the last month of the monitoring program, the screening system was removed from the process and the volatile solids concentration increased from a mean level of 8,210 mg/L to 18,090 mg/L. Figures were not provided for the effect on COD during this period.

The mean biogas production rate was 3350 m^3/day and ranged from 2550 m^3/day in the winter months to 4030 m^3/day in the summer months. The report also notes that after the screens were removed the biogas production increased from 4370 m^3/day for June and to 5490 m^3/day in August when monitoring stopped.

The biogas composition was tested during the 12 months and the methane content ranged from 54-70.4% and was reported as an average 63.2%.

Table 10 shows the biogas yield is reported for the destruction of COD and VS.

Table 10: Specific methane yield for bears lagoon piggery (Birchall 2009)

Parameter	Methane Yield m^3/kg COD	Methane Yield kg/kg COD	Methane Yield m^3/kg VS	Methane Yield kg/kg VS
July minimum	0.20	0.14	0.37	0.25
December maximum	0.43	0.29	0.58	0.40
Mean	0.27	0.18	0.48	0.33

On a stoichiometric basis, the destruction of 1 kg of COD produces a maximum fixed quantity of methane. The maximum possible conversion rate is 0.35 m^3 of CH_4/kg of COD destroyed or 0.25 kg of CH_4/kg of COD destroyed. For this trial, the average methane yield was 0.18 kg of CH_4/kg of COD, which is 72% below the stoichiometric maximum. The December result at 0.29 kg of CH_4/kg of COD is above the maximum possible limit and Birchall (2009) suggests that the higher result is due in part to accumulation of organic material during the cooler months and conversion of the this material as the pond warms.

The destruction of VS in the pond was reported as 64% and the destruction of COD was reported as 71%.

The report estimates a methane energy yield of 71,400 MJ/day and reports an electrical generation capacity of 207 kW at energy conversion efficiencies of 25%. The estimated power available ranged from 160 kW to 250 kW over the season. The report does not mention the additional potential for heat generation from a modern CHP gas engine, which is estimated to be approximately 450 kW for this methane production rate.

The annual spot price for electricity in Victoria has ranged from an annual average price of 26.35 \$/MWh to 54.80 \$/MWh. In the period 2009-10 the average annual price was 36.96 \$/MWh or 0.036 \$/kWh (AEMO 2010). Based upon an average generation capacity of 207 kW and average spot price of 0.036 \$/kWhr, the estimated sales revenue is \$64,385 per annum. Timing the generation capacity during periods of high spot prices would clearly increase the returns.

7.3.3. Grantham Piggery

Payne (2009) reports on a visit to an existing anaerobic pond at Grantham Piggery which was selected to trial an impermeable pond cover for biogas collection. The piggery is a 700-sow breeder unit (1400 SPU) with underfloor static pits that are released weekly. The pits are refilled with recycled water from the secondary pond. The pond cover was made from 1.5 mm thick HDPE welded onto 500 mm diameter HDPE flotation pipes and covers 750 m^2 of the 1500 m^2 pond. The cover was sourced from Dunedin New Zealand and installed in February 2009.

The cost of the cover was \$134,700, which includes \$79,850 for materials, \$3,400 for freight to site and \$51,450 for fabrication and installation on site. The system includes a gas recovery and flaring system. In the future, the energy from the gas may be recovered to provide heat to the creep heating system at the piggery.

It was reported during the visit (August 2009) that the biogas generation was 65 m^3/day. This quantity is estimated to be about one third of other reported values in Australia however; the cover only covers a part of ponds surface area.

7.3.4. Westpork Piggery

Westpork piggery installed an impermeable pond cover on the first of a series of lined ponds in 2007. The gas recovery system began operation but problems arose during 2008 leading to total cover failure by the end of 2008. Further details cannot be released at this stage.

7.3.5. Parkville Piggery Proposal

A case study of Parkville Piggery provided estimates for covering existing anaerobic lagoons (GHD Pty Ltd 2008). The piggery has since closed. Cost estimates to cover the first anaerobic lagoon where based upon a piggery capacity of 1200 sows. The piggery included a solids screening system and supplied a TS load of 3880 kg/day to two anaerobic lagoons operating in parallel. At the time of the study (1998) it was estimated that the cost to cover the two lagoons was AUS$410,000, with a payback period of 11 years.

7.3.6. Diamond Energy and Goulburn Valley Water

An interesting project has been successfully implemented between Sustainability Victoria, which is a part of the Victorian Government, Goulburn Valley Water and Diamond Energy based in Melbourne. Goulburn Valley Water treats wastewater originating from residential and companies in the food processing industry. The CHP two plants have been installed and are located at Shepparton and Tatura, North Victoria.

To handle the increased load on the plant, Goulburn Water upgraded the water treatment process by installing covered lagoons, which operate as anaerobic digesters and produce biogas. After observing the stability of the operation for a few years, the decision was taken to find a use for the biogas produced.

Diamond Energy won a tender to provide a gas engine system, which operates for a limited time each day. Each site produces 1100 kW of electrical power and one of the specific advantages of this design is the lagoon covers are allowed to inflate with gas during the night enabling on site storage of gas. The electrical generation is timed to coincide with peak demand periods, where the electricity is sold at a higher price on the spot electricity market.

The gas is scrubbed to remove corrosive contaminants, pressurised, dried and supplied directly to the gas engine. Start up, operation and shut down of the gas engines is automatic with no on site operator required. Remote operation and control of the engines is also available from the Melbourne office.

Sustainability Victoria provided $800,000 funding support for the project as well as assistance to access the various government groups to enable the project to proceed. Diamond Energy own and operate the gas engines and rent the site from Goulburn Water.

The total project budget was $4.08 million. There is a gas supply agreement between Diamond energy and Goulburn Water and a network connection agreement with the distribution network service provider. There is a supply and most likely a maintenance agreement with the equipment contractor Energen Solutions who are based in Brisbane. The greenhouse gas offset is 12,150 tonnes CO_2 equivalent per year.

7.4. Electricity Cost and Green Power

The National Electricity Market (NEM) operates as a wholesale market for the supply of electricity to retailers and end users in Queensland, New South Wales, Australian Capital Territory, Victoria, South Australia and Tasmania since 2005 (AEMO 2009). The Australian Energy Market Operator (AEMO) was created by the Council of Australian Governments and established to manage the electricity and gas markets from July 2009. The AEMO is responsible to run the NEM, which includes amongst other items, the control of electricity supply, transmission, and load shedding.

Electricity is traded on a spot price market, which is complex and includes hedge contracts and allowances for supply and demand, physical limitation on interconnections, transmission losses and distribution losses. There is currently a spot price maximum limit called *The Market Cap Price*, which is $10,000/MWh up to 30 June 2010. There is also a minimum spot price called the Market Floor Price, which is currently set at $1000/MWh.

Table 11 shows an indication of the spot price market data including the spot price for each state, which is termed the Regional Reference Price (RRP) and daily peak RRP.

Table 11: Average daily electricity spot price for each state

Date 2010	NSW	QLD	SA	TAS	VIC
3 May	23.48	20.61	25.34	21.72	24.29
12 May	36.22	26.41	39.42	43.26	40.77
17 May	39.89	21.40	41.86	78.65	45.72

Source : AEMO (2010).

Currently the renewable energy generator can expect to receive income from the sale of electricity to the national grid through sales on the spot market and through income from RECs.

7.5. Biogas Regulations

The biogas plant is treated the same as an industrial gas installation and the installation of a biogas plant must comply with the local and state gas safety regulations. The Standards Association of Australia, the Australian Gas Association and the Australian LP Gas Association have set down standards such as AS5601-2004 (Standards Australia 2004) for gas installations and AS/NZ1596-

2008 (Standards Australia/Standards New Zealand 2008), which covers the storage and handling of low pressure gas.

Each state has developed their own set of gas safety regulations, which is based upon the national standards.

The designers of a proposed biogas plant will be required to meet the local regulations in order to achieve a compliance certificate.

8. Anaerobic Digestion Plants Overseas

8.1. World Wide Plant Summary

The estimated worldwide energy production from anaerobic digestion is approximately 5300-6000 MW. For centuries, small farm based digesters have been used in India and China and it is estimated that this accounts for 95% or 5000 MW of the world wide capacity (California Energy Commission 2008). The estimated energy production from bioenergy in Australia is 226 MW (Geoscience Australia & ABARE 2009).

Development of anaerobic digestion technology has been occurring in Europe for the last 40 years. The California Energy Commission (2008) reports that renewable energy generated from biogas in Europe in 2008 is approximately 307 MW although Scholwin (2006) reports that Germany alone generates 800 MW. The reported number of plants and capacity is variable and it is estimated that the combined generation capacity in Europe is currently closer to 1000 MW. Table 12 shows the breakdown of approximate energy capacity per country.

Table 12: Estimated European anaerobic digestion capacity

Country	Capacity	Plants	Type
Germany	800 MW[b]	+4000[c]	Farm based plants
Denmark	40 MW	60 farm 20 CAD	Mixed farm and CAD plants
Italy	30 MW	80	Farm based plants
Sweden	20 MW		
Austria	20 MW		
UK		16	Mixed farm and CAD plants

Source : California Energy Commission (2008),

b) Scholwin (2006).

c) Little (2009).

8.2. European Plants

8.2.1. German AD Plants

It is estimated that in Germany there are in excess of 3700 biogas plants (New Zealand Pork 2009) in operation with an installed electrical capacity of approximately 800 MW (Scholwin 2006).

A modern German biogas plant is farm based and a simplified, standardised design with access to a strong technical support network (New Zealand Pork 2009). The system typically comprises three or four large tanks from 1500-5000 m^3 and a combined control room and energy generation building. There is a small reception tank to receive liquid slurry waste. On some plants, there is also a solids conveyor to load crop waste into the digester. The type of digester is liquid mixed, with mixing agitators mounted inside the tank. On some plants, digested biomass is pumped to a digestate storage tank and biogas is stored above the digestate in the same tank. The biogas supplies a gas engine, which produces electrical energy and heat. The electricity is sold to the local grid and the heat is exported from the plant to supply the local community heating scheme.

Table 13 shows examples of recent German farm based biogas plants. The feedstock to each plant is mixed animal manure and agricultural crops.

Table 13: Examples of German Farm Based Biogas Plants

Plant	Feedstock per day	Electrical Capacity	Thermal Capacity	Year
Gut Borken	30 m^3 cattle slurry 15 t stable manure 12 t corn silage 3 t crops	684 kW	17 MWh	2006
Hohen Wangelin	120 m^3 cattle slurry 20 m^3 pig slurry 16 t corn silage	835 kW	22 MWh	2006
Tangeln	10 m^3 cattle slurry 4 t stable manure 12 t corn silage 8 t grass silage	500 kW	11 MWh	2008
Rosenburg	24t corn silage 9 t grain silage 5 t grass silage	715 kW	16 MWh	2008
Dornhaner	24t corn silage 6 t grain silage 20 m^3 pig slurry	625 kW	15.5 MWh	Not specified

Source : UTS Biogastechnik GmbH (2009).

In 2000, there were less than 1000 plants in Germany. Few of the biogas plants had combined heat and power generation equipment. Then the German Government changed the law allowing renewable energy sources access to the electricity grid at attractive long-term prices. The German Government has established a Renewable Energy Sources Act 2000 and 2004 which guarantees a premium price for electricity generated from renewable energy (AFBI 2010). The term of the guarantee is for 20 years.

The German plants are small and typically two or three farmers work together to grow feedstocks to supply the plant and operate the plant. The typical biogas plant cost is approximately €1.5 million (AUS$2.2 million) and the German government does not provide any funding towards the capital cost. However, with guaranteed revenue for 20 years the owners can easily source bank loans (Kram 2010).
Kram (2007) reports that a 2002 assessment of the potential for electrical generation from biogas determined that 136 million MWh of electricity could be generated from biogas and energy crops showed the most potential at 65.6 million MWh followed by manure at 26.8 million MWh and crop residue at 24.7 million MWh.

The majority of modern German farm based biogas plants incorporate the generation of heat and electricity. There are new developments where some digestion plants are removing carbon dioxide and then supplying into existing natural gas pipelines. This overcomes the problem of finding a demand for the large quantities of heat generated (Kram 2007).

Kram (2007) reports of an alternative approach where a large combined heat and electrical power (CHP) facility is being established near the sewage treatment facility at Braunshwiger Zietung. The CHP plant has 20 km of biogas pipeline, which is connected to small biogas producers. In this way, the plant provides heat to approximately 7000 homes.

In 2004, the German Government revised the Renewable Energy Sources Act 2000 and included provisions that set premiums for using agricultural products, which includes energy crops and manure. In 2004, German farmers were allowed to grow energy crops, which are predominantly corn, sunflowers, Sudan grass and sugar beets, on 15,000 ha of land. Each year since the restrictions on land area has been increased allowing 90,000 ha in 2005 and 189,000 ha in 2006. It is estimated that by 2030 approximately 4.5 million ha could be used to produce energy crops.

The basis for the strength and growth of the German biogas industry is the guaranteed power price that is established and maintained by the German Government.

8.2.2. Danish CAD Plants

There is a very good report of Centralised Biogas Plants in Denmark produced by the Danish Institute of Agricultural and Fisheries Economics (Hjort-Gregersen 1999). This section on Danish CAD plants is largely sourced from this document.

The first CAD plant was built in Denmark in 1984. The focus on the initial CAD plants was energy production. As the number of CAD plants increased, it became evident that the CAD concept addressed a number of environmental issues related to agriculture, waste recycling and greenhouse gas reduction.

The Danish Government began to provide support for the development of this technology in a number of ways including the provision of legislative framework, supporting research and development programmes, and providing financial support in the form of investment grants and subsidies.

In Denmark, concern was increasing over the potential loss of nutrients from manure spreading and the effects on the environment. In 1987 the "Fresh Water Action Plan" was implemented which restricted the application of manure and provided restrictions on the utilisation of nutrients from animal manure. This effectively forced the Danish farmer to find larger land areas to spread manure and establish a manure storage facility on farm for typically 6-9 months of annual farm waste produced.

Some Danish CAD plants provide onsite manure storage areas, which are rented to the farmer. CAD plants began operating a transportation fleet to collect the waste stream from the farm and unloaded the waste into the manure storage area at the CAD plant. The digestate produced by the CAD process is transported back to the farm in the same trucks and unloaded into storage tanks, which can be located adjacent to the field where the manure is to be spread.

Typically, the Danish CAD process involves digestion at temperatures where pathogen levels are reduced. To control the spread of disease between farms, an additional sterilisation step is normally incorporated in the CAD process to enable effect control of weed and pathogens.

The heat energy produced by the first Danish CAD plant was supplied to a nearby village and the electricity that was generated was sold to the local grid. This concept of energy utilisation has been implemented by most of the CAD plants built in Denmark.

Detailed information is available for 20 CAD plants including feedstock mix, gas production, gas yield to feedstock mix, investment costs and financing information. A summarised version of this information is presented for seven plants in Table 14 to show the mix of feedstocks to the plant and economic state of the plant at the end of 1998.

Table 14: Danish Biogas Plants

	Units	Thorso	Arhus	V.Hjermitslev	Ribe	Blabjerg	Lemvig	Snertinge
Constructed	year	1994	1995	1984	1990	1996	1992	1996
Digester Capacity	m^3	2900	7500	1500	4650	5000	7000	2800
Process Temp	m^3	Thermo	Mesophilic	Mesophilic	Thermo	Thermo	Thermo	Thermo
Cattle manure	m^3	29432	18413	7015	91164	58650	51031	9949
Pig manure	m^3	45232	103401	3595	24492	23703	67372	19055
Poultry manure	m^3	1138			917			
Other manure	m^3	15939	88		2347	7207	1075	
Intestinal Waste	m^3	10026	3045		19695		11673	116
Fat	m^3	4200	1030		11887	5689	6441	6210
Fodder	m^3	125	833				564	41
Fish waste	m^3	1561		5296	2515	7285	5012	25
Fruit & veg waste	m^3		49			26		1586
Brewery waste	m^3							2208
Dairy waste	m^3		5460		5851	2507	7917	
Sugar industry	m^3							
Bleaching earth	m^3		1322					
Tannery	m^3			340		4509		
Medical	m^3	2308	5247		3059			3118
Other industry	m^3		403		51	1051	256	

Sewage	m^3	5052				4306	5046	1501
Household	m^3		54					
BIOMASS TOTAL	m^3	115013	139345	16246	161978	114933	156387	43809
Biomass per day	m^3	315	382	45	444	315	428	120
Biogas produced	m^3/day	8989	10575	4088	13047	9041	14526	4641
Gas yield	m^3/m^3 material	29	28	92	29	29	34	39
Farm suppliers		75	45	5	79	58	80	14
Total Investment	1000 Dkr	29100	54200	12416	45250	41900	55200	47800
Investment grant	%	22	20	35	39	23	26	19
Loans	%	78	80	65	54.7	77	74	81
Own Capital	%	0	0	0	6.1	0	0	0
Sales	1998	6706	6863	2949	9534	7901	10892	5377
Operating costs	1998	4212	8723	2070	5680	4092	6539	3198
Current income	1998	2495	-1860	879	3855	3809	4353	2180
Breakeven income	1998	1800	3500	950	2600	3000	4200	2850
Economic Situation	1998	Balanced and improving	Unsatisfactory	Balanced	Acceptable	Acceptable	Acceptable	Unsatisfactory

Source : Centralised Biogas Plants – (Hjort-Gregersen 1999)

The data in Table 14 shows that the CAD plants all operate on mixed feedstocks. More recent information shows the Thorso plant processed 69% manure, 29.6% raw animal material and 1.4% sewage sludge (Pedersen 2009). This is a different feed stock mix than the original list of feed stocks presented in the 1999 data (Hjort-Gregersen 1999).

The biogas plants are continually adapting to the available feedstock available and in some cases the plants economic performance is reduced due to operational instability and waste scarcity (Hjort-Gregersen 1999).

The digestate is treated in a variety of ways depending upon plant location relative to farms and the original design concept of the plant. Some digested slurry is stored in tanks on the CAD plant site, while other slurry is stored in tanks near the farms. Some digestate tanks are stored on the farms near the fields where the slurry is to be spread. Some plants have slurry separation equipment to provide a liquid stream for disposal on farm and a solids stream for sale as a high value bio fertiliser. At the time of the 1999 report by Hjort-Gregersen, slurry separation was not occurring to any large degree, as the market for the solid form of the digestate had not developed.

Danish CAD plant ownership is arranged in a number of ways. As of 1999 there are nine CAD plants owned by farmers as a cooperative company, five plants are owned by a cooperative between farmers and the heat distribution company for the local community, three plants are owned and operated by municipalities, two plants are private foundations and one plant is a limited company (Hjort-Gregersen 1999).

Gate fees are charged by the biogas plant for waste streams received at the plant. The 1999 rates were DKK 50-100/m^3 of waste received at the plant. Based upon current conversion rates to Australian currency this is equivalent to AUS$10-$20/m^3.

Disposal of organic waste by landfill is no longer allowed in Denmark. Disposal of organic waste must be either recycling or by incineration which incurs a tax. Table 15 is sourced from the work produced by (Hjort-Gregersen 1999) and shows the relative costs for the different methods of allowable disposal in Denmark.

Table 15: Waste disposal costs in Denmark (1999)

	Incineration DKK per t	Composting DKK per t	CAD Biogas Plant DKK per m^3	CAD Biogas Plant $ AUS per m^3
Treatment Costs	200-300	300 - 400	50 - 60	10 – 12[a]
Waste tax for disposal by combined heat and power plant	210	-	-	-
Waste tax for disposal by heat plant	260	-	-	-

Source : Centralised Biogas Plants – (Hjort-Gregersen 1999)

a) Conversion to Australian dollars based upon current exchange rate.

This table shows that there are significant savings to be made by supplying industrial or food processing waste to a biogas plant when compared to composting or incineration.

8.2.3. Other European plants

8.2.3.1. Rokai Pig Farm AD Plant Lithuania

A demonstration biogas plant was established in 2006 at Rokai Pig Farm, Kaunas Lithuania (Folkecenter for Renewable Energy 2006). The joint project was funded by the Danish Folkcenter for Renewable Energy (88%) and the AB VYCIA Farming Group (12%). The plant capacity is scaled to the quantity of resource available from the farm. The farm operates 11,000 pigs and produces 60 m^3 of manure per day. The plant has been set up with three horizontal digesters each with a capacity 300 m^3. The manure is mixed in a 30 m^3 tank and pumped into the digester at two hourly intervals. Digestate is displaced from the other end of the digester. The process operates at between 35 – 50°C. There is a 60 m^3 gas storage tank on site and a 300 kW gas burner and 300 kW oil/gas burner.

Electricity production is 700,000 kWhr/yr based upon an 80% time of cogeneration. Heat production is 1,600,000 kWh/yr based upon 80% cogeneration time and 20% of time covered by oil/gas burner. The electrical consumption of the pig farm is 3,700,000 kWh/yr of which 2,300,000 kWh is for farm heating.

8.2.3.2. AD in the UK

A recent review was completed in the United Kingdom concerning the establishment of anaerobic digestion in the UK and prospects for the future (Lukehurst 2007). Several of the comments from this review have been sourced for this section of the report.

From 1975 to 1998 there were 53 small anaerobic installations undertaken. In 2002, the Holsworthy Biogas plant was completed. Between 2003 and 2006, there were a further 15 installations mainly on farm digestion plants and municipal sewage plants. In 2007, there were four plants in planning stage.

The focus of the plant installations up to 1982 was on energy recovery due to escalating oil prices. The second period of strong interest occurred in 1995 relating to manure handling, slurry spreading and the associated odour problems. At this time, a 50% grant was made available for the cost of installing a digester. The grant was available from the Farm Waste Management Scheme. There were public protests in the area of North Cornwall and this to some extent lead to the Holsworthy Biogas Plant.

Since 2003, there has been a new surge in the installation of farm-scale biogas plants to process cattle slurry and more recently the large centralised biogas plants in England. Similar activity is occurring in Scotland, Ireland and Wales. The Scottish Executive has funded seven farm-based digesters in Northern Island. A fund of £15.2 million (AUD$25 million) has been made available for demonstration plants. In May 2007 the Welsh Assembly announced a 30% capital fund for the establishment of demonstration AD plants.

The review states that the main drivers for this increased level of activity are the Landfill Directive and the Animal By-Products Regulations. These regulations stipulate reduced targets for landfill disposal and costs if the targets are not met. There is a Landfill Allowance Trading Scheme (LATS) where the allowances can be traded between different authorities. The cost of landfill disposal is steadily increasing with the implementation of a landfill tax. The review claims that in addition to these measures the overriding incentive is the government's position to reduce carbon emissions by 60% by 2050. Table 16 shows a summary of the large-scale anaerobic digestion plants in the United Kingdom.

Table 16: Summary of large scale AD plants in the UK

	Digestion Temperature	Feedstock	Status
Holsworthy	Mesophilic	Cattle, pig and poultry manure, organic food waste.	Operational large scale
Leicester	Mesophilic	Biodegradable municipal waste	Operational large scale
Scottish Executive	Mesophilic	Sheep and cattle manure slurry	7 operational plants – small scale
Silver Hill Duck Farm Ireland	Mesophilic	Duck slurry	Operational large scale
Ludlow	Mesophilic	Biodegradable municipal waste	Under development
Ballytobin, Ireland	Mesophilic	Animal slurry, food processing waste	Operational small scale
Western Isles Scotland	Mesophilic	Biodegradable municipal waste	Under construction
Five Mile Town Northern Ireland	Mesophilic	Animal slurry, dairy waste	Planning preparation
Isle of Bute	Mesophilic	Animal slurry, dairy waste	Feasibility study
Westray	Mesophilic	Animal slurry, fish waste	Feasibility study
Isle of Mull	Mesophilic	Animal slurry	Feasibility study

Source: UK Anaerobic digestion plants www.anaerobic-digestion.com/html/ad_plants_in_the_uk.html

A Lancashire based company, Farmgen, has recently announced the purchase of Dryholme Farm in Cumbria with the intention of establishing an anaerobic digestion plant to produce 1 MW of power. The electricity produced will be sold into the grid.

The Dryholme Farm plant will process animal slurry and grass silage sourced from local farms. The plant is at the planning stage but is expected to be of a similar cost and scale to Farmgen's

Lancashire project at Carr Farm near Warton. The project costs are expected to be £2.5 million (The Bioenergy News Desk 2010).

8.2.3.3. Holsworthy CAD Biogas Plant UK

This was the first large scale UK based CAD plant. The Holsworthy Biogas Plant was built by a German company, (Farmatic Biotech Energy Ag) and opened in 2001. The plant was designed to accept a mixed feed stock comprising 146,000 tonne of cattle, pig and poultry manure and approximately 20% organic food waste (Farmatic Biotech Energy UK Ltd 2002).

The manure and food waste are unloaded into a reception pit and mixed. The mixture is then pasteurised for one hour at 70°C. The pasteurisation process kills all seeds, pathogens and viruses, including foot and mouth and tuberculosis (Farmatic Biotech Energy UK Ltd 2002). After pasteurisation, the mixture is pumped to one of two digesters. The digestate is returned to the supplying farms as a biofertiliser. The plant operates the transportation of the bio-fertiliser and animal manure to and from the plant. Gate fees are collected during the delivery of the food waste stream to the plant.

Biogas is produced and powers two gas engines to generate electricity and heat. The electricity produced is sold at a guaranteed contract price for 15 years. The contract price is index linked to move according to the retail price index. It is unclear whether the plant actually exports heat as anticipated.

The Holsworthy Biogas plant received a £3.85 million (AUS$6.3 million) contribution toward the overall project cost of £7.7 million (AUS$12.7 million) to build the plant. The income for the plant is from electricity sales and gate fees for food waste. The waste stream to the plant is collected at the plants cost and the farmers collect the digestate free of charge.

The plant changed ownership in 2003 and was operated for two years before going into financial administration in 2005. The new owners have invested £2.5 million (AUS$4.1 million) at the site to improve operational efficiency and mitigate environmental impact in particular odour. One of the operational problems was the impact of the cattle slurry, which contains straw. The straw content effects the operation of the digestion plant.

During 2007, the company owners were attempting to modify the plant planning permissions to improve the plant performance.

8.3. North American Plants

The number of anaerobic digesters in the USA are reported which process animal manures is 151 which includes 22 digestion plants for pig manure (U.S. EPA 2010). Table 17 shows the details for the pig manure digesters.

Table 17: Anaerobic digesters processing pig manure in the United States

Farm	Year On line	Digester Type	Installed Capacity (kW)	Methane Emission Reductions (tons CH_4/yr)
Apex Pork	1998	Covered Lagoon	40	119
Barham Farms	1997	Covered Lagoon		74
Black Farms	2008	Covered Lagoon		222
Boland Farm	1998	Covered Lagoon		104
Butler Farms	2008	Covered Lagoon		306
Christensen Hog Farm	2008	Covered Lagoon		182
Circle Four Farms	2005	Covered Lagoon		5,971
Danny Kluthe Farm	2005	Complete Mix	80	106
David High	1998	Vertical Plug Flow	22	15
Geerlings Hillside Farms Overisel Hog Facility	2008	Complete Mix	130	175
Martin Farms	1994	Covered Lagoon	25	55
Murphy Brown LLC - Kenansville Farm #2539	2008	Partial Cover Lagoon		78
Pine Hurst Acres	2004	Complete Mix	47	55
Piney Woods School	1998	Covered Lagoon	5	5
Premium Standard - Valley View Farm (Crystal Peak)	2006	Covered Lagoon		3,922
Premium Standard 1	2002	Unknown	2,000	4,130
Premium Standard 2	2002	Unknown	160	382
Rocky Knoll Swine Farm	1985	Horizontal Plug Flow	130	35
Seaboard Foods Wakefield Farm	2002	Permeable Cover Lagoon		241
Vestal Farm	2003	Covered Lagoon	30	362
Wyoming Premium Farms 1	2003	Complete Mix	80	27
Wyoming Premium	2004	Complete Mix	160	190

Farms 2

Source : U.S. EPA (2010).

A record of the current 124 anaerobic digestion systems processing dairy manure is shown in Appendix 1. The complete mix digester is also known as the continuous stirred tank reactor (CSTR) and is popular in Europe, especially in the German farm based systems. The mixed plug flow digesters shown in Appendix 1 have the higher energy generation capacity. The plug flow reactors are reported to work well with scrape systems and have a good track record with dairy manure although the system requires high solids manure from 11-14% and is not compatible with sand bedding (Burns 2004).

The United States Department of Agriculture (USDA) operates a funding program for research into renewable energy developments as well as a Rural Development grants program for development and funding of renewable energy projects. Many of the anaerobic digestion systems installed in the United States have received partial funding (U.S. EPA 2010). In 2008 under George Bush, the USDA launched the Green Information Technology Strategic Plan, which outlines GHG reduction targets and commitments to achieving those targets. There are state funded programs such as the 'focus on energy program' which have provided incentives to install 22 new biogas plants for dairy manure in Wisconsin (Little 2009). With the change of president, a new approach is under way to reduce dependence on foreign oil imports and support renewable energy projects.

Little (2009) provides an insightful summary of the North American position, "While much progression is being made, it is unlikely that North America will see the same kind of exponential growth that occurred in Germany between 2002 and 2007, when the number of anaerobic digesters increased from approximately 200 to more than 4000. For starters, North America is unlikely to see prices for biogas reach the feed-in tariff levels of Germany, which reached as high as €0.21/kWh (C$0.342) and made the development of smaller-scale biogas plants (less than 500 kW) financially viable. It appears instead that North America is following Denmark's growth model, where a feed-in tariff rate of DKK 0.745 (C$0.163) has prompted developers to build larger, multi-party biogas plants and to use by-products and manure as substrates, rather than purchase commodities such as corn, as is economical in the German market. This is beneficial as it provides the impetus to find better uses for the millions of tonnes of organic by-products that go to waste across the continent every year. Either way, the North American biogas industry is in the luxury position of being able to look across the pond and draw lessons from an already-mature industry. "The history of agricultural biogas is the history of much too many mistakes being made and repeated," said Jens Bo Holm-Nielsen, one of the world's leading minds in the field of biogas from the University of Denmark. "Now we are getting a golden chance to adjust and get it right.""

Recent information regarding the current state of the biogas industry is fragmented. In 2007, the Canadian Biogas industry is estimated to be more than 86 plants, which include biogas generated from landfill, and municipal waste treatment and the pulp and paper. It is reported that more than 10 farm based biogas plants were in operation (Barclay 2007).

Ontario has seen the most development and the other states look towards the Ontario model to try and achieve more progress in biogas development (Barclay 2007). The Ontario Power Authority introduced a feed in tariff (FIT) program in 2009, which is intended to stimulate the development of renewable energy projects. For Biogas plants, the position is still unclear as the FIT rates are set for each generator type and biogas is towards the lower end of the rates.

The Ontario Biogas Systems Financial Assistance Program (OBSFA) provides for up to 70% funding or a $35,000 limit for feasibility, design and planning studies of a biogas plant. If the project proceeds then the OBSFA provides up to 40% or up to a limit of $400,000 (Canadian) for each biogas plant for construction, implementation and commissioning of each biogas plant (Ontario MAAF 2010).

9. New Technologies and Developments in Energy Production

9.1. Fuel Cells

The fuel cell generates DC power by directly combining biogas and oxygen from the air. In an electrochemical reaction, unlike the gas engine, there is no conversion of the energy available in the biogas to mechanical energy and heat. The by-products of the fuel cell are carbon dioxide and water. The conversion efficiency is expected to be 50% (Monnet 2003). A number of fuel cell plants are operating in Japan and the USA and achieve an energy conversion efficiency of 41%. The technology is however very expensive.

9.2. Microturbines

Methane gas generated from anaerobic digestion and utilised for heating can be used at any scale. Classically, gas for power generation is most effective at >500 kW. However, emergence of newer cogeneration engines and microturbines has allowed effective scaling down to 100 kW. Micro turbines are available which can operate over a range of loads for extended periods and provide flexibility and can provide better fuel efficiency than the traditional technologies.

9.3. Gas Upgrading by Carbon Dioxide Removal

To make biogas a viable proposition for vehicle fuel the methane content must be increased. There are a range of technologies available to achieve this including wet scrubbing, glycol absorption, carbon molecular sieves and membrane separation (IEA Biology 1999). There are now processes available such as the Guild Process which compresses the gas and removes water, carbon dioxide and hydrogen sulphide and to enable the farmer to sell the enriched gas into a natural gas reticulation system (Guild Associates 2010).

9.4. Pre-Treatment of Waste Stream

New technologies such as ultrasonic, chemical and biological treatments are available for the treatment of waste streams that are more resistant to digestion.

Ultrasonic pre-treatment of the organic material in the manure stream promotes the degradation of the more difficult to hydrolyse compounds and increases the methane gas yields. Wu-Hann (2009) demonstrated an increase of 56% average methane yield from swine manure slurry for 30 seconds. This type of technology may be applied to the digestion of difficult to decompose waste streams such as spent deep litter.

Carrere (2009) showed a 64% increases in methane production by heating the pig manure slurry to 190°C and in a separate experiment reports an increase of 78% by a combination of raising the pH to10 through the addition of sodium hydroxide and increasing the temperature to 190°C.

10. Conclusions

The processing of farm manure and production of bioenergy has been practised for decades. Commercial scale biogas production emerged in Northern Europe initially to develop an alternative energy source to fuel oil. As the first biogas plants began to operate and a better understanding of the biogas process was achieved, other advantages in using this technology emerged. These advantages include methods of recycling manure waste, improved environmental performance through nutrient recovery, reductions in odour emissions from raw manure spreading, heat recovery and improved GHG performance.

The economic balance of the biogas plant is tenuous and to achieve a long-term positive outcome the plant must have all revenue streams in place. In the majority of cases, a financial grant ranging from 20-40% of the capital cost has been provided through government assistance programs to reduce the financial burden of debt servicing. Even with this level of assistance, there are still cases of some plants struggling to achieve a positive cash flow.

The German biogas industry is the world leader with by far the highest number of installed plants and the highest number of anticipated new installations. The success of the German biogas industry is largely due to guaranteed long-term power prices for renewable energy and simple plant design with good technical support.

The Danish biogas industry developed the most large-scale centralised biogas plants through the 1990s, but there has been little development since.

In Europe, the key driver behind the biogas development is establishing an alternative renewable energy source to fuel oil.

Having observed the progress in Europe, the United Kingdom and North America are developing their respective biogas industries with mainly farm based systems and a small number of larger centralised plants. The Government from each country provides some form of support to develop the local biogas industry through a variety of funding schemes and legislation.

Government commitments have been to achieve GHG emission targets and this has focused interest in increasing renewable energy production. Biogas generation plays a part in this but it appears to be behind wind and hydro schemes as the more favoured choices.

The biogas industry in Australia has developed in a similar way to the countries outside Europe. Landfill gas and biogas from sewage plants are developed first then digestion of manure waste and mixed wastes follows.

The conditions in Australia are almost completely the opposite of the conditions in Northern Europe. Australia has a low population density and large land mass and warm to hot climate. To establish a large centralised digestion plant in Australia that is economically successful will be challenging. The long distances between significant sources of organic waste will result in high transport costs to and from the plant. To be economic the plant would also have to have a demand for the heat generated that either offsets costs or provides a sales return. Community heating schemes, which are a convenient heat demand for the European biogas plants do not exist in Australia. Apart from the spot price electricity market and RECs system, there is no incentive to sell electricity that is generated from a renewable energy source on the Australian market.

The German farm based system may be a better option to match the Australian conditions. For a farm scaled design, the transport costs can be eliminated and potentially the heat generated could be used on farm to provide heat to a pig-breeding unit in a similar way to the anaerobic digestion system at Berrybank farm.

For the smaller farm the costs of installing a farm based tank digestion system is likely to be prohibitive. The covered anaerobic lagoon with gas flaring or energy recovery is a more practical option.

For any of the options considered the economic viability will only be achieved if all of the potential sales returns actually generate an income or significantly offset costs. This includes the sale of digestate, and heat and electrical power. The economic feasibility of establishing a biogas industry in Australia will be improved through increased levels of Government support and attractive renewable energy power pricing to the generator.

11. Implications & Recommendations

Further research is recommended to quantify the costs and benefits of establishing a covered pond digestion system with flaring and with energy recovery for the small and medium sized piggeries. This should include the cost of covering the existing pond and providing a new smaller covered pond with higher solids loading.

Further research is recommended to quantify the costs and benefits for a farm-based system using the German model to determine the economic lower limit and potential for receiving mixed waste streams, which can be locally sourced.

Investigation of the feasibility of the larger centralised plant should be completed and based upon selecting an area with high pig animal density to determine if the economics associated with transport and digestate sales are likely to provide a viable revenue stream along with electricity and heat sales.

12. Intellectual Property

This information has been sourced from the public domain.

13. Technical Summary

Anaerobic digestion of animal manure and organic waste is well established overseas but is still developing in Australia. The Australian biogas plants installed so far predominately operate on gas produced from sewage waste, food and abattoir waste. Berrybank pig farm in Victoria is perhaps the best-known local example of a successful anaerobic digestion based farm. The biogas industry is well developed in Europe and is developing in the United Kingdom and North America. This project reviews the international developments and investigates the feasibility of applying the process in Australia.

Commercial scale anaerobic digestion started in Northern Europe in 1984 and developed in two directions over the next decade. In Denmark, the move was towards large centralised anaerobic digestion plants where the manure is transported from up to 80 farms to the plant and the digestate is returned back to the farm or sold. Electricity that is generated in the plant is sold to the local grid and generated heat is normally sold to local community heating schemes. As the first Danish biogas plants began to operate and a better understanding of the biogas process was achieved, other advantages in using this technology emerged. These advantages include methods of recycling manure waste, improved environmental performance through nutrient recovery, reductions in odour emissions from raw manure spreading, heat recovery and improved GHG performance.

In Germany, the system design is much smaller and is suited to the waste produced from one farm or several local farms. The German biogas industry is significantly larger than any other country and is growing at a faster rate. The German Government has introduced legislation, which guarantees power pricing from renewable energy sources and provides a reliable income for the 20-year term of the contract. Significant areas of land are made available to grow energy crops, which are supplied to the biogas plants specifically to produce electricity. Finding a way to use the heat generated from the biogas plants is always a challenge to convert it into a revenue stream. Some of the new German biogas projects are looking at novel ways of using the biogas by purifying it with carbon dioxide removal and injection into the local gas network or transporting biogas produced from a collection of biogas plants over 20 km to a centralised power generation plant that supplies heat to the adjacent community.

The Biogas industry in North America and the United Kingdom is developing but the progress to date is slower than Europe and the level of Government support is significantly less than some European nations.

The economic balance of the biogas plant is tenuous and to achieve a long-term positive outcome, the plant must have all revenue streams in place. In the majority of cases in Europe and North America, a financial grant ranging from 20-40% of the capital cost has been provided thorough Government assistance programs to reduce the financial burden of debt servicing. Even with this level of assistance, there are still cases of some plants struggling to achieve a positive cash flow.

The Danish biogas industry developed first and now has the largest scale centralised biogas plants, but there has been little development since the1990s.

The German biogas industry is the world leader with by far the highest number of installed plants and the highest number of anticipated new installations. The success of the German biogas industry is largely due to guaranteed long-term power prices for renewable energy and simple plant design with good technical support.

In Europe, the key driver behind the biogas development is establishing an alternative renewable energy source to fuel oil.

Having observed the progress in Europe, the United Kingdom and North America are developing their respective biogas industries with mainly farm based systems and a small number of larger centralised plants. The Government from each country provides some form of support to develop the local biogas industry through a variety of funding schemes and legislation.

Government commitments have been designed to achieve GHG emission targets and this has focused interest in increasing renewable energy production. Biogas generation plays a part in this, but it appears to be behind wind and hydro schemes as the more favoured choices.

The biogas industry in Australia has developed in a similar way to the countries outside Europe. Landfill gas and biogas from sewage plants are developed first; digestion of manure waste and mixed wastes follows.

The conditions in Australia are almost completely the opposite of the conditions in Northern Europe. Australia has a low population density and large land mass and warm to hot climate. To establish a centralised digestion plant in Australia that is economically successful will be challenging. The long distances between significant sources of organic waste will result in high transport costs to and from the plant. To be economic the plant would also have to have a demand for the heat generated that either offsets costs or provides a sales return. Community heating schemes, which are a convenient heat demand for the European biogas plants do not exist in Australia. Apart from the spot price electricity market and RECs system, there is no incentive to sell electricity that is generated from a renewable energy source on the Australian market.

The German farm based system may be a better option to match the Australian conditions. For farm scaled systems the transport costs can be eliminated and potentially the heat generated could be used on farm to provide heat to a pig-breeding unit in a similar way to the anaerobic digestion system at Berrybank piggery.

For the smaller farm the costs of installing a farm based tank digestion system is likely to be prohibitive. The covered anaerobic lagoon with gas flaring or energy recovery is a more practical option.

For any of the options considered, the economic viability will only be achieved if all of the potential sales returns actually generate an income or significantly offset costs. This includes the sale of digestate and electrical power and use of heat and electrical power on site. The economic feasibility of establishing a biogas industry in Australia will be improved through increased levels of Government support and attractive renewable energy power pricing to the generator.

Further research is recommended to quantify the costs and benefits of establishing a covered pond digestion system with flaring and with energy recovery for the small and medium sized piggery. This should include the cost of covering the existing pond and providing a new smaller covered pond with higher solids loading.

Further research is recommended to quantify the costs and benefits for a farm based system using the German model to determine the economic lower limit and potential for receiving mixed waste streams which can be locally sourced.

Investigation of the feasibility of the larger centralised plant should be completed and based upon selecting an area with high pig animal density to determine if the economics associated with transport and digestate sales are likely to provide a viable revenue stream along with electricity and heat sales.

14. References

ABS 2006, *Agricultural Census* Cat. No. 7125.0 - Agricultural commodities: Small area data Australia 2005-2006, Australian Bureau of Statistics, Canberra, < http://www.abs.gov.au >.

AEMO 2009, *An introduction to Australia's national electricity market*, Australian Energy Market Operator Limited, < http://www.aemo.com.au/corporate/0000-0145.pdf >.

AEMO 2010, *Average market price*, Australian Energy Market Operator, viewed 18 May 2010, < http://www.aemo.com.au/data/avg_price/averageprice_main.shtml >.

AFBI 2010, *Anaerobic digestion plants for agriculture*, Agri-Food and Bioscience Institute, viewed 25 March 2010, < http://www.afbini.gov.uk/index/services/services-specialist-advice/renewable-energy/re-anaerobic-digestion-intro/re-anaerobic-digestion-plants.htm >.

Barclay, J 2007, *Biogas in Canada*, Report to IEA Bioenergy Task 37, November 2007, Lille, France.

Batstone, DJ 2006, *Sunshine Coast regional biosolids feasibility study : Final Report*, Advanced Wastewater Management Centre, The University of Queensland.

Batstone, DJ, Keller, M, Angelidaki, I, Kalyuzhnyi, SV, Pavlostathis, SG & Rozzi, A 2002, *Anaerobic digestion model No. 1 (ADM1)*, IWA Taskgroup for Mathematical Modelling of Anaerobic Digestion Processes, IWA Publishing, London.

Birchall, S 2009, *Biogas production by covered lagoons - performance data from Bears Lagoon Piggery*, Rural Industries Research and Development Corporation, RIRDC Project No PRJ-002705, October 2009, Barton, A.C.T.

Black, J 2000, *Agronomic value for broadacre crops of deep litter from pig sheds*, Pig Research and Development Corporation, Pig Research and Development Corporation Report BMI 13/1228, Canberra.

Burns, RT 2004, *Animal waste anaerobic digester basics*, Agricultural & Biosystems Engineering Department, Iowa State University.

California Energy Commission 2008, *Biomass - anaerobic digestion*, State Of California, viewed 25 March 2010, < http://www.energy.ca.gov/biomass/anaerobic.html >.

Carrère, H, Sialve, B & Bernet, N 2009, 'Improving pig manure conversion into biogas by thermal and thermo-chemical pretreatments', *Bioresource Technology*, vol. 100, no. 15, pp. 3690-3694.

Chynoweth, DP, Wilkie, AC & Owens, JM 1998, 'Anaerobic processing of piggery wastes: A review', Paper submitted to the *1998 ASAE Annual International Meeting*, Orlando, Florida, 11-16 July 1998.

Conn, KL, Topp, E & Lazarovits, G 2007, 'Factors influencing the concentration of volatile fatty acids, ammonia, and other nutrients in stored liquid pig manure', *Journal of Environmental Quality*, vol. 36, no. 2, pp. 440-447.

Craggs, R, Park, J & Heubeck, S 2008, *Covered anaerobic ponds for anaerobic digestion and biogas capture: piggeries*, New Zealand Pork, NIWA, NIWA Information Series No. 32, viewed 10 June 2010, < http://www.biogas.org.nz/Publications/WhosWho/biogas-pond-booklet.pdf >.

Danish Biogas Association 2010, *Digested biomass as a fertiliser*, viewed 26 March 2010, < http://www.landbrugsraadet.dk/view.asp?ID=2281 >.

DEWHA 2009, *Energy markets - renewable power stations*, Department of the Environment, Water, Heritage & the Arts, Canberra, viewed 15 June 2010, < https://www.ga.gov.au/renewable/gmaps/operating.html >.

Farmatic Biotech Energy UK Ltd 2002, *Holsworthy biogas plant - Anaerobic digestion*, Cheltenham.

Folkecenter for Renewable Energy 2006, *Rokai Pig Farm Demonstration Biogas Plant*, Folkecenter for Renewable Energy <http://www.folkecenter.dk/en/rokai/rokai.html >.

Geoscience Australia 2010, *Map of operating renewable energy generators in Australia*, Department of the Environment, Water, Heritage and the Arts, Canberra, viewed 25 March 2010.

Geoscience Australia & ABARE 2009, 'Chapter 12 - Bioenergy ', in *Australian Energy Resource Assessment*, Canberra.

GHD Pty Ltd 2008, *Assessment of methane capture and use from the intensive livestock industry*, RIRDC Project No PRJ-000875, Rural Industries Research and Development Corporation, RIRDC Publication No 08/025, June 2008, Barton, ACT.

Guild Associates 2010, *Guild biogas purification system*, Guild Associatees Inc, Dublin, viewed 17 May 2010, < http://www.moleculargate.com/biogas-digester-gas-purification/biogas-purification.html >.

Gunasekera D, Catherine Tulloh, Melanie Ford & Edwina Heyhoe 2008, 'Climate change: Opportunities and challenges in Australian agriculture', in *Proceedings of Faculty of Agriculture, Food & Natural Resources Annual Symposium 2008*, University of Sydney, Sydney, 13 June 2008, pp. 1-6.

Hjort-Gregersen, K 1999, *Centralised biogas plants - Integrated energy production, waste treatment and nutrient redistribution facilities*, J Christensen (ed.), Danish Institute of Agricultural and Fisheries Economics, October 1999.

IEA Biology 1999, *Biogas upgrading and utilisation*, Task 24: Energy from biological conversion of organic waste, S Lundeberg (ed.), RVF/Swedish Association of Waste.

IPCC 2006, *IPCC Guidelines for National Greenhouse Gas Inventories*, HS Eggleston, L Buendia, K Miwa, T Ngara and K Tanabe (eds.), Prepared by the National Greenhouse Gas Inventories Programme, IGES, Japan.

Karakashev, D, Batstone, DJ, Trably, E & Angelidaki, I 2006, 'Acetate oxidation is the dominant methanogenic pathway from acetate in the absence of methanosaetaceae', *Applied and Environmental Microbiology*, vol. 72, no. 7, pp. 5138-5141.

Kram, J 2010, 'A New Day for Biogas: Germany Leads the Way in Europe', *Biomass Magazine*.

Kram, JW 2007, 'A new day for biogas: Germany leads the way in Europe', *Biomass Magazine (Online)*, no. June 2007, accessed, < http://www.biomassmagazine.com/article.jsp?article_id=1156 >.

Lallai, A, Mura, G & Onnis, N 2002, 'The effects of certain antibiotics on biogas production in the anaerobic digestion of pig waste slurry', *Bioresource Technology*, vol. 82, no. 2, pp. 205-208.

Little, R 2009, 'North America's biogas industry grows up', *Bioenergy Canada (Online)*, no. March 2009, BBI Biofuels Canada, Kitchener, Canada accessed, < http://www.bioenergymagazine.ca/article.jsp?article_id=317&q=little >.

Lukehurst, CT 2007, *AD on the move - United Kingdom 2007*, Task 37 (UK), Broadstairs, Kent <www.ramiran.net/doc07/Biogas%20III/Clare_Lukehurst.pdf >.

Metcalf & Eddy Inc. 2003, *Wastewater engineering : Treatment & reuse*, McGraw-Hill, New York.

Monnet, F 2003, *An introduction to anaerobic digestion of organic waste. Final report*, Remade Scotland, November 2003.

Navickas, K 2007, 'Biogas for farming, energy conservation and envioronment protection', in *International symposium, Biogas, technology and environment*, Faculty of Agriculture, University of Maribor, 25-29 November 2007.

New Zealand Pork 2009, *Waste to wealth*, Sustainable Farming Fund Project L07/009 New Zealand Pork and the Sustainable Farming Fund.

Nicholas, PJ, McGahan, EJ & Tucker, RW 2006, *Producer guidelines for the use of spent bedding*, Project No. 1969, Australian Pork Limited, Canberra.

Ontario MAAF 2010, *Ontario biogas systems financial assistance program*, Ministory of Agriculture, Food and Rual Affairs, Government of Ontario, viewed 18 May 2010, < http://www.omafra.gov.on.ca/english/engineer/biogas/ >.

Pavlostathis, SG & Giraldo-Gomez, E 1991, 'Kinetics of anaearobic treatment: A critical review', *Critical Reviews in Envioronmental Science and Technology*, vol. 21, no. 5-6, pp. 411-490.

Payne, H 2009, *Biogas capture study tour to Queensland and New Zealand*, Agricultrual Produce Commission, Pork Producers Committee.

Pedersen, SJ 2009, *Declaration of biogas slurry* Thorsø Environment and Biogas AMBA Kongensbrovej, < www.thorsobiogas.dk/index.php?option=com_content&view=article&id=37&Itemid=27 >.

Poad, GD, McGahan, EM & Redding, MR 2010, *Low cost options for reducing effluent pond methane*, Australian Pork Limited, Project No. 2299, June 2010, Canberra.

Scholwin, F 2006, 'Biogas to energy - applications, market development and future opportunites', in *Use of bioenergy in the Baltic Sea Region, Proceedings of the 2nd IBBC*, Straslund, Germany.

Siegrist, J, Vogt, D, Garcia-Heras, J & Gujer, W 2002, 'Mathematical model for meso and thermophillicanaerobic seawge sludge digestion', *Environmental Science and Technology*, vol. 36, pp. 1113-1123.

Standards Australia 2004, *Gas installations* (AS 5601-2004), Sydney NSW.

Standards Australia/Standards New Zealand 2008, *The storage and handling of LP Gas* (AS/NZS 1596-2008).

Svoboda, I 2003, *Anaerobic digestion, storage, oligolysis, lime, heat and aerobic treatment of livestock manures, Final Report*, Provision of research and design of pilot schemes to minimise livestock pollution to the water environment in Scotland, FEC Services Ltd, Kenilworth, Warwickshire.

The Bioenergy News Desk 2010, 'AD firm to build biogas plant in Cumbria', *The Bioenergy Site (Online)*, 26 January 2010, 5M Enterprises Ltd, < http://www.thebioenergysite.com/news/5415/ad-firm-to-build-biogas-plant-in-cumbria >.

U.S. EPA 2010, *Guide to anaerobic digesters*, AgSTAR Program, United States Environmental Protection Agency, < http://www.epa.gov/agstar/operational.html >.

UTS Biogastechnik GmbH 2009, *Biogas - Renewable energy - Our future*, Hallbergmoos, Germany, viewed 26 May 2010, < http://www.uts-biogas.com/index.php?id=501&L=2 >.

van Lier, JB 2008, 'High-rate anearobic wastewater treatment: diversifying from end-of-the-pipe treatment to resource-oriented conversion techniques', *Water Science and Technology*, vol. 57, no. 8, pp. 1137-1148.

Wu-Haan, W, Burns, RT, Moody, LB, Grewell, D & Raman, RD 2009, 'Evaluation of ultrasonic pretreatment on anaerobic digestion of different animal manures', *American Society of Agricultural and Biological Engineers*, vol. 53, no. 2, pp. 577-583.

Zhu, J 2010, 'Crop residues and swine manure enhance methane generation', *National HogFarmer*, 15 December, Penton Media, accessed 26 March 2010, < http://nationalhogfarmer.com/facilities-equipment/manure-handling/1215-mixture-enhance-methane-generation/ >.

15. Appendix - Anaerobic Digesters Processing Dairy manure in the United States

Farm	Year On line	Digester Type	Installed Capacity (kW)	Methane Emission Reductions (tons CH_4/yr)
Fiscalini Farms	2008	Complete mix	720	254
Tollenaar Holsteins Dairy	2008	Complete mix	250	345
Cushman Dairy	1997	Complete mix	80	43
USDA-Beltsville ARS facility, Unmixed Tank	1994	Complete mix	15	13
den Dulk Dairy	2007	Complete mix		67
Green Meadows Dairy	2007	Complete mix	800	216
Scenic View Dairy - Fennville	2006	Complete mix	800	578
Scenic View Dairy - Freeport	2008	Complete mix	1,600	559
Cayuga Regional Digester Bioenergy Enterprise	2007	Complete mix	625	82
Patterson Farms	2005	Complete mix	250	88
Ridgeline Farm	2001	Complete mix	130	34
Sheland Farms	2007	Complete mix	125	36
Quasar Energy Group - Wooster	2010	Complete mix	400	
Bernie Faber Dairy (CalGon Dairy)	2002	Complete mix	100	91
Brubaker Farms	2007	Complete mix	160	68
Mains Farm	2006	Complete mix	90	46
Penn England Farm	2006	Complete mix	130	61
Reinford Farms	2007	Complete mix	130	61
Wanner's Pride-N-Joy Farm	2007	Complete mix	160	30
Huckabay Ridge / Microgy	2008	Complete mix		64
Crave Brothers Dairy Farm / Clear Horizons LLC	2007	Complete mix	633	101
Five Star Dairy Farm	2005	Complete mix	775	176
Green Valley Dairy	2007	Complete mix	1,200	705
Norswiss Farms	2006	Complete mix	850	257
Sunrise Dairy (formerly Suring Community	2005	Complete mix	250	168

Dairy)				
Vir-Clar Farms	2004	Complete mix	350	82
Wild Rose Dairy	2005	Complete mix	775	60
Blakes Landing Dairy	2004	Covered lagoon	75	78
Bob Giacomini Dairy	2009	Covered lagoon	80	76
Bullfrog Dairy	2008	Covered lagoon	300	834
Cal Poly Dairy	1998	Covered lagoon	30	44
CAL-Denier Dairy	2008	Covered lagoon	65	190
Castelanelli Bros. Dairy	2004	Covered lagoon	180	599
CottonWood Dairy	2004	Covered lagoon	700	1,264
Hilarides Dairy	2004	Covered lagoon	750	91
Lourenco Dairy	2006	Covered lagoon		351
Strauss Family Dairy	2004	Covered lagoon	25	25
Vintage Dairy	2008	Covered lagoon		1,264
Coyne Farm	2008	Covered lagoon		282
Fessenden Family Dairy	2008	Covered lagoon	500	161
Ridgecrest Dairy	2008	Covered lagoon		332
Will-O-Crest Farm	2008	Covered lagoon		211
Broumley Dairy Farm	2008	Covered lagoon		243
University of Florida Dairy Research Unit	2000	Fixed film	30	119
Langerwerf Dairy	1982	Horizontal plug flow	60	38
Meadowbrook Dairy	2004	Horizontal plug flow	160	13
Freund Farm	1997	Horizontal plug flow		52
Top Deck Holsteins	2002	Horizontal plug flow	130	53
Hillcrest Dairy (Formerly New Horizons)	2002	Horizontal plug flow	320	306
Haubenschild Farms	1999	Horizontal plug flow	155	63
Northern Plains Dairy	2003	Horizontal plug flow	260	209
AA Dairy	1998	Horizontal plug flow	130	39
EL-VI Farms	2004	Horizontal plug flow		71
Emerling Farms	2006	Horizontal plug flow	230	75
New Hope View Farm	2001	Horizontal plug flow	70	171
Noblehurst Farms	2003	Horizontal plug flow	130	77
Sunny Knoll Farm	2006	Horizontal plug flow	230	102
SUNY at Morrisville	2007	Horizontal plug flow	50	29
Twin Birch Dairy	2003	Horizontal plug flow	120	97
Tillamook_1 (2 digesters)	2003	Horizontal plug flow	250	518
Tillamook_2 (last 2 digesters)	2008	Horizontal plug flow	300	518
Brookside Dairy	2006	Horizontal plug flow	85	30
Dovan Farms	2006	Horizontal plug flow	100	30

Four Winds Farm	2006	Horizontal plug flow	140	45
Hillcrest Saylors Farm	2007	Horizontal plug flow	130	69
Mason Dixon Farms	1979	Horizontal plug flow	600	489
Oregon Dairy Farm	1983	Horizontal plug flow	45	53
Schrack Farms	2006	Horizontal plug flow	200	82
Foster Brothers Farms	1982	Horizontal plug flow	125	23
Jer-Lindy Farms	2008	Induced blanket reactor	37	15
Huls Dairy	2008	Induced blanket reactor	50	72
Wadeland Dairy	2004	Induced blanket reactor	150	121
Wright Whitty Davis Farms, Inc.	2006	Mixed plug flow	200	259
Bettencourt's Dry Creek Dairy	2008	Mixed plug flow	2,250	538
Dean Foods Big Sky Dairy	2008	Mixed plug flow	1,500	421
Hunter Haven Farms, Inc.	2005	Mixed plug flow	270	54
Scheidairy Farms	2005	Mixed plug flow	120	54
Bos Dairy	2005	Mixed plug flow	1,050	287
Fair Oaks Dairy - Digester 2	2008	Mixed plug flow	800	279
Herrema Dairy	2002	Mixed plug flow	800	299
Hidden View	2007	Mixed plug flow	950	279
Windy Ridge Dairy	2006	Mixed plug flow		557
Willow Point Dairy	2007	Mixed plug flow		185
Riverview Dairy	2009	Mixed plug flow		454
West River Dairy	2009	Mixed plug flow		349
Aurora Ridge Dairy	2009	Mixed plug flow	500	118
Boxler Dairy	2009	Mixed plug flow		
Lamb Farms	2010	Mixed plug flow	450	402
Sunnyside Farms	2009	Mixed plug flow	1,600	936
Swiss Valley Farms	2009	Mixed plug flow	300	56
Bridgewater Dairy, LLC	2008	Mixed plug flow	800	296
Blue Spruce Farm, Inc.	2005	Mixed plug flow	240	67
Gervais Family Farm	2009	Mixed plug flow	200	58
Green Mountain Dairy, LLC	2007	Mixed plug flow	300	64
Maxwell Farm / Neighborhood Energy, LLC	2008	Mixed plug flow	225	46
Montagne Farm	2007	Mixed plug flow	300	73

Pleasant Valley Farms - Berkshire Cow Power, LLC	2006	Mixed plug flow	600	119
Westminster Farms	2009	Mixed plug flow	225	73
Farm Power Northwest, LLC	2009	Mixed plug flow		109
G DeRuyter & Sons Dairy	2007	Mixed plug flow	1,200	316
Qualco Energy/Quil Ceda Power Corp.	2008	Mixed plug flow	450	525
Vander Haak Dairy	2005	Mixed plug flow	450	68
Bach Digester, LLC	2010	Mixed plug flow	300	259
Central Sands Dairy, LLC	2008	Mixed plug flow	1,200	240
Clover Hill Dairy, LLC	2007	Mixed plug flow	300	259
Double S Dairy	2004	Mixed plug flow	200	228
Emerald Dairy	2006	Mixed plug flow		332
Gordondale Farms	2002	Mixed plug flow	140	58
Grotequt Dairy Farm, Inc.	2009	Mixed plug flow	600	165
Holsum Dairy - Elm Road	2007	Mixed plug flow	1,200	274
Holsum Dairy - Irish Road	2004	Mixed plug flow	700	274
Lake Breeze Dairy	2006	Mixed plug flow	600	175
Maple Leaf Dairy	2010	Mixed plug flow	1,200	415
Maple Leaf West	2010	Mixed plug flow		829
Norm-E-Lane, Inc. (NEL)	2008	Mixed plug flow	500	415
Pagels Ponderosa Dairy	2009	Mixed plug flow	800	274
Quantum Dairy	2005	Mixed plug flow	300	352
Statz Brothers, Inc.	2009	Mixed plug flow	600	137
Volm Farms	2009	Mixed plug flow		
Baldwin Dairy	2006	Modified Mixed plug flow	200	218
Miedema Dairy	2008	Partial cover lagoon		106
NMSU / Gonzalez Dairy	2008	Two-phase batch		
Midwest Dairy Institute	2006	Unknown	375	183
Fair Oaks Dairy - Digester 1	2004	Vertical plug flow	800	279

Source : U.S. EPA (2010)