Ministry of Agriculture & Forestry

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Methane from Animal Waste Management Systems

Final Report

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Contents

Executive Summary i

1 Introduction 1

2 Greenhouse Gas Emissions from Animal Waste 2
- 2.1 The Main Greenhouse Gases and Global Warming Potentials 2
- 2.2 Sources of Emissions of Greenhouse Gases from Animal Waste Management 2
- 2.3 The Emissions Trading Scheme and Carbon Credits 4

3 Current Animal Waste Management Methods in New Zealand 5
- 3.1 Introduction 5
- 3.2 Waste Management Methods 5
- 3.3 Collection and Treatment Methods for Specific Animal Waste Types 7

4 Animal Waste Generation and Biogas Production 9
- 4.1 Animal Waste Generation 9
- 4.2 Biogas Generation from Animal Wastes 9
- 4.3 Potential Methane Emissions from Animal Waste in New Zealand 11
- 4.4 Geographic Potential for Biogas Generation Based on Climatic Differences in New Zealand 12
- 4.5 Summary of Potential Methane Emissions from Animal Waste in New Zealand 13

5 Potential Modifications to Current Waste Management Practices to Reduce Greenhouse Gas Emissions 14
- 5.1 Enhanced Collection and Management of Animal Wastes 14
- 5.2 Collection and Management of Greenhouse Gas Emissions 15

6 Potential Role of On-Farm Biogas Plants 16
- 6.1 Potential Benefits of Biogas Plants on Farms 16
- 6.2 Concept Description of Biogas Plants 17
- 6.3 Historical Perspective of Biogas Plants in New Zealand 22

6.4 Utilisation of Biogas as a Fuel 23

7 Modelling of Biogas Generation for Specific Farm Types 25

7.1 Model Development 25

7.2 Manure Generation 25

7.3 Biogas Generation 28

7.4 Biogas Use 31

7.5 Baseline Emissions Assuming Anaerobic Lagoon 35

8 Economic Analysis of Biogas Systems for Specific Farm Types 36

8.1 Dairy Cows 500 Head Herd, 10% Manure Collection 36

8.2 Dairy Cows 500 Head, 60% Manure Collection 38

8.3 Dairy Cows Large Herd (900 Head), 10% Manure Collection 41

8.4 Dairy Cows Large Herd (900 Head), 60% Manure Collection 43

8.5 Small Piggery (1,000 Head) 46

8.6 Large Piggery (10,000 Head) 48

8.7 Poultry 53

8.8 Summary of Economic Analysis 55

9 Issues Related to Technology Application 57

9.1 Livestock Management and Waste Systems 57

9.2 System Design, Operations and Maintenance 57

9.3 Efficiency of the Digestion Process and Electricity Generation 58

9.4 Economic Efficiency 58

10 Conclusions 59

11 Acknowledgments 61

12 Literature Cited 61

Annex 1: Methane Calculation and Economic Analysis Model 63

Annex 2: Typical Cost Data for Two Types of Biogas Systems 73

Annex 3: Biogas Plant Construction: Design and Operation 79

Annex 4: Biogas Scrubbing: Providing Methane for Vehicle Fuel 84

List of Tables

Table 2-1: Global Warming Potentials of the Five Main Greenhouse Gases (Excluding Carbon Dioxide) at Lifetimes of 20, 100 and 500 Years* 2
Table 4-1: Approximate Quantities of Manure Produced by Various Animals and Birds per Day* 9
Table 4-2: Volumes of Biogas Likely to be Generated from Various Animal Wastes Within a Period of 15-20 Days at 35ºC* 10
Table 4-3: Calculated CH4 Emissions Based on a Large Pig Farm at Various Locations in New Zealand1 13
Table 4-4: Summary of Potential Methane Emissions from Animal Wastes in New Zealand Expressed as Tonnes of Carbon Dioxide Equivalent Using a Global Warming Factor for Methane of 21 13
Table 5-1: Trends in the Quantity and Nature of Feed Imported onto Average NZ Dairy Farm (Tonnes DM) 14
Table 7-1: Farm Types 25
Table 7-2: Daily Manure Generation on Typical New Zealand Farms 27
Table 7-3: Potential Daily Biogas Generation from Anaerobic Digestion of Manure Produced by Typical New Zealand Farms 29
Table 7-4: Digester, Lagoon and Biogas Volumes 30
Table 7-5: Biogas Potential for Heating Cost Savings and Electricity Generation Potential 32
Table 7-6: Calculated Annual Baseline Emissions and Net Emission Reductions from Biogas1 35
Table 8-1: Economic Analysis Dairy Cows 500 Head Herd, 10% Manure Collection (Covered Existing 128m^3 Anaerobic Lagoon) 36
Table 8-2: Economic Analysis Dairy Cows 500 Head Herd, 10% Manure Collection (New Lined 128m^3 Covered Anaerobic Lagoon) 37
Table 8-3: Economic Analysis Dairy Cows 500 Head Herd, 10% Manure Collection (85m^3 Tank Digestion, 20 Years) 38
Table 8-4: Economic Analysis Dairy Cows 500 Head, 60% Manure Collection (Covered Existing 765m^3 Anaerobic Lagoon) 39
Table 8-5: Economic Analysis Dairy Cows 500 Head, 60% Manure Collection (New Lined 765m^3 Covered Anaerobic Lagoon) 39
Table 8-6: Economic Analysis Dairy Cows 500 Head Herd, 60% Manure Collection (510m^3 Tank Digestion, 20 Years) 40
Table 8-7: Economic Analysis Dairy Cows 500 Head, 10% Manure Collection (Covered Existing 225m^3 Anaerobic Lagoon) 41
Table 8-8: Economic Analysis Dairy Cows 900 Head, 10% Manure Collection (New Lined 225m^3 Covered Anaerobic Lagoon) 42
Table 8-9: Economic Analysis Dairy Cows 900 Head, 10% Manure Collection (150m^3 Tank Digestion, 20 Years) 43
Table 8-10: Economic Analysis Dairy Cows 900 Head, 60% Manure Collection (Covered Existing 1,380m^3 Anaerobic Lagoon) 44
Table 8-11: Economic Analysis Dairy Cows 900 Head, 60% Manure Collection (New Lined 1,380m^3 Covered Anaerobic Lagoon) 44
Table 8-12: Economic Analysis Dairy Cows 900 Head, 60% Manure Collection (920m^3 Tank Digestion, 20 Years) 45
Table 8-13: Economic Analysis 1000 Head Piggery (10 years, Covered Existing 450m^3 Anaerobic Lagoon) 46
Table 8-14: Economic Analysis 1000 Head Piggery (10 years, New Covered 450m^3 Anaerobic Lagoon) 47
Table 8-15: Economic Analysis 1000 Head Piggery (300m^3 Tank Digestion, 20 years) 48
Table 8-16: Economic Analysis Large Piggery (10,000 Head, 10 years, Covered Existing 4,500m^3 Lagoon) 49
Table 8-17: Cost Sensitivity Analysis (Capital and Operating Costs) Large Piggery (10,000 Head, 10 years, Covered Existing 4,500m^3 Lagoon) 49

Table 8-18: Economic Analysis Large Piggery (10,000 Head, 10 years, New Covered 4500m^3 Lagoon)..........50
Table 8-19: Cost Sensitivity Analysis (Capital and Operating Costs) Large Piggery (10,000 Head, 10 years, New Covered 4,500m^3 Lagoon)..........51
Table 8-20: Economic Analysis Large Piggery (10,000 Head, 20 years, 3,000m^3 Tank Digestion) 51
Table 8-21: Cost Sensitivity Analysis (Capital and Operating Costs) Large Piggery (10,000 Head, 20 years, 3,000m3 Tank Digestion)..........52
Table 8-22: Economic Analysis Poultry (50,000 Head, 10 years, Covered Existing 330m^3 Lagoon) 53
Table 8-23: Economic Analysis Poultry (50,000 Head, 10 years, New Covered 330m^3 Lagoon)..........54
Table 8-24: Economic Analysis Poultry (50,000 Head, 20 years, 220m^3 Tank Digestion)..........55

List of Figures

Figure 6-1: Covered anaerobic lagoon treating meat processing wastewater, Invercargill...........17
Figure 6-2: Covered anaerobic lagoon in Brazil 18
Figure 6-3: Covered anaerobic lagoon in Mexico. 18
Figure 6-4: Biogas digester and engine shed, Landcorp Farm, Eyrewell, Canterbury..........19
Figure 6-5: Biogas-diesel cogeneration engine for electricity generation 20
Figure 6-6: Components of a typical biogas plant 21

Executive Summary

This report describes research conducted as part of MAF's Climate Change "Plan of Action" Research Programme 2007/8 on the sub-category topic of "Methane from Animal Waste Management Systems".

Greenhouse gas (GHG) emissions from animal wastes are described and the sources of the specific greenhouse gases carbon dioxide, methane and nitrous oxide in the context of animal wastes management are outlined.

It is important in this research to set down in some detail the current animal waste management methodologies on New Zealand farms for dairy, pig and poultry wastes because these methods, and possible future enhancements to them, have much relevance to on-farm methane generation and an accompanying controlled approach to collecting and utilising these emissions via anaerobic lagoons or biogas digesters. Accordingly, Section 3 of this report describes these current collection and management methods for dairy, pig and poultry wastes.

To obtain relevant and robust input data for the economic models developed in this project the expected volumes of wastes from dairy cows, pigs and poultry have been calculated and the associated expected annual volumes of biogas (methane) have thus been derived. These estimates have been extended to calculate the national methane emissions from dairy cows, pigs and poultry and thus the total quantity of carbon dioxide equivalents from methane emissions from animal wastes in New Zealand on an annual basis. The geographic potential and associated variation for on-farm biogas production based on climate differences in New Zealand has also been established.

There are potential modifications and enhancements to the collection and management of animal wastes and to the generation, collection and management of associated methane emissions which are being or could be made to ultimately reduce greenhouse gas emissions from animal wastes in New Zealand. Section 5 of this report outlines these improvements and enhancements.

The role of on-farm biogas plants is discussed in some detail. The various potential benefits from an environmental stand-point in achieving regulatory compliance and, ultimately, in economic terms are considered in this report. The historical context of biogas plants in New Zealand is outlined and the reasons for the fall-off in biogas generation and utilisation in recent years are examined. The concepts underpinning a typical biogas plant are illustrated, along with various examples. The utilisation of biogas as a fuel is also discussed, with the various options of process heating, electricity generation, and use as a vehicle fuel being examined. The further option of flaring the gas to produce carbon dioxide as an emission, rather than simply releasing methane, has major implications in GHG reduction terms and economically via the concept of carbon credits, which is also discussed.

Manure and biogas generation was calculated for seven different farm types that could be reasonably representative of New Zealand dairy, pig and poultry farms. Biogas volumes and net emission reductions as a result of biogas use were calculated for each farm type based on typical biogas systems (covered existing anaerobic lagoon, new lined covered anaerobic lagoon, and tank digestion).

The results of the study indicate that capture and management of methane from collection and management of animal waste using biogas systems have potential to reduce greenhouse gas emissions from livestock farms. For example, potential net emission reductions of about 3,868 t CO_{2e} could be achieved from a 10,000 head pig farm by capturing methane from animal wastes through use of anaerobic digestion (either covered lagoons or tank digestion) and conversion to CO_2 by combustion.

Introduction of a biogas system to a farm operation for reduction in methane emissions from animal waste may require changes in animal management to maximize waste collection. This is especially the case for dairy cows, where currently only about 10% of total manure produced is able to be collected because typically the only time cows spend on hard surfaces is in the dairy shed during milking. If manure collection for dairy cows could be increased significantly (e.g. through feeding on hard standing pads, or animal housing for longer periods) greater potential exists for methane capture and management in a biogas system. For example, potential annual net emission reductions from biogas digestion of wastes for a 900 head dairy herd is about 217t CO_{2e} based on 10% manure collection compared to about 1,305 t CO_{2e} based on 60% manure collection.

While there is potential for biogas systems to reduce on-farm methane emissions, the scenarios analysed under this study indicate that such systems are generally not economically viable at present (poultry and some pig farm scenarios excepted). Analysis for farm scenarios indicates that use of biogas for on-farm electricity generation and C credits is non-economic for most dairy and some pig farm scenarios at current prices and costs under the assumptions made in the study. However, economic viability does vary according to a wide range of factors, including livestock type and number of head per farm, manure management systems used, biogas technology used, electricity price (where electricity generated from biogas is used to substitute for grid supplied electricity), C credit price (if methane emissions reductions from biogas can be eligible under the Emissions Trading Scheme), and capital and operating and maintenance costs. Due to these many variables affecting biogas viability in New Zealand, it is recommended that detailed analysis (with steps similar to those used in Section 8 of this study) should be conducted by all farms considering investment in biogas because viability will be farm specific.

Biogas technology is still relatively new in New Zealand, with few systems currently operating despite a number of large biogas investments in the 1980s and 1990s. The lessons learned from these earlier investments and also current biogas investments should be collated so that new entrants to biogas in New Zealand have access to the full range of knowledge generated in this area. Given the changing energy situation and potential ETS in New Zealand, it is timely for MAF Policy to consider drawing this experience together for the benefit of rural sector investors considering biogas development in the future.

This work has developed and presented a detailed model, encompassing a series of variables, and with a significant degree of associated necessary complexity, to investigate possible scenarios for methane generation from animal wastes on dairy, pig and poultry farms. For optimum utility it will be necessary to produce a simplified version of the model, probably with an associated “User Guide”, to lead farmers through the practical application of the model to their particular animal waste management circumstances.

It is therefore recommended that the results of this work and, in particular, the mechanics of application of the economic model, be simplified and consolidated into a user-friendly package that farmers can adapt to the circumstances of their individual operations. This would enable them to assess the physical and economic viability of collecting wastes and carrying out anaerobic digestion to produce biogas, with that biogas either utilised for electricity generation (and possibly waste heat usage) or simply flared, in each case with associated carbon credits.

1 Introduction

The Ministry of Agriculture and Forestry (MAF) has developed a Climate Change - "Plan of Action" Research Programme 2007/8, which includes in 'Cluster 4 – Agricultural Mitigation' a sub-category research topic of "Methane from Animal Waste Management Systems". The aims of this research are:

- identification and analysis (including economic analysis) of options for managing poultry, piggery and dairy waste, in a manner that reduces greenhouse gas emissions:
- measurement of the variation of biogas production from anaerobic ponds in different climatic areas of New Zealand;
- development of models that can estimate potential energy/electricity production from on-farm biogas systems, greenhouse gas emissions (and emission reductions) as a result of on-farm biogas systems

MWH provided a proposal to MAF (see Appendix 1) and was subsequently awarded a contract by MAF to carry out this research project.

This report is presented in fulfilment of the contract with MAF.

2 Greenhouse Gas Emissions from Animal Waste

2.1 The Main Greenhouse Gases and Global Warming Potentials

'Greenhouse' gases are gases that have a molecular structure such that they obstruct the radiation of heat from the earth, thus acting like the glass or membrane over a greenhouse. The gases that are most effective at absorbing this radiated heat are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons and sulphur hexafluoride.

The above 'greenhouse' gases have differing abilities to absorb the heat radiated from the earth and are assigned factors (their 'global warming potential') based on their absorbing ability relative to that of carbon dioxide. The factors depend on the lifetime over which the effect of the gases is assessed. A gas which is quickly removed from the atmosphere may initially have a large effect but over a longer period the effect will be much less important. The 'global warming potentials' of each of the five main greenhouse gases (relative to carbon dioxide) are given in Table 2-1 for different time horizons.

Table 2-1: Global Warming Potentials of the Five Main Greenhouse Gases (Excluding Carbon Dioxide) at Lifetimes of 20, 100 and 500 Years*

Gas	Global Warming Potential Relative to Carbon Dioxide		
	20 years	100 years	500 years
Methane	72	21	7.6
Nitrous oxide	310	298	153
Hydrofluorocarbon -134a	3,830	1,430	435
Hydrofluorocarbon -23	12,000	14,800	12,200
Sulphur hexafluoride	15,100	22,800	32,600

*Adapted from IPCC 2007 report on "GWP Values and Lifetimes, Assessment Report 4"

The 'global warming potential' value usually referred to is the value at 100 years. In the case of methane, this means that 1kg of methane gas is estimated to have 21 times the global warming potential of 1kg of carbon dioxide. [Note: The GWP for methane ranges from 21 – 25, according to various sources. For the purposes of this study it has been assumed to be 21.]

Both methane and nitrous oxide can be produced as by-products of the management of animal wastes.

2.2 Sources of Emissions of Greenhouse Gases from Animal Waste Management

The main greenhouse gas emissions resulting from animal manures and waste management practices are carbon dioxide, methane and nitrous oxide. Potential sources of each of these greenhouse gas emissions are discussed in the following sections.

2.2.1 Carbon Dioxide Emissions

Carbon dioxide (CO_2) emissions result from the decomposition of animal wastes in the presence of a sufficient supply of air to ensure aerobic conditions. Under aerobic conditions naturally occurring bacteria utilise the oxygen in air to oxidise the biodegradable carbon in the animal waste to carbon dioxide.

Aerobic conditions occur when animal wastes are:

- treated in an oxidation pond or an aerated lagoon
- composted with sufficient turning and aeration of the compost heap
- spread thinly enough onto land to allow aerobic soil conditions to be maintained

Carbon dioxide emissions should not lead to any net change to the global greenhouse gas balance because all of the carbon oxidised to carbon dioxide is likely to have been ingested by the animals as food (grass, grain etc), which will have absorbed carbon dioxide from the air during their growing cycle via photosynthesis.

2.2.2 Methane Emissions

When organic carbon, as contained in animal waste, decomposes without sufficient air to oxidise the carbon to carbon dioxide the biodegradable carbon is converted to a mixture of carbon dioxide and methane (CH_4), usually called ‘biogas’. Because of the high organic strength of animal waste and because the waste has been produced under anaerobic (i.e. in the absence of air) conditions within the digestive system of the animal, animal wastes are inherently anaerobic and can be expected to generate methane unless they are managed in such a way as to aerate them. Even manure deposited on the ground (such as ‘cowpats’) is anaerobic inside and emissions of methane are produced as it lies on the ground.

Because methane has a global warming potential that is 21 times greater than carbon dioxide, emissions of methane can result in increased global warming rather than maintaining the carbon cycle as would happen if the carbon was fully oxidised to carbon dioxide. Consequently, a reduction of methane emissions from animal waste or conversion of the methane to carbon dioxide is necessary to ensure that the carbon cycle is maintained.

Anaerobic conditions develop and biogas is generated:

- in ponds or basins where animal manure is collected and/or stored
- where collected animal manures are spread too thickly on land
- from animal manures deposited in the field such as ‘cowpats’
- where animal manure is collected in piggeries and poultry sheds

2.2.3 Nitrous Oxide Emissions

Nitrous oxide (N_2O) is a potent greenhouse gas because of its high global warming potential (see Table 2.1). It can be a significant emission from animal wastes under certain conditions, particularly when animal manures are applied to soil.

Emissions of nitrous oxide are not the focus of this contract and are not discussed further in this report. MAF research grants 158-4 and 166-4 within ‘Cluster 4 – Agricultural Mitigation’ are directed at reduction of nitrous oxide emissions.

Also, a recent review of "Mitigation of the greenhouse gas nitrous oxide from deposition of animal excreta and application of effluent to land" by AgResearch scientist Jiafa Luo *et al* provides a good summary of the potential greenhouse gas emissions and methods of manure management that might be adopted to reduce N_2O emissions.

2.3 The Emissions Trading Scheme and Carbon Credits

The New Zealand Emissions Trading Scheme (ETS) is part of the New Zealand government's response to climate change. Emissions trading is intended to help reduce greenhouse gas emissions, encourage and support action on climate change, and help put New Zealand on a path to sustainability (MfE, 2008).

The agriculture sector is the largest single source of greenhouse gas emissions in New Zealand, contributing about 49% of NZ's total emissions (MfE, 2008). Approximately 2/3 of this consists of methane from livestock.

Under its MOU with the agriculture sector in 2003, the New Zealand government agreed that it would bear the cost of the agriculture sector's non-CO_2 emissions during the first commitment period (2008-2012) of the Kyoto Protocol provided the sector contributes to research into ways to reduce greenhouse gas emissions from agricultural activities. The aim of that research is to deliver safe, cost effective abatement strategies to lower ruminant methane and nitrous oxide emissions.

The amended Climate Change Response Act 2002 currently makes processing companies (e.g. dairy and meat processors) responsible for participating in the ETS, and excludes individual farmers.

An alternative approach being considered is to give the responsibility to participate to individual farmers. This would lead to higher compliance costs for farmers and the agricultural sector as a whole, but would improve the incentives for farmers to reduce emissions.

The final decision about who will participate in the ETS must be made by 30 June 2010 (MfE 2008). MfE (2008) states that if processing companies become mandatory participants in the ETS, there may be an option for farmers to opt in so they can take direct responsibility for the emissions from their farms.

One implication of the ETS for individual farmers is that if they do opt in they will be able to generate and trade carbon (C) credits arising from emissions reductions from their current baseline situation. As a result, technologies such as biogas have potential for reducing methane emission levels and so earn C credits that could be tradeable under the ETS. This paper investigates the potential for biogas as a technology for reducing greenhouse gas emissions and the economic viability of various biogas capture technologies under several different dairy, pig and poultry farm scenarios.

3 Current Animal Waste Management Methods in New Zealand

3.1 Introduction

Most animals in New Zealand graze pasture and deposit urine and manure in patches in the field. This is in contrast to many other countries where most animals are housed, which results in the need to collect and manage the wastes.

The only animal wastes normally collected from housed animals in New Zealand are those from intensive pig farming and poultry farming. In addition, some of the waste produced each day by dairy cows is collected while the cows are in the milking shed. There is only one beef cattle feedlot in New Zealand (Five Star), where all the waste is collected. Other situations where animal wastes may be collected are feeding pads operated on some farms.

3.2 Waste Management Methods

3.2.1 Direct Irrigation onto Land

The majority of dairy farmers in New Zealand wash wastes from the milking shed into a sump and irrigate it directly onto land without any treatment. In some cases a holding tank or basin will be used to allow irrigation to be avoided in wet weather. There are increasing incidences of dairy waste running off land in wet weather and causing pollution of surface water, which is likely to force construction of more holding facilities.

Irrigation of un-treated piggery wastes and poultry wastes also occurs, but is less accepted due to odour issues.

3.2.2 Anaerobic Lagoons

The two-pond system promoted in the past by the New Zealand Ministry of Agriculture is still the most common system used for the management and treatment of wastes from dairy sheds, piggeries and sometimes poultry farms when treatment is provided. This system comprises an anaerobic lagoon followed by an oxidation (aerobic) pond. The main advantages of this system are that, if it is correctly designed, it requires no power for operation, has low management requirements and can produce a reasonably well treated effluent. However, the effluent quality is such that it is only suitable for disposal to land and not to a water body.

The conventional two-pond system uses an open anaerobic lagoon for the first pond, which carries out the primary treatment of the animal waste. However, the break down of the waste and the reduction of its organic strength results in the generation of biogas and its release into the atmosphere, and this is the major source of greenhouse gas emissions from animal waste management in New Zealand.

Anaerobic lagoons can be covered so that the biogas generated can be collected and combusted to convert the methane emissions to carbon dioxide, thus eliminating any net global warming. This is discussed further in Section 5.2.

3.2.3 Farm Biogas Plants

The term 'biogas plant' usually refers to an enclosed tank (often called a digester) in which the animal waste is broken down by anaerobic bacteria just as occurs in an anaerobic lagoon. The main difference is that the digester is usually heated to promote rapid anaerobic activity and, therefore, the digester can have a much smaller volume than an anaerobic lagoon.

Since the anaerobic process takes place in a closed digester tank, the biogas produced can be completely captured and either burnt by flaring or utilised in gas engines, thus eliminating any net global warming.

There have been a number of biogas plants on farms in New Zealand in the past (as discussed in Section 6.3) but at present few of these are in operation. Further discussion of farm biogas plants for New Zealand, their applicability, economics and the modelling of relevant parameters is provided in Sections 6 and 7.

3.2.4 Aerobic Systems

Farm wastes are usually of such high strength that they consume all the readily available oxygen and become anaerobic. However, if enough oxygen is supplied to sustain aerobic conditions the biodegradable carbon in the animal wastes can be broken down directly to carbon dioxide and water without any generation of biogas or other greenhouse gases.

To supply sufficient oxygen to sustain aerobic conditions in a lagoon it is necessary to use electrically powered aerators that transfer oxygen from the air into the liquid waste. A lagoon fitted with electrically powered aerators is called an aerated lagoon.

Treatment of animal waste in an aerated lagoon avoids greenhouse gas emissions other than carbon dioxide, but it involves high energy inputs and therefore high operating costs to drive the aerators. There may be indirect global warming implications associated with the production of the electricity used to power the aerators, although in New Zealand most of the electricity is likely to have been produced from hydro sources with minor such implications.

3.2.5 Composting

Composting is an aerobic process that can also avoid greenhouse gas emissions other than carbon dioxide provided that the composting process is well managed and maintained in a fully aerobic condition. However, the viability of composting depends on the animal waste being relatively dry – typically at least 20% solids content (< 80% moisture). Composting requires frequent turning of the animal waste, which may require significant use of machinery and labour as well as energy inputs that have an indirect global warming effect. Composting often requires the addition of a 'bulking agent' such as sawdust, which increases the mass of the composted waste relative to the raw animal waste. This is not a problem if a market can be established for the compost, but often a market does not exist.

3.2.6 Land Treatment

Disposal of animal wastes to land is typically carried out by irrigation of liquid effluent to pasture, most usually following treatment using a combined anaerobic/aerobic two-pond system. If this treatment is effective the effluent can be disposed to land, as long as compliance with the conditions of the relevant resource consent is achieved. As discussed elsewhere, these conditions typically set limits on, at least, BOD and nitrogen loading rates.

If there is no anaerobic and/or aerobic treatment step it is highly probable that the effluent will not be able to meet the consent conditions, unless a very large area is available for disposal. In reality it is usual for farms to have difficulty in meeting their effluent disposal conditions and this may still be so even with anaerobic treatment.

3.3 Collection and Treatment Methods for Specific Animal Waste Types

3.3.1 Piggeries

Piggeries in New Zealand usually raise the pigs in stalls with either a concrete floor with a door opening to a central waste collection channel into which the waste is scraped, or a slatted floor through which the wastes can fall to a collection channel below. The waste is either moved down the collection channel by a scraper system or hosed down into a sump. Periodic wash-down of the stalls and channels with water is usually necessary to minimise odour build-up and maintain hygienic conditions in the piggery.

Waste from the sump may be irrigated directly onto land using a tanker or effluent sprinkler system, or it may be pumped to a treatment system such as an anaerobic lagoon. The waste may need further water added to make it dilute enough for disposal by these methods.

If the waste is to be further treated in an anaerobic lagoon or a biogas plant it is preferable to minimise the amount of water used for waste collection so as to keep the volume of the waste as small as possible and hence minimise the size of the lagoon or digester required. Re-use of some of the lagoon or digester contents for washdown is one way of minimising the volume of waste loaded into the biogas plant.

Sometimes the stalls have dirt floors or are lined with straw or sawdust and the waste has to be shovelled or raked out in relatively dry form. In such cases the waste may be managed by composting, but there is potential for significant methane, ammonia and N_2O emissions if the composting process is not well managed and not maintained in a fully aerobic condition.

3.3.2 Poultry

Layer hens are usually housed in cages on raised tiered ‘benches’ so that the waste produced falls through the floor of the cage and forms a long heap under each row of cages. The waste is relatively dry and is periodically scraped out of the shed by a small tractor fitted with a scraper blade. It is not usual to wash down the floor in poultry sheds.

Layer chicken waste may be left in piles to slowly decompose, in which case it is likely to be anaerobic in the centre of the heap and will thus generate biogas. Alternatively, the waste can be diluted with water to produce a slurry that can be treated in a two-pond system or a biogas plant before being discharged onto land.

Broiler chickens are usually housed in large rooms with the floor covered in wood shavings. The waste is mixed with the wood shavings and is thus quite dry. It is periodically scraped out of the shed by a small tractor fitted with a scraper blade. The only time the rooms may be washed down is between batches, at which time disinfectants and/or bleaches may be used to kill insect pests.

Broiler chicken waste cannot easily be treated in a two-pond system or a biogas plant because of the presence of the inert wood shavings used as bedding. Composting is a more suitable treatment method and the waste may also be dry enough to burn. Both options can eliminate the generation of methane by converting the biodegradable carbon in the wastes directly to carbon dioxide, thus minimising net greenhouse gas emissions. However, this requires that aeration is adequate and the compost is maintained in an aerobic condition.

3.3.3 Dairy

Most of the waste produced by dairy cows is deposited in the field, with only about 10% of the daily waste being deposited in the dairy shed. Waste is invariably washed out of the dairy shed by hosing down after milking, thus producing a dilute waste slurry. This is usually collected in a sump and irrigated onto land, either directly or after treatment in a two-pond system.

Some farmers use standing pads to house cows for a period in winter, which keeps the animals off land that can otherwise become pugged in wet weather. In such cases waste is collected from the standing pad, again typically by hosing into a sump or into a pond system. These husbandry changes are discussed further in Section 5.1.1.

If bedding is laid on the standing pad the waste may be produced in a drier form that will be more suitable for composting.

4 Animal Waste Generation and Biogas Production

4.1 Animal Waste Generation

The volume of animal waste produced depends on the size of the animal but also depends on the nature and quantity of the feed intake. Another factor is the relative efficiency of the animal in utilising food. Ruminants such as cows and sheep are much more efficient at extracting energy and nutrients from their feed than are monogastric animals such as pigs and poultry.

Many studies have been carried out to establish the quantity of waste that is produced by the various species of animals each day. The studies have resulted in a range of values due to the wide range of factors that influence the quantity, including the nature of the feed, whether animals are held in barns or yards or are in the field, the age of the animal and differing intakes and digestion efficiency of individual animals. Typical values are summarised in Table 4-1.

Table 4-1: Approximate Quantities of Manure Produced by Various Animals and Birds per Day*

Animal/bird	Fresh manure (kg/d)	Total solids (% of fresh)	Total solids (kg/d)
Dairy cow (500kg)	35	13	4.5
Beef steer (400kg)	25	13	3.2
Breeding sow (200kg)	16	9	1.4
Fattening pig (50kg)	3.3	9	0.3
Sheep	3.9	32	1.25
Turkey	0.4	25	0.09
Layer hen	0.12	25	0.03
Meat chicken	0.10	21	0.02

* From New Zealand Ministry of Agriculture & Fisheries Aglink FPP603:1985

Since animal production, at least for meat producing purposes, is based on fattening the animals through a period of growth, the feed intake and waste output each vary over the growth period. The calculation of the total manure generation from an operation such as a pig farm therefore requires information on the numbers of pigs in each age bracket multiplied by the mass of waste expected from pigs within that age/weight group, and similarly for the other animal types.

4.2 Biogas Generation from Animal Wastes

When anaerobic conditions exist and animal wastes are decomposed by anaerobic bacteria with the generation of biogas, the quantity of biogas that results depends on the nature of the animal waste, ammonia concentration, the time allowed for the waste to digest (retention time) and the temperature of digestion. The retention time is related to the temperature of the waste because anaerobic bacteria are very sensitive to temperature and decompose organic matter much faster at temperatures of 35^{o}C and above.

The ultimate quantity of biogas that can potentially be generated depends on the biodegradable carbon content of the waste, although some of the carbon is usually present in the form of compounds such as lignin and lignocellulose that take a very long time (of the order of years) to be broken down by anaerobic bacteria, even at warm temperatures.

Usually animal wastes will not be held under anaerobic conditions for more than a few months at most so that only the more easily decomposable components will be converted to biogas and water. Easily decomposable components are simple organic compounds such as sugars, volatile fatty acids (acetic acid, etc) whilst more complex compounds such as fats take longer to be broken down and longer chain substances like lignin take even longer. Most biodegradable compounds are present in the solids contained in manures rather than in the water fraction because the readily biodegradable components of the animal feed have been consumed by the animal. Therefore, the quantity of biogas that is likely to be generated from an animal waste is best expressed in terms of the biodegradable solids content.

Different animal wastes therefore produce different quantities of biogas over the same period depending on their composition. The waste from ruminants such as cows and sheep contains a relatively small fraction of biodegradable organic matter because the high efficiency of the ruminant digestion system extracts these compounds. In contrast, the relatively poor digestion ability of monogastrics such as pigs and poultry leaves a larger fraction of biodegradable organic matter in the waste. Considerably more biogas can thus be produced from a kilogramme of dry matter pig or poultry waste than from a kilogramme of dry matter cow or sheep waste.

Table 4-2 gives the approximate volumes of biogas and the likely composition of the biogas that can be generated from various animal wastes over a period of approximately 15-20 days at 35ºC, which is the temperature at which animal wastes are excreted. The same volumes would take longer to generate at the lower temperatures at which the wastes are likely to be held, which may be as low as 10ºC in New Zealand.

Table 4-2: Volumes of Biogas Likely to be Generated from Various Animal Wastes Within a Period of 15-20 Days at 35ºC*

Animal	Biogas Produced (L/kg solids)	% Methane in Biogas
Cow	190-220	68
Pig	170-450	55-65
Sheep	180-220	56
Chicken	300-450	57-70

*Data from New Zealand Ministry of Agriculture & Fisheries Aglink FPP603:1985

Note: Antibiotics find extensive use in pig and poultry farming and, by their very nature, the residues of these agents within the collected animal manure may have a detrimental effect on the methanogenic bacteria responsible for biogas production. The extent of antibiotics residues in particular manures will need to be considered in any farm enterprise seeking to install anaerobic digestion systems to produce and utilise biogas.

4.3 Potential Methane Emissions from Animal Waste in New Zealand

4.3.1 Emissions from Dairy Cow Wastes

Methane is emitted into the atmosphere from cowpats, and also from waste that is collected in milking sheds and then treated in open anaerobic lagoons.

Yamulki et al (1999) have shown that emissions of methane from cowpats range from 0.21-1.46g/cow/day. If a value of 1.0g/cow/day is taken as representative, this amounts to about 365g/cow/year. Total emissions of methane from cowpats deposited by the 3,916,810 dairy cows in New Zealand (LIC National Dairy Statistics 2006-07) could thus amount to about 1,430 tonnes of methane per year, equivalent to 30,030 tonnes of carbon dioxide.

Some of the methane generated from cowpats may be absorbed into the soil where it can react with nitrous oxide and thus reduce atmospheric emissions of N_2O. Saggar et al (2007) have reported that the uptake of methane by pasture soils in New Zealand is something less than 1kg/ha/year. Thus, with dairy farms covering an effective area of 1,412,925ha, as much as 1,412,925kg of methane could potentially be absorbed by the soil each year. However, methane can only be absorbed into the soil under and near each cowpat, and thus the reduction in methane emissions from cowpats due to uptake by the soil would be far less than the figure above.

The extent of methane emissions from treatment of dairy cow wastes in anaerobic lagoons depends largely on the extent to which such lagoons are used for treatment, which is difficult to quantify without carrying out a detailed survey of all dairy farms. The majority of dairy farmers collect milking shed wastes to a sump and irrigate it out onto pasture within hours or days of collection and therefore, provided the waste is irrigated at a low application rate, there should be negligible emissions of methane. Probably only about 15% of dairy cow wastes are collected and treated in anaerobic lagoons, usually as part of a two-pond system. If it is assumed that about 10% of the daily waste production by dairy cows is deposited in the milking shed, the total waste from dairy cows deposited in the milking shed and subsequently undergoing anaerobic digestion would be about 2,056,325kg of fresh waste per day. From the values in Tables 4.1 and 4.2, this would be expected to generate about 52,877,000L of biogas each day containing about 68% methane, or 35,956,360L of methane per day. The mass of methane generated would be about 25,665kg/d. The annual emissions of methane would be about 9,368 tonnes, equivalent to about 196,730 tonnes of carbon dioxide per year.

4.3.2 Methane Emissions from Pig Wastes

Virtually all pigs in New Zealand are housed and thus nearly all the wastes generated are able to be collected. However, as with the waste from dairy cows, the majority of the waste collected at piggeries is spread on farmland without treatment. Probably only about 40% of piggery wastes are treated in anaerobic lagoons or two-pond systems.

The census of pig numbers as at 30 June 2006 (Statistics New Zealand 2007 Agricultural Census) was 36,507 sows, 6,799 mated gilts and 312,195 ‘other pigs’. The other pigs would cover a range of ages and sizes depending on how far they were through the fattening cycle. Based on the values in Table 4.1, the mass of fresh pig waste probably produced each day is about 1,723,140kg.

Based on the values in Tables 4.1 and 4.2, and assuming 40% of the waste undergoes anaerobic decomposition, the volume of biogas containing 60% methane that could be generated each day would be about 21,600,000L. The mass of methane produced each year would then be about 3,376 tonnes, equivalent to about 70,895 tonnes of carbon dioxide.

4.3.3 Methane Emissions from Poultry Wastes

Virtually all chickens in New Zealand are housed and thus nearly all the wastes generated are collected. However, as discussed in Section 3.3.2, poultry wastes are generally collected in a relatively dry form and are not often washed into pond systems. Poultry waste that is collected dry is usually composted and often sold as fertiliser to home gardeners.

Nevertheless, there are a number of poultry farms that do collect the waste into pond systems for treatment prior to irrigation onto land, including the largest egg producing farm in New Zealand operated by Mainland Poultry at Waikouaiti near Dunedin.

As at 30 June 2006 (Statistics New Zealand INFOS Database) there were 12,513,270 broiler chickens (being raised for meat) and 3,324,740 layer chickens in New Zealand. Based on the discussion in Section 3.3.2, it is unlikely that any of the broiler chicken waste is treated in pond systems or in such a manner that significant emissions of methane are generated.

If it is assumed that 40% of poultry farms treat waste from layer hens in pond systems, the mass of fresh waste according to Table 4.1 that would be treated would be about 3,324,740 x 0.4 x 0.12 = 159,588kg/d. Based on the data in Tables 4.1 and 4.2, anaerobic breakdown of the mass of waste would be expected to generate about 15,958,760L of biogas containing 65% methane, or 6,835kg of methane. The mass of methane produced each year would then be about 2,495 tonnes, equivalent to about 52,395 tonnes of carbon dioxide. This figure is a hypothetical figure, however, as it is based on the assumptions as stated.

4.4 Geographic Potential for Biogas Generation Based on Climatic Differences in New Zealand

The potential for biogas (and methane) generation from management of animal wastes varies according to temperature, with the potential for more biogas being generated per kg of manure with increasing temperature. This is not because the ultimate generation of biogas differs but because higher temperatures result in higher generation of biogas over the period of management.

Table 4.3 indicates baseline methane production calculated for a range of locations within New Zealand using the IPCC (2006) methane emission model (Annex 1) for a large pig farm. This model uses a Methane Conversion Factor (MCF) operating on volatile solids in the manure that varies according to mean annual temperature. The MCF based on IPCC (2006) model calculations ranges from 75% in Whangarei to 66% in Invercargill (Table 4.3). In calculating methane production based on pig populations and data from a large (10,000 head) piggery, the methane produced through a non-heated biogas system (e.g. covered anaerobic lagoon) would vary by a factor of 13% from Invercargill to Whangarei. However, this could be offset by providing a longer retention time by constructing a larger anaerobic lagoon or digester. Alternatively, this would imply an additional 13% of process heat energy inputs would be required for a heated biogas digester system located in the Invercargill area to make up for greater heat losses due to radiation and more heat to warm the animal waste to the optimum digester operating temperature.

The same calculations for dairy cows and poultry indicate a similar 13% variance in methane production from Invercargill to Whangarei.

Table 4-3: Calculated CH_4 Emissions Based on a Large Pig Farm at Various Locations in New Zealand[1]

Location	Mean Annual Temperature (°C)	Methane Conversion Factor (MCF)[2] (%)	Max. Methane Producing Capacity for Pigs (B_0)[3]	Baseline CH_4 Production (t CH_4/year)[4]	CH_4 Production in CO2 Units (t CO_2/year)[5]
Whangarei	16	75	0.45	204	4,291
Hamilton	14	73	0.45	199	4,177
Masterton	13	71	0.45	193	4,062
Christchurch	12	70	0.45	191	4,005
Timaru	11	68	0.45	185	3,891
Invercargill	10	66	0.45	180	3,776

1 Data based on 10,000 head pig farm in the Wairarapa and modelled for each geographic location. Assume model uncertainty factor 20%.
2 MCF default value from IPCC (2006).
3 B_0 default value from IPCC (2006).
4 Manure management system is covered anaerobic lagoon. Methane calculations based on IPCC (2006) Tier 2 method.
5 Calculated as t CH_4 production/year X Global Warming Potential$_{CH4}$ (GWP) (21 tCO_{2e}/tCH_4).

4.5 Summary of Potential Methane Emissions from Animal Waste in New Zealand

The potential annual emissions of methane as estimated in the Sections above is summarised in expressed as carbon dioxide equivalent. The table does not include potential methane emissions from waste generated by other farmed animals in New Zealand (sheep, beef cattle, deer etc) that may occur from waste deposits in the field. Table 4-4 indicates that dairy cow waste from anaerobic treatment comprises a major part of the annual emissions.

Table 4-4: Summary of Potential Methane Emissions from Animal Wastes in New Zealand Expressed as Tonnes of Carbon Dioxide Equivalent Using a Global Warming Factor for Methane of 21

Animal	Source of Emissions	Annual Emissions (tonnes CO_2 equivalent)
Cow	Waste deposited in the field (cowpats)	30,030
	From anaerobic treatment	196,730
Pig	From anaerobic treatment	70,895
Chicken	From anaerobic treatment	52,395
Total		350,050

5 Potential Modifications to Current Waste Management Practices to Reduce Greenhouse Gas Emissions

5.1 Enhanced Collection and Management of Animal Wastes

5.1.1 Dairy Wastes

Most dairy farms in New Zealand are pasture-based (some may supplement feed with externally sourced material such as green crops or fruit and vegetable processing wastes). Deposited manure therefore only accumulates on permanent surfaces, from where it can be easily collected following milking sessions. In turn these sessions typically occur only twice per day and, at some farms under recent husbandry practices, once per day. Therefore, with current dairy cow husbandry practices the typical manure quantity which is collectible is 8 – 10% of the total daily manure production (Longhurst et al, 2000).

There are animal husbandry changes occurring that will have a significant effect on the quantity of collectible manure; while these changes are not driven by a primary desire to collect more manure this will in fact be a positive spin-off. These changes include the following:

- There is a trend towards laying concrete feed pads immediately prior to (in fact connected to) the milking shed pad. The intention is to increase milk production by facilitating supplementary feeding while the animals await milking. In terms of manure collectability such an increased hard cover area will allow significantly more manure (perhaps up to 20% of the total) to be collected.
- The trend to greater use of higher cost feed supplements has been accompanied by greater use of hard feed pads in contrast to the practice of feeding silage to cows out on pasture. This trend has two effects: it increases the quantity of waste produced per cow; and it increases the quantity of waste that is collected and handled through the effluent system.

Table 5-1: Trends in the Quantity and Nature of Feed Imported onto Average NZ Dairy Farm (Tonnes DM)

Feed Type	1998/99	2006/07	Change
Grass silage and hay	0.25	0.5	200%
Maize and cereal silage	0.1	0.6	600%
Concentrate	0.09	0.4	440%
Total per cow	0.44	1.5	340%

Source: DairyNZ

- At least in the colder climate areas of New Zealand, such as Southland, there is a significant move towards the provision of covered housing for the animals and their retention under cover on a 24-hour basis, at least over the winter months ((P. Stevens, pers comm.). Feeding is based on cut-and-carry of grass grown on-farm for consumption under cover. The end result is improved animal comfort and health, and major reductions in pasture and stock-race pugging problems. A further obvious spin-off for manure treatment is that 100% of the animals' waste production can be collected.
- There is a trend in some parts of New Zealand to grazing dairy cows off the farm through the June-July period. This is likely to increase as requirements around nitrate leaching limits are developed and their implementation expanded across catchments with sensitive water quality constraints.

These husbandry changes entail, on a pro-rata basis, less water wash-down and thus a more concentrated effluent is available for anaerobic digestion and biogas production. Recent papers in the literature have provided further details of management methods to reduce water use in dairy operations (e.g. South East Dairy Effluent Guidelines, No 17, 2005).

Continued mechanical improvements in manure scraper systems are also assisting the collection of greater quantities of manure and conservation of water use is leading to more concentrated manure being collected.

5.1.2 Pigs

Current manure collection at New Zealand piggeries is based on collection on concrete surfaces at (mainly) covered pens by mechanised scraper systems, followed by wash-down for cleaning purposes and collection of this further diluted effluent stream. In intensive pig farm operations based on permanently housed animals effectively 100% of the available manure can be collected.

These husbandry methods are unlikely to change at New Zealand piggeries in the future.

5.1.3 Poultry

Poultry farms, either for egg collection or fattening for meat (broilers), are typically based on permanently caged birds. The manure falls through the metal grille of the cage bottoms and is scraped up mechanically. Effectively all the manure can be collected.

The resulting manure is low in moisture content and is particularly suitable for disposal either by combustion or by composting. There has been limited use of poultry manure for biogas production in New Zealand (e.g. Mainland Poultry, Waikouaiti, near Dunedin) but the practice is not at all widespread.

There is not anticipated to be any significant changes to poultry farming methods, at least for egg collection or rearing for meat, in the foreseeable future.

5.2 Collection and Management of Greenhouse Gas Emissions

The use of anaerobic lagoons for waste treatment has been discussed in Section 3 above. By covering the ponds and either utilising the collected biogas for electricity generation or some other on-farm use, or by simply flaring the gas to produce carbon dioxide, around 75% of the GHG impact of the methane resulting from anaerobic digestion can be eliminated (source: MAF website). There are various available means of covering anaerobic lagoons; this is obviously made somewhat more difficult where the lagoons are particularly large but, typically, a satisfactory form of cover can be constructed by using a heavy duty material such as HDPE or similar plastic, with this either floating on the surface of the pond or held on a suitable frame.

As an alternative, the collected animal wastes can be utilised to generate biogas (around 50% methane) in a digester, as already described. Again, the biogas so generated can be used beneficially for electricity generation, as a vehicle fuel, to raise heat, or it can simply be flared to thus reduce GHG emissions.

A further alternative management methodology which greatly reduces or even eliminates methane generation is to treat the effluent aerobically; this implies an extensive energy input to drive the mechanical aerators which are required.

6 Potential Role of On-Farm Biogas Plants

6.1 Potential Benefits of Biogas Plants on Farms

The main feature of a biogas plant is the basin or tank in which the animal waste is broken down by naturally occurring anaerobic bacteria (bacteria that function in the absence of air) into biogas and water. Other components assist this process to take place and also capture the biogas generated. No inputs are required for the process itself, although heating the animal waste can increase the rate of the process and reduce the size of the basin or tank required.

The potential benefits of a biogas plant are:

- The raw animal waste is stabilised by the anaerobic process and converted to a less odorous liquid with lower solids content and a lower biochemical oxygen demand, and this is more suitable for spreading onto land as a fertiliser. However, the standard of treatment is not sufficient for the waste residue post-anaerobic digestion to be discharged to surface water.
- If the biogas is collected and burned so that the methane content is converted to carbon dioxide, the global warming effect that would otherwise result from the release of methane to the atmosphere is greatly reduced.
- The biogas collected can be combusted in a cogeneration engine to produce electricity.
- The biogas collected may be utilised as a fuel.

However, there is a significant capital cost in constructing a biogas plant and there will usually be operating inputs required by the farmer. These factors may offset the potential benefits.

As discussed earlier the application of rules made by regional councils under the RMA may mean that resource consents are required for farm activities such as disposal of animal wastes to land and possibly for the discharge of odorous contaminants to air, particularly in the case of large piggeries or dairy herd sizes. For each case a set of conditions, which may well be restrictive and onerous, will be placed on these consents.

Management of animal wastes by anaerobic digestion, either using anaerobic lagoon systems or via biogas plants results in the reduction of the biological oxygen demand (BOD) of the effluent and also in a reduction in odour by converting odorous compound precursors into non-odorous derivatives. It follows that anaerobic digestion can provide significant assistance in meeting consent conditions requirements and thus in achieving RMA compliance on farms.

A further benefit of anaerobic digestion of animal wastes is that the residue post-digestion (the so-called "digestate") is in a form which is much more amenable to soil assimilation and thus to environmentally safe disposal to land.

6.2 Concept Description of Biogas Plants

6.2.1 Covered Anaerobic Lagoon

The simplest form of biogas plant is an anaerobic lagoon with a cover. Ideally the lagoon should be lined with a membrane to ensure containment of the animal waste and prevention of any risk of contamination of the ground and groundwater below. The cover can then be welded to the liner to form a fully enclosed system.

Figure 6-1: Covered anaerobic lagoon treating meat processing wastewater, Invercargill.

Figure 6-1 above shows a large covered anaerobic lagoon treating meat processing wastewater at South Pacific Meats near Invercargill. The lagoon is lined and covered with an HDPE membrane. The biogas is currently burned in a flare.

Many covered anaerobic lagoons for treatment of animal wastes and reduction of greenhouse gas emissions are in operation in (for example) Brazil and Mexico, as shown in Figure 6-2 and Figure 6.3 below. The biogas is usually burned in a flare to reduce the greenhouse gas emissions and thus earn carbon credits. However, the covered anaerobic lagoons also play a role in waste treatment and some farmers utilise the biogas as a fuel.

Figure 6-2: Covered anaerobic lagoon in Brazil

Figure 6-3: Covered anaerobic lagoon in Mexico.

The main disadvantage of covered anaerobic lagoons under New Zealand conditions is that when the ambient temperature decreases the anaerobic breakdown process slows down, treatment performance reduces and biogas generation drops off as well. This makes utilisation of the biogas difficult as, just when the demand for process heat increases in winter, the availability of biogas as a fuel is at its lowest.

In contrast, in warmer climates like Mexico and Brazil, anaerobic activity remains high over most of the year.

Covered anaerobic lagoons also need to be constructed with a system of sludge removal pipes to facilitate periodic removal of inert solids and sediment (sludge) that would otherwise accumulate and reduce the active volume of the lagoon.

6.2.2 Biogas Digester

A biogas digester overcomes the variable performance of a covered anaerobic lagoon by including a means of heating the waste in the digester to a steady operating temperature of typically 35^{o}C (the optimum ‘mesophilic’ temperature) or about 55^{o}C, referred to as the ‘thermophilic’ temperature.

A biogas digester thus produces a steady output of biogas, provided that the input of animal waste stays at the same level. However, a disadvantage is that a proportion of the energy in the biogas has to be used to heat the animal waste in the digester. This is the case even when the biogas is used to generate electricity and what might otherwise be waste heat is used to heat the digester. Another disadvantage is that a biogas plant has a much higher capital cost than a covered anaerobic lagoon of equivalent animal waste capacity, even though its volume and ‘footprint’ will be much smaller. Figure 6.4 shows a typical digester (200 m^3) from the Landcorp Farm, Eyrewell, Canterbury that began operation in 2008. Figure 6.5 shows a typical biogas-diesel cogeneration engine for electricity generation.

Figure 6-4: Biogas digester and engine shed, Landcorp Farm, Eyrewell, Canterbury

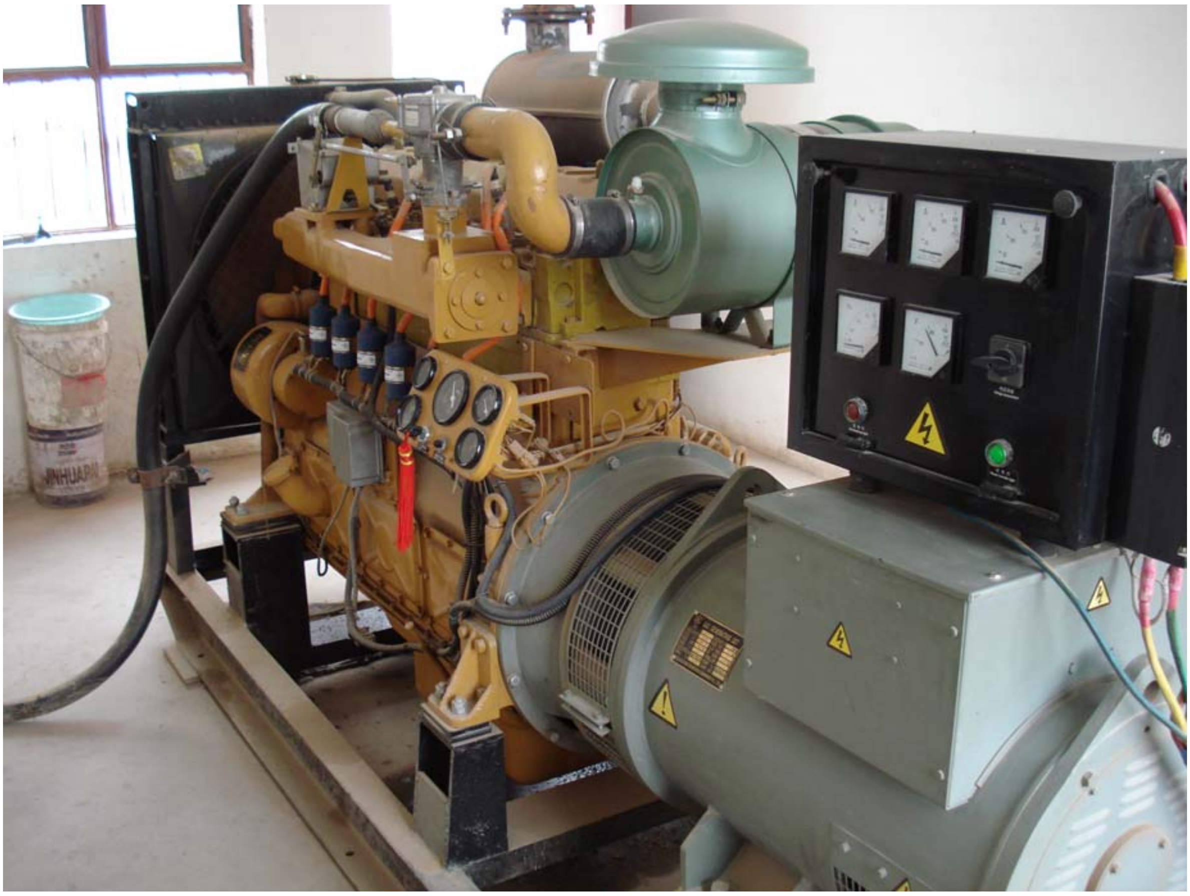

Figure 6-5: Biogas-diesel cogeneration engine for electricity generation

The typical components of a biogas plant are shown in Figure 6.6.

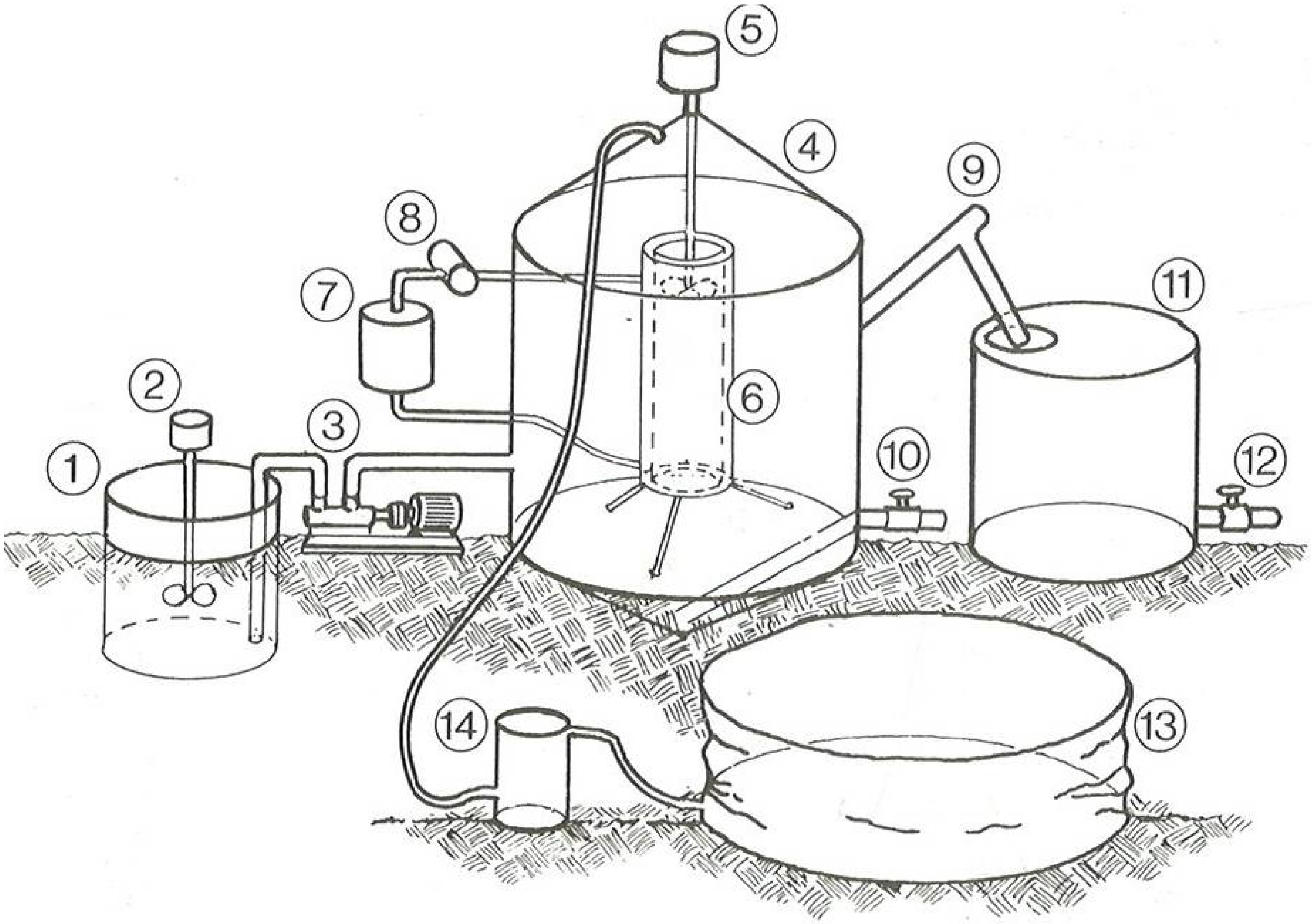

Fig. 1 : Components of a biogas plant. (1) Pre-mix tank; (2) Mixer; (3) Loading pump; (4) Digester; (5) Digester mixer; (6) Heat exchanger/eductor tube; (7) Water heater; (8) Circulating pump; (9) Effluent overflow pipe; (10) Sludge drain; (11) Effluent storage tank; (12) Effluent tank outlet; (13) Biogas storage bag; (14) Biogas filter to remove sulphides.

Figure 6-6: Components of a typical biogas plant

6.3 Historical Perspective of Biogas Plants in New Zealand

In the mid-1970s when the 'oil crisis' made the world aware of its dependence on oil from the Middle East, New Zealand like many other countries evaluated alternatives for energy supply. 'Car-less' days were introduced, and the New Zealand Government boosted staff in the Ministry of Energy and established the New Zealand Energy Research and Development Committee and the Liquid Fuels Trust Board. These organisations carried out a systematic study of the potential to produce transport fuels from biomass, including waste materials and crops grown for fuel production. In parallel, a programme of utilisation of compressed natural gas (CNG) from New Zealand's Maui gas field for use as a vehicle fuel was promoted and at one stage reached 100,000 vehicle conversions.

Farmers became aware of their need for diesel fuel to keep farms operating and their vulnerability to restrictions on supply. A number of farmers grew rape (canola) and produced rapeseed oil to replace diesel whilst other farmers constructed biogas plants on their farms, with the aim of using compressed biogas (CBG) in the same manner as CNG. A simple farm scale system for purification and compression of biogas was developed by Ministry of Agriculture scientists who were able to assist farmers to establish biogas plants and CBG stations.

By the mid-1980s there were sixteen biogas plants on farms in New Zealand. Several tour groups came from Sweden, Denmark and Germany to learn from the New Zealand experience of CNG, the design and operation of farm biogas plants and the use of biogas as CBG.

When Roger Douglas became Finance Minister in the 1984 Labour Government and promoted his belief that all enterprises should be driven by economic forces, he also disbanded the New Zealand Energy Research and Development Committee and the Liquid Fuels Trust Board, and discontinued the strategic planning role of the Ministry of Energy. Government support for the CNG programme in New Zealand was also discontinued. The Ministry of Agriculture group that had developed the biogas programme was diverted to earning income through application of the technology to waste treatment projects and was eventually sold off to private enterprise.

As a result of the elimination of technical support for biogas plants on farms, along with the real price of petrol and diesel reducing and supplies seeming to be restored, the biogas plants in New Zealand gradually closed down.

In contrast, whilst the biogas programme in New Zealand slowly went out of existence, in other countries such as Sweden, Denmark and Germany, from which tour groups had come to learn from New Zealand's technology, biogas technology has continued to develop steadily to the extent that today CBG can be purchased at service stations, some communities are supplied with most of their energy in the form of biogas and in Sweden there is even a train service fuelled by biogas. The development of biogas production and use in these countries has been driven by environmental concerns, including the reduction in greenhouse gas emissions, increasingly stringent environmental standards regarding discharges to land and water, mitigation of odour issues from animal waste management and sustainability of the fuel supply.

6.4 Utilisation of Biogas as a Fuel

6.4.1 Utilisation for Process Heat

Biogas can be used as produced in heaters and boilers, although it is advisable to remove the hydrogen sulphide content to reduce the risk of corrosion of appliance components (see section 6.4.4).

Where the biogas plant is based on a digester operated at 35 °C or 55 °C, the primary use for the biogas is to heat the digester. This may utilise most of the biogas produced, especially if the feedstock is an animal waste such as cow manure that does not produce a high yield of biogas. A larger quantity of biogas will be used in colder parts of the year because the animal waste will probably be colder and heat losses from the digester will be higher.

The disadvantage of using surplus biogas for process heat is that usually the requirement for process heating is highest over the winter months, which is when the biogas surplus will be least. It is not feasible to store biogas for much more than one day because of its high volume, so it cannot be stored for use in winter. This can lead to poor utilisation of the biogas generated and hence poor economics.

If there is a use for surplus biogas that extends throughout the year, such as a fuel for a brick-making kiln, the utilisation of biogas can be high and the economics of biogas production and use will be much more favourable. However, such uses are not common.

6.4.2 Utilisation for Electricity Generation

Biogas can be used as produced in a gas engine (or a modified petrol or diesel engine) connected to a generator set to generate electricity. Again, it is advisable to eliminate the hydrogen sulphide content to reduce the risk of corrosion of engine components.

Burning biogas in a generator converts only about 35% of the energy in the biogas to electrical energy, with the remainder of the biogas energy being converted into heat. However, this heat can be captured from the engine by the radiator and the heated water can then be used for digester heating by circulating it through a heat exchanger inside the digester. This can result in good efficiency in the use of the biogas energy.

A major advantage of using biogas to produce electricity is that there is likely to be a demand for electricity throughout the year, not only on the farm but throughout the country. If the farm is unable to use all the electricity produced, there is a national electricity grid into which surplus electricity can be fed.

Another advantage of producing electricity is that electricity has a higher value than the raw biogas and thus the economic return is higher.

6.4.3 Utilisation as Vehicle Fuel

Biogas can be used as produced to fuel vehicles but the performance of the vehicles will be poor due to the relatively low energy density of biogas and the spatial range of biogas-fuelled vehicles will be limited because it is difficult to carry a large volume of biogas on a vehicle. It is therefore necessary to purify and compress biogas to achieve good engine performance and to be able to travel a reasonable distance.

Biogas can easily be purified by washing with water under pressure to dissolve the carbon dioxide content and to also absorb contaminants such as hydrogen sulphide. A simple 'scrubber' system that can be operated in conjunction with the compression of the biogas was developed by Ministry of Agriculture scientists in 1979. It was based on a process developed in Germany during the Second World War and since also applied in the UK and the USA. The process is described in the New Zealand Ministry of Agriculture Aglink FPP 665, "Energy: Biogas Scrubbing, Providing Methane for Vehicle Fuel", published in 1983.

A New Zealand example of using biogas for vehicle fuel is a biogas plant constructed in 1981 on the poultry farm owned by the Winmill family at Waikouaiti, just north of Dunedin. The biogas plant comprised four $45m^3$ digesters made of cast-in-situ concrete panels. Initially the digesters were heated with electricity to free all the biogas produced for use as vehicle fuel. At one stage 28 vehicles were fuelled with compressed, scrubbed biogas (about 96% methane) including cars, trucks, tractors and the local mail van and taxi. As electricity prices rose a wood-fired boiler was used for digester heating. Some of the gas was also used in place of electricity to heat the building in which broiler chickens were raised and a large steel pressure tank was used to store the gas. The biogas plant closed around 1999 when major expansion of the poultry farm occurred and the farm ownership changed.

A potential advantage of using biogas as a vehicle fuel is that there is likely to be enough demand throughout the year for the CBG to fuel farm vehicles, and also cars and trucks owned by the farmer. Another advantage of using the biogas as CBG is that as a vehicle fuel it has the highest value so that the economic return is likely to be higher, despite the additional capital expenditure and operating costs for purification and compression. However, despite these potential advantages of biogas as a vehicle fuel, it is no longer used for this purpose in New Zealand and there is limited data available for this use in New Zealand. For this reason, economic analysis of biogas for vehicle use was not conducted in Section 8.

6.4.4 Removal of Contaminants from Biogas

The most significant contaminant in biogas produced by anaerobic digestion of animal manures is hydrogen sulphide. This is an acidic gas and can give rise to significantly increased corrosion in the biogas reticulation system, including a gas engine if this is used, if it is not removed.

The most common means of removing hydrogen sulphide from biogas is by water scrubber (see note in section 6.4.3 above). While this is an effective approach it does have an associated energy input requirement to operate the scrubber system. A dilute alkaline scrubbing solution greatly enhances H_2S removal efficiency but there is then a requirement for safe disposal of the spent solution. An alternative approach is to pass the biogas through an activated carbon filter. This, again, is an effective means of removing H_2S but there is an ongoing requirement to regenerate or replace the filter material on a regular basis, depending on the loading rate.

Recently, new biologically-based methods of biogas purification have become available. Conventional biofiltration is one such method and trickling filters have also been used. A further biological method which is gaining widespread acceptance is the use of thiobacillus species in a fixed film reactor based on plastic rings within a packed column. The method has low operating costs and achieves effectively total removal of hydrogen sulphide from the biogas stream (Ranade and Dighe).

7 Modelling of Biogas Generation for Specific Farm Types

7.1 Model Development

7.1.1 Approach

The approach to modelling of farm biogas plants in this project is based on four sets of calculations:

1. Manure Generation
2. Biogas Generation
3. Baseline Methane Emissions Prior to Biogas Collection and Management
4. Economic Modelling of Various Livestock Types, Farm Sizes, and Biogas Applications

The assumptions made and detailed calculations for each step are given in Annex 1.

In order to keep the scope of the modelling studies manageable, it was decided to undertake calculations for seven different farm types that could be expected to be reasonably representative of New Zealand dairy, pig and poultry farms. These farm types are given in Table 7-1. Field visits were made to examples of larger dairy (Landcorp Farm, Eyrewell, Canterbury) and pig farms (Noel Read Farm, Wairarapa) with biogas experience, to verify assumptions and input data. Prior experience from work done by one of the authors on the Waikouaiti poultry farm biogas system was applied in verifying the poultry modelling input data.

Table 7-1: Farm Types

Livestock Type	Head (no.)
Dairy cows (10% manure collectible)	500
Dairy cows (60% manure collectible)	500
Dairy cows – large herd (10% manure collectible)	900
Dairy cows – large herd (60% manure collectible)	900
Pigs	1,000
Pigs – large piggery	10,000
Poultry (layer hens)	50,000

7.2 Manure Generation

Manure generation for each of the seven farm types was calculated (Table 7.2) using the equations in Annex 1, Section 2.1.

Two manure collection scenarios were assessed for dairy cows:

1. Common current practice where manure is only collected during milking (10% of total manure generated), and

2. Management practice where dairy cows spend up to 60% of their time housed or on concrete pads where manure can be collected ("herd home" concept). Research work is being undertaken in the Waikato with the herd home concept and some farms in Southland are also considering large scale housing of dairy cows (P. Stevens, pers comm.). Under such a scenario, it was assumed that 60% of manure was collectible for modelling purposes.

Data in Table 7-2 indicates relatively small amounts of collectible total solids manure available for biogas generation from smaller dairy and piggery operations, especially dairy cows under typical management practices where a low percentage of manure is collectible. Under the "herd home" management practice the potential for manure collection is much higher as indicated in the total collectible manure/day. As a result, the manure management practice used for dairy cows is a key factor influencing raw material quantities collectible for biogas digestion. In addition, cows are typically milked for 10 months per year with the result that manure can only be collected from each cow for 10 months of the year. This has been factored into the analysis.

Percentage of collectible manure for pigs and poultry is assumed to be 100% because pigs and poultry are housed, thus enabling virtually all manure to be collected. The volume of manure generated by poultry is small per bird and the manure has a higher percentage of total solids per kg of raw manure than for dairy cows and pigs. This may also relate to the method of collection in that most poultry manure is scraped, rather than hosed down as is the case for dairy cow and pig wastes.

Table 7-2: Daily Manure Generation on Typical New Zealand Farms

Livestock Type	Head (No.)	Raw Manure/ Animal (kg/day)[1]	Total Solids (% of Fresh)[1]	Manure TS (kg/d)	Wash Water (L/animal)	Manure as Collected		Total Manure (Liquid and Total Solids) (kg/d)	Total Manure TS (kg/d)	% Collectible	Total Collectible Manure (kg/d)	Total Collectible Manure TS (kg/d)
						L/animal	%TS					
Dairy cows (10% manure collectible) /a	500	35	13	4.5	50	85	5.3	42,500	2,250	10	4,250	225
Dairy cows (60% manure collectible) /a	500	35	13	4.5	50	85	5.3	42,500	2,250	60	25,500	1,365
Dairy cows - large herd (10% manure collectible) /a	900	35	13	4.5	50	85	5.3	76,500	4,050	10	7,650	405
Dairy cows - large herd (60% manure collectible) /a	900	35	13	4.5	50	85	5.3	76,500	4,050	60	45,900	2,430
Pigs/b	1,000	5	9	0.45	10	15	3.0	15,000	450	100	15,000	450
Pigs - large piggery/b	10,000	5	9	0.45	10	15	3.0	150,000	4,500	100	150,000	4,500
Poultry/c	50,000	0.12	25	0.03	0.1	0.22	13.6	11,000	1,500	100	11,000	1,500

[1] Data from New Zealand Ministry of Agriculture and Fisheries AgLink FPP603 (1985)

Notes:
/a 500kg milking cow milked for 10 months/year
/b Combination of breeding sows and fattening pigs based on field visit data, assuming 10% sows and boars, 90% fattening pigs of varying ages and weights
/c Laying hens

7.3 Biogas Generation

Potential biogas and methane generation from each of the farm types is given in Table 7-3. Calculations for dairy farms assume 10 months milking per year.

For the seven farm types, overall potential volumes of biogas vary considerably, from 46m^3/day for a 500 head dairy herd using typical current herd management practices (10% manure collectible) to 1,395m^3/day for a large pig farm where 100% of manure is collected. As a result, different biogas systems and amount of biogas for use varies considerably among farm types and manure management practices.

Methane content of the biogas varies among animal types, and average figures from Table 4.2 are used for each animal type (i.e. 68% for dairy cow biogas, 60% for pig biogas, and 65% poultry biogas). Converting the potential volume of biogas produced to methane, the weight of methane produced ranges from about 6 tonnes/year for a 500 head dairy herd under traditional manure management systems (10% collectible) to 69 tonnes/year for a 900 head dairy herd with 60% manure collection. Due to the higher collectible proportion (100%) for pigs, the large pig farm with 10,000 head would generate about 205 tonnes of methane per year. In terms of CO_2 equivalents, the methane potentially produced ranges from 134 t CO_2e/yr for the 500 head dairy herd (10% manure collectible) to 4,298 t CO_2e/year for the large pig farm. These data become important in terms of calculation of the potential for biogas in terms of generating carbon credits through reductions in methane emissions.

Table 7-3: Potential Daily Biogas Generation from Anaerobic Digestion of Manure Produced by Typical New Zealand Farms

Livestock Type	Head (No.)	Total Collectible Manure (kg/d)	Total Collectible Manure TS (kg/d)	Typical Volume Biogas Produced /a (L/kg TS)	Potential Volume of Biogas (L/day	% Methane in Biogas	Potential Volume of Methane (L CH_4/day)	Density of CH_4 (kg/L)	Kg CH4/ day	Kg CH_4/yr /b	t CH_4/yr	t CO_2e/ yr
Dairy cows (10% manure collectible)	500	4,250	225	205	46,125	68	31,365	0.00067	21	6,392	6.4	134
Dairy cows (60% manure collectible)	500	25,500	1,350	205	276,750	68	188,190	0.00067	126	38,352	38	805
Dairy cows - large herd (10% manure collectible)	900	7,650	405	205	83,025	68	56,457	0.00067	38	11,505	11.5	242
Dairy cows - large herd (60% manure collectible)	900	45,900	2,430	205	498,150	68	338,742	0.00067	227	69,033	69	1,450
Pigs	1,000	15,000	450	310	139,500	60	83,700	0.00067	56	20,469	20	430
Pigs - large piggery	10,000	150,000	4,500	310	1,395,000	60	837,000	0.00067	561	204,688	205	4,298
Poultry	50,000	11,000	1,500	375	562,500	65	365,625	0.00067	245	89,414	89	1,878

Notes:

/a Based on typical values for volume of biogas/kg TS at 20-day retention time using B_0 values for each livestock type (IPCC 2006).
/b For dairy farms assume 10 months milking although herd management will vary from farm to farm.

Digester volume required varies considerably among the various farm types in relation to amount of collectible manure total solids (Table 7.4). In calculating the digester volume, it is assumed that a 20 day retention time is required based on the fresh volume of total collectible manure plus any water used in collection (MAF, 1985). However, MAF (1985) recommends that it is worthwhile building a digester up to 50% larger than necessary because the additional cost is likely to be small. This can allow for some additional capacity during peak periods, and for short periods production can be also be boosted to up to double the usual rate by loading more material into the digester each day (MAF, 1985). For the scenarios modelled, the required digester size varies from 85m^3 for a 500 head dairy herd to a capacity of 3,000m^3 for a large piggery operation (Table 7-4). If the additional capacity recommended by MAF (1985) is incorporated, then the recommended digester size would be about equal to the potential volume of biogas per day column in Table 7-4. Under this scenario, the smallest digester size for the seven farm types would be about 85m^3 in volume.

Table 7-4 also includes anaerobic lagoon volume required to manage the fresh volume of total collectible manure and wash water where an anaerobic lagoon is the manure management system used.

The calculations in Table 7-4 assume that part of the biogas volume is required to heat the digester to operate at the optimum temperature of 35^{o}C. This temperature will vary with location, boiler efficiency, digester insulation, and temperature of the feedstock entering the digester. For the purpose of calculations in Table 7-4, it has been assumed that the feedstock temperature is 15^{o}C, the biogas has an energy content (Lower Heating Value) of 20MJ/m^3, and a boiler efficiency of 75%. Based on these assumptions, it is estimated (D. Stewart, *pers comm*) that the approximate amount of biogas used for digester heating is on average about 25-40% for dairy cows, 15% pigs, and 8% poultry. The difference in the proportion of biogas generated that is used for heating the digester is largely due to the different amounts of biogas that are generated from the different wastes but is also affected by the water content of the waste, ambient temperature, and digester insulation. For dairy shed effluent, the proportion used for heating can be up to 50% in winter. Once the amount of biogas used for heating has been subtracted, the remaining biogas is available for other uses.

Table 7-4: Digester, Lagoon and Biogas Volumes

Livestock Type	Head (No.)	Total Collectible Manure (including collection water) (kg/d)	Digester Volume Required /a (m^3)	Lagoon Volume /b (m^3)	Potential Volume of Biogas /c (m^3/day	Biogas Used for Digester Heating /c (m^3/day)	Potential Net Biogas Volume (m^3/day)	Potential Volume of Biogas (m^3/year)
Dairy cows (10% manure collectible)	500	4,250	85	128	46	12	35	14,030
Dairy cows (60% manure collectible)	500	25,500	510	765	277	69	208	84,178
Dairy cows - large herd (10% manure collectible)	900	7,650	153	230	83	21	62	25,253
Dairy cows - large herd (60% manure collectible)	900	45,900	918	1,377	498	125	374	151,521
Pigs	1,000	15,000	300	450	140	21	119	50,918
Pigs - large piggery	10,000	150,000	3,000	4,500	1,395	209	1,186	509,175
Poultry	50,000	11,000	220	330	563	45	518	205,313

Notes:
a/ Based on a 20-day retention time, volume = 20 x daily manure volume (as collected)
b/ Based on a 30-day retention time = 30 x daily manure volume (as collected)
c/ Based on typical values for volume of biogas/kg TS at 20-day retention time using B_0 values for each livestock type (IPCC 2006).
d/ Assumes use of some of the biogas for heating the digester to operate at 35^{o}C, feedstock 25^{o}C, biogas contains 20MJ/m3, and boiler efficiency of 75%. Assumes 40% cows, 15% pigs, 8% poultry.

7.4 Biogas Use

In the 1970's when there were a number of biogas plants operating in New Zealand the main use for the biogas was for fuelling vehicles, both petrol and diesel. Some biogas was used for heating purposes and at one plant the biogas was used to generate electricity. At that time, the biogas was more valuable as a vehicle fuel than for conversion to electricity.

The two most common major uses of on-farm biogas produced by biogas plants overseas are for a) generation of electricity through combustion in a co-generation plant and b) use to produce heat for warming animal sheds and homes. In New Zealand the only operating biogas plant that uses the biogas for generating electricity with heat exchange for milk cooling purposes is at the Landcorp Farm, Eyrewell, Canterbury.

7.4.1 Heat Cost Savings

The potential of biogas for process heat savings will vary by farm type, farm size and whether or not energy is used for process heat as part of the farm operation. Examples of potential uses of process heat could include pig or poultry shed heating; heat exchange for milk cooling in dairy farms, such as at the Landcorp Farm, Eyrewell, Canterbury; and water heating for plant cleaning (which is a significant energy use). It could also include substitution for use of electricity for heating of pig sheds where farms use heat lamps for maintaining shed temperatures. It is not practical to model all of the potential farm size, type, biogas system and heat use scenarios.

Table 7.5 shows potential heating cost savings (expressed in terms of diesel saved) and electricity generation potential for the seven farm types analysed. Diesel is used for comparison with biogas and electricity generation as a means of depicting the energy content of biogas relative to a fossil fuel whose energy content is readily understood.

The analysis of potential heat cost savings is based on the following assumptions:

1. Heat energy is generated by combustion of biogas in a co-generation engine and part of the excess heat generated is available for on-farm use.
2. Biogas tank digestion system and a percentage of the biogas heat energy generated is used to heat the digester to maintain optimum digestion conditions (350C). The percentage used for digester heating is assumed to be 40% for dairy cow manure, 15% pigs, and 8% poultry (D. Stewart pers comm.). This figure will vary based on water content of the manure as collected, tank insulation, air temperature, and season.
3. Substitution of diesel by biogas as the energy source (1 m3 biogas is equivalent to 0.5 kg diesel heat energy).
4. Cost calculations are based on the current (July 2008) retail diesel price (NZ$1.84/litre) and sensitivity analysis is conducted for -10%, +10%, +25% of the current retail price.

Results in Table 7-5 show significant amounts of potential diesel energy could be saved by use of the process heat generated by biogas, especially for the large pig farm scenario where the surplus heat generated could be used to substitute for diesel-fired boiler or other energy sources for pig shed heating. Significant amounts of surplus heat could potentially be available also from the large dairy herd with 60% manure collection management and from the large poultry operation. Smaller potential savings are feasible from the smaller farm sizes analysed.

Table 7-5: Biogas Potential for Heating Cost Savings and Electricity Generation Potential

Assumptions			
Gas-electricity conversion 2.0 KwH/m^3 gas	2.0	Biogas system self consumption:	
Heat value of biogas 22MJ/m^3 (4780 Kcals/m^3)		Dairy	40%
1 m3 biogas = 0.5 kg diesel heat energy	0.5	Pigs	15%
		Poultry	8%

	Dairy 500 Head (10% manure collection)	Dairy 500 Head (60% manure collection)	Dairy 900 Head (10% manure collection)	Dairy 900 Head (60% manure collection)	Pig Farm 1,000 Head	Pig Farm 10,000 Head	Poultry
Total biogas produced per year (m^3/year)	14,030	84,178	25,253	151,521	50,918	509,175	205,313
Heating Cost Savings							
Losses: Energy used to heat biogas digester (m^3/yr)	5,612	33,671	10,101	60,608	7,638	76,376	16,425
Net Biogas available for heat energy generation (m^3/yr)	8,418	50,507	15,152	90,912	43,280	432,799	188,888
Net Diesel/petrol heat energy (kg) saved by biogas/yr	4,209	25,253	7,576	45,456	21,640	216,399	94,444
Diesel Cost Savings (NZ$) ($1.66) -10%	6,987	41,921	12,576	75,457	35,922	359,223	156,777
Diesel Cost Savings (NZ$) ($1.84) Current Price (July 2008)	7,744	46,466	13,940	83,639	39,817	398,175	173,777
Diesel Cost Savings (NZ$) ($2.02) +10%	8,502	51,012	15,304	91,821	43,713	437,127	190,776
Diesel Cost Savings (NZ$) ($2.30) +25%	9,680	58,083	17,425	104,549	49,772	497,719	217,221
Tonnes diesel saved/yr	4	25	8	45	22	216	94

	Dairy 500 Head (10% manure collection)	Dairy 500 Head (60% manure collection)	Dairy 900 Head (10% manure collection)	Dairy 900 Head (60% manure collection)	Pig Farm 1,000 Head	Pig Farm 10,000 Head	Poultry
Electricity							
Potential power generation capacity (kw/yr)	28,059	168,356	50,507	303,041	101,835	1,018,350	410,625
Engine capacity (kw)	7	40	12	70	20	195	80
Engine biogas consumption/hr (assume 60% efficiency) (m^3)	4.2	24	7.2	42	12	117	48
Daily consumption (Assume 12 hrs) (m3/day)	50	288	86	504	144	1,404	576
Operating months/year	10	10	10	10	12	12	12
Potential Annual consumption by engine (m^3/yr)	15,330	87,600	26,280	153,300	52,560	512,460	210,240
Electricity Cost Savings (NZ$)/year ($0.084/kwh) Spot price	2,357	14,142	4,243	25,455	8,554	85,541	34,493
Electricity Cost Savings (NZ$)/year ($0.12/kwh) (-34%)	3,367	20,203	6,061	36,365	12,220	122,202	49,275
Electricity Cost Savings (NZ$)/year ($0.15/kwh) (-16%)	4,209	25,253	7,576	45,456	15,275	152,753	61,594
Electricity Cost Savings (NZ$)/year ($0.18/kwh) Current	5,051	30,304	9,091	54,547	18,330	183,303	73,913
Electricity Cost Savings (NZ$)/year ($0.21/kwh) (+16%)	5,892	35,355	10,606	63,639	21,385	213,854	86,231
Electricity Cost Savings (NZ$)/year ($0.23/kwh) (+28%)	6,454	38,722	11,617	69,699	23,422	234,221	94,444
Electricity Cost Savings (NZ$)/year ($0.25/kwh) (+39%)	7,015	42,089	12,627	75,760	25,459	254,588	102,656

In terms of potential cost savings, the amount of diesel cost saved is significant in most cases, especially for the larger farm operations. However, the real magnitude of such savings would depend on the switching costs from current sources of heat energy to biogas-generated heat energy and associated plant and equipment.

While Table 7-5 indicates significant potential savings substitution of biogas for diesel as an energy source for process heating, discussions with farmers indicate that fewer farms are currently using diesel for heating because of the diesel price, and most use electricity. As a result, electricity cost savings from biogas for process heating are probably more attractive than diesel substitution at present.

7.4.2 Electricity Generation

The analysis of potential electricity generation is based on the following assumptions:

1. Biogas is combusted in a co-generation engine and used to generate electricity for on-farm use. It is also assumed that any excess electricity can be sold back into the local grid at wholesale prices.
2. Biogas tank digestion system so that the biogas generated can be captured for combustion in the co-generation plant.
3. About 10% of any electricity generated would be required to run the biogas system.
4. Co-generation plant would run an average of 12 hours per day, and the plant would operate 365 days per year for pig and poultry farms, and 10 months per year for dairy farms. This also assumes that adequate biogas is generated at all times to enable the co-generation plant to run.
5. A co-generation engine with the appropriate capacity is available to use all of the biogas generated. In practice, there is likely to be a very limited size and generation capacity range for biogas rated generation sets in the 10-50Kw range. For the farms with smaller biogas generation potential (dairy 500 and 900-head 10% manure collection, pig farm 1000 head), the analysis in Table 7-5 is used to demonstrate the theoretical potential or otherwise of electricity generation using biogas for such farms rather than perhaps being a practical option.
6. Cost calculations are based on a typical farm supply electricity price (NZ$0.18/kwh) and breakeven electricity price where this is higher than the current price of $0.18/kwh. For large scale pig production, sensitivity analysis was conducted for prices of $0.15/kwh and $0.21/kwh (+/-16% current price). Price data was obtained from Ministry of Economic Development Schedule of Domestic Electricity Prices, 15 February 2008. It is likely that farms with large electricity consumption would obtain price discounts from electricity suppliers, and that the prices used may be high in some cases.
7. Cost calculations in Table 7.5 do not include switching costs and cost of generation plant installation. Such costs are included in the economic analysis.

Results in Table 7-5 indicate significant electricity generation potential, especially for the larger pig farm scenario where there is significant potential for electricity cost savings, especially as the cost of electricity increases. The required generator sizes given in Table 7-5 are indicative only based on the above assumptions. A practical approach would be to install an appropriate generator size that is readily available and run it for the required hours to consume the available biogas, and also to provide sufficient gas storage to even out the variation in rate of gas generation over the day and from day to day. This would mean that all the gas available (assuming digester heating by the engine radiator cooling water system) would be available for conversion to electricity, but this would not be spread over the full day. The full value of the electricity generation would only be realised if it could be exported to the grid or if the farmer can match his operations to when the electricity is being generated.

The purpose here is to show the potential value of the electricity that could be generated with the proviso that it would require management to obtain full utilisation.

In situations where electricity is generated and the surplus heat is used for farm process heating, there is considerable potential for energy substitution and cost savings. However, this potential will vary considerably according to each farm's specific parameters.

7.5 Baseline Emissions Assuming Anaerobic Lagoon

In order to calculate potential C credits, it is necessary to first calculate the potential baseline methane emission (in CO_2 equivalents) under a pre-biogas situation. The IPCC (2006) model for calculation of baseline emissions based on open lagoon systems was used to estimate the baseline emissions from each farm type prior to the introduction of biogas systems. The model was then used to estimate the potential net emission reductions for each of the seven farm types under a biogas capture and management system. This model is described in Appendix 1, Section 2.3.

For the purposes of this study, the following assumptions were made:

1. Central New Zealand location with mean annual average temperature of 13 0C.
2. Open anaerobic lagoon is the baseline livestock waste management system.
3. 10% leakage from the biogas system.

The calculated potential baseline emissions, potential leakage, and net emission reductions from investment in biogas are summarised for the seven farm types in Table 7-6.

Table 7-6: Calculated Annual Baseline Emissions and Net Emission Reductions from Biogas[1]

Livestock Type	Head (No.)	Baseline Emission		Potential Leakage from Biogas System		Potential Net Emission Reduction	
		t CH_4	t CO_{2e}	t CH_4	t CO_{2e}	t CH_4	t CO_{2e}
Dairy cows (10% manure collectible)	500	6.4	134	0.6	13	5.8	121
Dairy cows (60% manure collectible)	500	38	805	3.8	80	34	725
Dairy cows - large herd (10% manure collectible)	900	11.5	241	1.1	24	10.4	217
Dairy cows - large herd (60% manure collectible)	900	69	1,450	6.9	145	6.2	1,305
Pigs	1,000	20	430	2.0	43	18	387
Pigs - large piggery	10,000	205	4,298	20	430	185	3,868
Poultry	50,000	89	1,878	9	188	80	1,690

[1] Based on calculations using IPCC (2006) model.

The largest baseline emissions and potential net emission reductions would occur with the large piggery, large poultry, or large dairy herd with 60% manure collection. The potential net emission reductions (t CO_{2e}) are the potential C credits that could be accrued under each of the farm types. These data have been used in the economic model to assess the economic impact of C credits from biogas investment.

8 Economic Analysis of Biogas Systems for Specific Farm Types

Economic analysis was conducted for the seven farm types in Table 7.6. Biogas systems analysed varied among farm types ranging from covering of an existing anaerobic lagoon for biogas capture, construction of a new, lined anaerobic lagoon, and tank digestion for larger farms with large manure volumes. For each of these biogas capture types, economic analyses were conducted for electricity generation, gas flaring for C credits, and a combination of these activities. The assumptions made in the economic analysis are described in Annex 1, Section 2.4.

Economic analysis of process heat from biogas generation as a diesel substitute was not conducted due to the current high price of diesel and use of diesel for process heating no longer seems to be a common practice. It should be noted that pig farms visited during the study used heat lamps for heating of pig sheds because of the relatively cheaper price of electricity compared to diesel combustion for heating.

8.1 Dairy Cows 500 Head Herd, 10% Manure Collection

Analysis was conducted for a typical 500 head dairy herd where cows spend most of their time in the pasture and only 10% of the manure produced is collected (from dairy sheds at milking time). Analysis was conducted for biogas generation and capture scenarios of a) covering an existing lagoon (or ponds) of appropriate volume (128m^3), b) development of a new lined lagoon of appropriate volume (128 m^3), and c) tank digestion (85 m^3) for generation and capture of biogas.

8.1.1 Covered Existing Lagoon (128m^3)

Results in Table 8.1 indicate that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices. Investment in biogas for electricity generation at this small scale would only become viable at an electricity price of $0.77/kwh, which is much higher than the current price to farms (typically about $0.18/kwh). Investment in biogas for C credits from gas flaring would only become viable at about $178/t CO_{2e}, a price that is much higher than the current EC C market price of about $40/t CO_{2e}. Combining returns from electricity generation and C credits on emission reductions would only become viable at an electricity price of about $0.44/kwh and C credit price of $105/t CO_{2e}.

Table 8-1: Economic Analysis Dairy Cows 500 Head Herd, 10% Manure Collection (Covered Existing 128m^3 Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $45,900 Operating: $14,060/yr	$0.18/kwh	-	-92,053	-	Current typical price
	$0.77/kwh	10.2	421	7.1	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $27,400 Operating: $15,560/yr	$40/t CO_{2e}	-	-93,170	-	Current price, EU C market
	$178/t CO_{2e}	10.1	105	7.1	Breakeven price

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity generation and C credits on ERs Costs: Capital: $48,400 Operating: $15,560/yr	$0.18/kwh + $40/t CO_{2e}	-	-84,048	-	Current prices
	$0.44/kwh + $105/t CO_{2e}	10.3	637	7.1	Breakeven prices

8.1.2 New Covered Lagoon (128m^3)

This analysis assumed that a farm with a 500 head dairy herd without any suitable existing pond system but wanting to invest in biogas would need to construct a new lined and covered anaerobic lagoon of approximately 128m^3 volume. Results in Table 8.2 indicate that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices. Investment in biogas for electricity generation at this small scale would only become viable at an electricity price of $0.86/kwh, which is much higher than the current price to farms (typically about $0.18/kwh). Investment in biogas for C credits from gas flaring would only become viable at about $198/t CO_{2e}, a price that is much higher than the current EC C market price of about $40/t CO_{2e}. Combining returns from electricity generation and C credits on emission reductions would become viable at an electricity price of $0.55/kwh and C credit price of $100/t CO_{2e}.

Therefore, it is unlikely that biogas capture for electricity generation, C credits or combining both would be viable for some time yet using either of the two lagoon scenarios analysed and the assumptions made.

Table 8-2: Economic Analysis Dairy Cows 500 Head Herd, 10% Manure Collection (New Lined 128m^3 Covered Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $60,900 Operating: $14,060/yr	$0.18/kwh	-	-105,690	-	Current price
	$0.86/kwh	10.4	891	7.0	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $42,400 Operating: $17,060/yr	$40/t CO_{2e}	-	-106,806	-	Current price, EU C market
	$198/t CO_{2e}	10.0	0	7.2	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $63,400 Operating: $17,060/yr	$0.18/kwh + $40/t CO_{2e}	-	-96,445	-	Current prices
	$0.55/kwh + $100/t CO_{2e}	10.4	862	7.0	Breakeven prices

8.1.3 Tank Digestion (85m³)

Economic analysis was also conducted for small scale tank digestion (85m³). Results in Table 8.3 indicate that neither electricity generation nor gas flaring for sale of C credits, or a combination of these would be viable at current electricity or C credit prices due to the relatively small amounts of biogas generated relative to the capital costs of the tank digestion infrastructure. The very high electricity ($2.12/kwh) and C credit ($497/t CO_{2e}) prices required for tank digestion to breakeven in this scenario suggest that it will be some time before tank digestion based on herds of this size could be viable unless there is a significant technology change.

Table 8-3: Economic Analysis Dairy Cows 500 Head Herd, 10% Manure Collection (85m³ Tank Digestion, 20 Years)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $220,400 Operating: $33,410/yr	$0.18/kwh	-	-419,854	-	Current price
	$2.12/kwh	10.1	1,447	9.2	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $201,900 Operating: $36,410/yr	$40/t CO_{2e}	-	-427,884	-	Current price, EU C market
	$497/t CO_{2e}	10.0	92	9.5	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $222,900 Operating: $36,410/yr	$0.18/kwh + $40/t CO_{2e}	-	-407,886	-	Current prices
	$1.15/kwh + $251/t CO_{2e}	10.0	365	95	Breakeven price

8.2 Dairy Cows 500 Head, 60% Manure Collection

Analysis was conducted for a 500 head dairy herd where cows spend 60% of time housed or on pads ("herd homes") and 60% of the manure produced is collected. Analysis was conducted for biogas generation and capture scenarios of a) covering an existing lagoon (or ponds) of appropriate volume (765m³), b) development of a new lined lagoon of appropriate volume (765m³), and c) tank digestion (510m³) for generation and capture of biogas.

8.2.1 Covered Existing Lagoon (765m³)

Results in Table 8.4 indicate that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices. Investment in biogas for electricity generation at this small scale would only become viable at an electricity price of $0.40/kwh, which is significantly higher than the current price. Investment in biogas for C credits from gas flaring would become viable at about $71/t CO_{2e}.

However, combining returns from electricity generation and C credits on emission reductions would become viable at an electricity price of about $0.21/kwh and C credit price of $49/t CO_{2e}, neither of which are significantly higher than the current prices of $0.18/kwh and $40/t CO_{2e}, respectively. This scenario of combined electricity generation and C credit sale could become viable with a small rise in electricity prices and moderate increase in C prices.

Table 8-4: Economic Analysis Dairy Cows 500 Head, 60% Manure Collection (Covered Existing 765m^3 Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation	$0.18/kwh	-	-205,127		Current price
Costs: Capital: $187,200 Operating: $36,560/yr	$0.40/kwh	10.2	1,767	7.1	Breakeven price
C credits on emission reductions, gas flaring	$40/t CO_{2e}	-	-122,351	-	Current price, EU C market
Costs: Capital: $69,700 Operating: $39,560/yr	$71/t CO_{2e}	11.2	3,193	6.8	Breakeven price
Electricity generation and C credits on ERs	$0.15/kwh + $35/t CO_{2e}	-8.8	-110,627	18	
	$0.18/kwh + $40/t CO_{2e}	0.7	-62,164	10.6	Current prices
Costs: Capital: $187,200	$0.21/kwh + $45/t CO_{2e}	8.1	-13,703	7.7	
Operating: $39,560/yr	$0.21/kwh + $49/t CO_{2e}	10.3	2,497	7.1	Breakeven price

8.2.2 New Covered Lagoon (765m^3)

Neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices (Table 8.5). Investment in biogas for electricity generation at this scale would only become viable at an electricity price of $0.45/kwh, which is significantly higher than the current price. Investment in biogas for C credits from gas flaring would become viable at about $82/t CO_{2e}. Combining returns from electricity generation and C credits on emission reductions would become viable at an electricity price of about $0.24/kwh and C credit price of $53/t CO_{2e}, neither of which are significantly higher than the current prices of $0.18/kwh and $40/t CO_{2e}, respectively. This scenario of combined electricity generation and C credit sale could become viable with a small rise in electricity prices and moderate increase in C prices.

Table 8-5: Economic Analysis Dairy Cows 500 Head, 60% Manure Collection (New Lined 765m^3 Covered Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation	$0.18/kwh	-	-252,082	-	Current price
Costs: Capital: $238,850 Operating: $36,560/yr	$0.45/kwh	10.2	1,835	7.1	Breakeven price
C credits on emission reductions, gas flaring	$40/t CO_{2e}	-	-169,306	-	Current price, EU C market
Costs: Capital: $121,350 Operating: $39,560/yr	$82/t CO_{2e}	10.2	787	7.1	Breakeven price

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity generation and C credits on ERs	$0.18/kwh + $40/t CO_{2e}	-3.5	-109,119	13.2	Current prices
Costs: Capital: $241,350 Operating: $39,560/yr	$0.24/kwh + $53/t CO_{2e}	10.0	-46	7.2	Breakeven price

8.2.3 Tank Digestion (510m[3])

The economic analysis in Table 8.6 indicates that tank digestion for wastes from a 500 head herd, 60% manure collection is not economic for electricity generation or gas flaring for C credits at current prices. For electricity generation to be viable, the price would need to reach at least $0.77/kwh, and for C credits to be viable, the price would need to reach near $163/t CO_{2e}, both of which are much higher than current prices. Combining returns from electricity generation and C credits, tank digestion would be viable at an electricity price of about $0.42c/kwh and C price of $89/t CO_{2e}, both of which are much higher than current prices.

If process heat generated through a cogeneration engine is used to replace diesel sources of energy for milk processing, then this is not viable at current diesel prices. However, use of diesel for such purposes is an unlikely scenario at present because of relatively cheaper electricity prices for cooling.

These results suggest that it will be some time before tank digestion based on herds of this size and the scenarios used here could be viable unless there is a significant technology change.

Table 8-6: Economic Analysis Dairy Cows 500 Head Herd, 60% Manure Collection (510m[3] Tank Digestion, 20 Years)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity Generation	$0.18/kwh	-	-759,535	-	Current price
Costs: Capital: $513,200 Operating: $68,160/yr	$0.77/kwh	10.3	9,240	9.4	Breakeven price
C credits on emission reductions, gas flaring	$40/t CO_{2e}	-	-691,208	-	Current price, EU C market
Costs: Capital: $395,700 Operating: $71,160/yr	$163/t CO_{2e}	10.2	9,926	9.4	Breakeven price
Electricity generation and C credits on ERs	$0.18/kwh + $40/t CO_{2e}	-	-583,797	-	Current prices
Costs: Capital: $513,200 Operating: $71,160/yr	$0.42/kwh + $89/t CO_{2e}	10.1	3,874	9.4	Breakeven price
Process heat diesel substitution	$1.84/l	-	-375,909		Current price
Costs: Capital: $513,200 Operating: $68,160/yr	$2.96/l	10.0	367	9.5	Breakeven price

8.3 Dairy Cows Large Herd (900 Head), 10% Manure Collection

Analysis was conducted for a 900 head dairy herd where cows spend most of their time in the pasture and only 10% of the manure produced is collected (from dairy sheds at milking time). Economic analysis was conducted for biogas generation and capture scenarios of a) covering an existing lagoon (or ponds) of appropriate volume (225m^3), b) development of a new lined lagoon of appropriate volume (225 m^3), and c) tank digestion (150m^3) for generation and capture of biogas.

8.3.1 Covered Existing Lagoon (225m^3)

Results in Table 8.7 indicate that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices based on this scenario. Investment in biogas for electricity generation at this scale would become viable at an electricity price of $0.57/kwh, which is much higher than the current price to most farms. Investment in biogas for C credits from gas flaring would only become viable at about $121/t CO_{2e}. Combining returns from electricity generation and C credits on emission reductions would be viable at prices of $0.33/kwh for electricity and C credit price of $70/t CO_{2e}. Therefore, electricity and C credit prices would need to rise significantly above current prices for biogas generation for these uses to be viable, based on this analysis and assumptions made.

Table 8-7: Economic Analysis Dairy Cows 500 Head, 10% Manure Collection (Covered Existing 225m^3 Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation	$0.18/kwh	-	-109,281	-	Current price
Costs: Capital: $65,100 Operating: $18,060/yr	$0.57/kwh	10.3	750	7.1	Breakeven price
C credits on emission reductions, gas	$40/t CO_{2e}	-	-97,882	-	Current price, EU C market
flaring Costs: Capital: $31,600 Operating: $21,060/yr	$121/t CO_{2e}	10.2	303	7.1	Breakeven price
Electricity generation and C credits on ERs	$0.18/kwh + $40/t CO_{2e}	-	-79,825		Current prices
Costs: Capital: $67,600 Operating: $21,060/yr	$0.33/kwh + $70/t CO_{2e}	10.0	71	7.1	Breakeven price

8.3.2 New Covered Lagoon (225m^3)

Results in Table 8.8 indicate that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices based on this scenario. Investment in biogas for electricity generation at this scale would become viable at an electricity price of $0.64/kwh, which is much higher than the current price to most farms. Investment in biogas for C credits from gas flaring would only become viable at about $137/t CO_{2e}. Combining returns from electricity generation and C credits on emission reductions would be viable at prices of $0.38/kwh for electricity and C credit price of $75/t CO_{2e}. As with covering an existing lagoon, electricity and C credit prices would need to rise significantly above current prices for biogas generation for these uses to be viable, based on this scenario and assumptions made.

Table 8-8: Economic Analysis Dairy Cows 900 Head, 10% Manure Collection (New Lined 225m^3 Covered Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $85,900 Operating: $18,060/yr	$0.18/kwh	-	-128,190	-	Current price
	$0.64/kwh	10.5	1,590	7.0	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $52,400 Operating: $21,060/yr	$40/t CO_{2e}	-	-116,791	-	Current price, EU C market
	$137/t CO_{2e}	10.4	788	7.0	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $88,400 Operating: $21,060/yr	$0.18/kwh + $40/t CO_{2e}	-	-98,734	-	Current prices
	$0.38/kwh + $75/t CO_{2e}	10.0	117	7.1	Breakeven price

8.3.3 Tank Digestion (150m^3)

Based on the assumptions, capital and operating costs of this study, the economic analysis in Table 8.9 indicates that tank digestion for wastes from a 900 head herd, 10% manure collection would not be economic for electricity generation or gas flaring for C credits at current prices. For electricity generation to be viable, the price would need to reach at least $0.77/kwh, and for C credits to be viable, the price would need to reach near $163/t CO_{2e}, both of which are much higher than current prices. Combining returns from electricity generation and C credits, tank digestion would be viable at an electricity price of about $0.42c/kwh and C credit price of $89/t CO_{2e}, both of which are much higher than current prices.

These results suggest that there would need to be significant electricity and C price rises before tank digestion based on herds of this size, and the scenarios used here would be viable unless there is a significant technology change from that assumed in this study.

Table 8-9: Economic Analysis Dairy Cows 900 Head, 10% Manure Collection (150m^3 Tank Digestion, 20 Years)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $263,400 Operating: $49,250/yr	$0.18/kwh	-	-575,421	-	Current price
	$1.66/kwh	10.2	3,117	9.4	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $229,400 Operating: $52,500/yr	$40/t CO_{2e}	-	-546,215	-	Current price, EU C market
	$366/t CO_{2e}	10.1	1,301	9.5	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $265,900 Operating: $52,500/yr	$0.18/kwh + $40/t CO_{2e}	-	-508,579	-	Current prices
	$0.90/kwh + $176/t CO_{2e}	10.1	1,281	9.5	Breakeven price

Major factors affecting economics of biogas generation from the 900 head herd with 10% manure collection are low manure yields, tank digester equipment and construction costs, cogeneration plant costs, and operating and maintenance costs, especially labour.

8.4 Dairy Cows Large Herd (900 Head), 60% Manure Collection

Analysis was conducted for a 900 head dairy herd assuming that cows are housed for 60% of the time and that 60% of total manure is captured and available for biogas digestion. The analysis assumed a 1,380m^3 lagoon size and 920m^3 tank digester size.

8.4.1 Covered Existing Lagoon (1,380m^3)

Results in Table 8.10 indicate that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices based on this scenario. Investment in biogas for electricity generation would become viable at an electricity price of $0.31/kwh. Investment in biogas for C credits from gas flaring would only become viable at about $49/t CO_{2e}, which would equate to a 20% price increase over the current C credit price of $40/t CO_{2e}. Combining returns from electricity generation and C credits on emission reductions would be viable at current prices of $0.18/kwh for electricity and C credit price of $40/t CO_{2e}. The breakeven price combination would be at approximately $0.16/kwh for electricity and $37/t CO_{2e} for C credits.

Table 8-10: Economic Analysis Dairy Cows 900 Head, 60% Manure Collection (Covered Existing 1,380m^3 Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $281,200 Operating: $46,340/yr	$0.18/kwh	-	-209,790	35	Current price
	$0.31/kwh	10.9	10,271	6.9	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $83,700 Operating: $49,340/yr	$40/t CO_{2e}	-	-60,115	30.3	Current price, EU C market
	$45/t CO_{2e}	2.1	-23,667	9.0	
	$49/t CO_{2e}	11.7	5,492	7.1	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $283,700 Operating: $49,340/yr	$0.15/kwh + $35/t CO_{2e}	7.7	-24,465	7.8	
	$0.16/kwh + $37/t CO_{2e}	10.6	7,037	7.0	Breakeven prices
	$0.18/kwh + $40/t CO_{2e}	15.4	62,762	5.9	Current prices
	$0.21/kwh + $45/t CO_{2e}	22.3	149,994	4.9	

8.4.2 New Covered Lagoon (1,380m^3)

Biogas generation for electricity and C credits is less economic where a new covered anaerobic lagoon is installed, due to higher capital costs of construction (Annex 2). Results in Table 8.11 indicate that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices based on this scenario. Investment in biogas for electricity generation would become viable at an electricity price of $0.34/kwh. Investment in biogas for C credits from gas flaring would only become viable at about $55/t CO_{2e}. However, combined returns from electricity generation and C credits on emission reductions would be viable (FIRR of 11.2%) at current prices of $0.18/kwh for electricity and C credit price of $40/t CO_{2e}. Financial viability is relatively price sensitive with FIRR increasing to 17.4% with a 12% increase in electricity price and 16% increase in C credit price.

Table 8-11: Economic Analysis Dairy Cows 900 Head, 60% Manure Collection (New Lined 1,380m^3 Covered Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $332,216 Operating: $46,340/yr	$0.18/kwh	-	-256,168	41	Current price
	$0.25/kwh	-2.2	-137,674	12.3	
	$0.34/kwh	11.1	14,676	6.9	Breakeven price

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
C credits on emission reductions, gas flaring Costs: Capital: $134,716 Operating: $49,340/yr	$40/t CO_{2e}	-	-106,493	-	Current price, EU C market
	$45/t CO_{2e}	-6.1	-137,674	12.3	
	$55/t CO_{2e}	10.5	2,852	7.0	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $334,716 Operating: $49,340/yr	$0.15/kwh + $35/t CO_{2e}	4.2	-70,843	9.0	
	$0.18/kwh + $40/t CO_{2e}	11.2	16,389	6.8	Current prices, breakeven prices
	$0.21/kwh + $45/t CO_{2e}	17.4	103,620	5.6	

8.4.3 Tank Digestion (920m^3)

Based on the assumptions, capital and operating costs of this study, the economic analysis in Table 8.12 indicates that tank digestion for wastes from a 900 head herd, 60% manure collection would not be economic for electricity generation or gas flaring for C credits at current prices. There would need to be a significant increase in electricity price and C price to achieve viability. Combining returns from electricity generation and C credits, tank digestion would be viable at an electricity price of about $0.29/kwh and C price of $66/t CO_{2e}, both of which are considerably higher than current prices.

These results suggest that there would need to be significant electricity and C credit price rises before tank digestion based on herds of this size and the scenarios used here would be viable unless there is a significant technology change from that assumed in this study.

Table 8-12: Economic Analysis Dairy Cows 900 Head, 60% Manure Collection (920m^3 Tank Digestion, 20 Years)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $746,700 Operating: $75,140/yr	$0.18/kwh	-	-838,197	-	Current price
	$0.54/kwh	10.1	6,153	9.4	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $549,200 Operating: $75,140/yr	$40/t CO_{2e}	-	-700,038	-	Current price, EU C market
	$110/t CO_{2e}	10.2	6,974	9.4	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $749,200 Operating: $78,140/yr	$0.18/kwh + $40/t CO_{2e}	-4.0	-475,035	27.0	Current prices
	$0.29/kwh + $66/t CO_{2e}	10.3	11,264	8.8	Breakeven prices

While the 900 head dairy herd with 60% manure collection is closer to economic viability than the same herd with 10% manure collection, the major factors affecting the economics of biogas generation from the dairy cow herds analysed are low manure yields in relation to tank digester equipment and construction costs, cogeneration plant costs, and operating and maintenance costs, especially labour.

8.5 Small Piggery (1,000 Head)

For a typical piggery of about 1,000 head, the economic analysis was conducted based on three biogas capture scenarios: a) covering an existing 450 m^3 anaerobic lagoon, b) construction and covering of a new lagoon (450 m^3); and c) tank digestion (300 m^3 digester) for generation and capture of biogas.

For each of these biogas capture types, economic analyses were conducted for electricity generation, gas flaring for C credits, and a combination of these activities.

8.5.1 Covered Existing Lagoon (450m^3)

Results in Table 8.13 indicate that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices based on this scenario. Investment in biogas for electricity generation would become viable at an electricity price of $0.43/kwh, and investment in biogas for C credits from gas flaring would only become viable at about $96/t CO_{2e}. Combining returns from electricity generation and C credits on emission reductions would be viable at current prices of $0.27/kwh for electricity and C credit price of $50/t CO_{2e}, both of which are about 50% higher than current prices.

Table 8-13: Economic Analysis 1000 Head Piggery (10 years, Covered Existing 450m^3 Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $99,700 Operating: $26,930/yr	$0.18/kwh	-	-138,674	-	Current price
	$0.43/kwh	10.9	3,538	6.9	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $42,200 Operating: $29,930/yr	$40/t CO_{2e}	-	-119,081	-	Current price, EU C market
	$96/t CO_{2e}	11.2	1,978	6.8	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $99,700 Operating: $29,930/yr	$0.18/kwh + $40/t CO_{2e}	-14.6	-71,234	27.3	Current prices
	$0.27/kwh + $50/t CO_{2e}	10.4	1,580	7.0	Breakeven prices

8.5.2 New Covered Lagoon (450m³)

Table 8.14 indicates that neither electricity generation nor gas flaring for sale of C credits would be viable at current electricity or C credit prices based on this scenario. Investment in biogas for electricity generation would become viable at an electricity price of $0.49/kwh, and investment in biogas for C credits from gas flaring would only become viable at about $111/t CO_{2e}. Combining returns from electricity generation and C credits on emission reductions are not viable at current prices, but would become so at prices of about $0.28/kwh for electricity and C credit price of $62/t CO_{2e}. These breakeven prices are about 50% higher than current prices.

Table 8-14: Economic Analysis 1000 Head Piggery (10 years, New Covered 450m³ Anaerobic Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $135,250 Operating: $26,930/yr	$0.18/kwh	-	-170,992	-	Current price
	$0.49/kwh	11.0	5,350	6.9	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $77,750 Operating: $29,930/yr	$40/t CO_{2e}	-	-151,399	-	Current price, EU C market
	$111/t CO_{2e}	10.7	2,087	7.0	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $137,750 Operating: $29,930/yr	$0.18/kwh + $40/t CO_{2e}	-	-103,552	36.5	Current prices
	$0.28/kwh + $62/t CO_{2e}	10.2	892	7.1	Breakeven prices

8.5.3 Tank Digestion (300m³)

Results in Table 8.15 indicate that tank digestion would not be economic for electricity generation or gas flaring for C credits at current prices. There would need to be a significant increase in electricity price and C credit price to achieve viability. Similarly, combined returns from electricity generation and C credits, tank digestion would require significant prices rises in the electricity price to about $0.52/kwh and C price of $118/t CO_{2e}, both of which are nearly three times higher than current prices.

These results suggest that there would need to be significant electricity and C credit price rises before tank digestion based on piggeries of this size and the scenarios used here to be viable, unless there is a significant technology change from that assumed in this study.

Table 8-15: Economic Analysis 1000 Head Piggery (300m^3 Tank Digestion, 20 years)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $352,200 Operating: $51,430/yr	$0.18/kwh	-	-576,360	-	Current price
	$0.92/kwh	10.3	6,880	9.3	Breakeven price
C credits on emission reductions, gas flaring Costs: Capital: $294,700 Operating: $54,430/yr	$40/t CO_{2e}	-	-550,269	-	Current price, EU C market
	$237/t CO_{2e}	10.0	912	8.9	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $354,700 Operating: $54,430/yr	$0.18/kwh + $40/t CO_{2e}	-	-467,075	-	Current prices
	$0.52/kwh + $118/t CO_{2e}	10.1	1,478	9.0	Breakeven prices

8.6 Large Piggery (10,000 Head)

Analysis was conducted for a large piggery (10,000 head) assuming biogas generation and capture scenarios of a) covering an existing lagoon of 4,500m^3 volume, b) development of a new lined lagoon (4,500 m^3), and c) tank digestion (total of 3,000 m^3 comprised of 3 x 920 m^3 digesters) for generation and capture of biogas.

For each of these biogas capture types, economic analyses were conducted for electricity generation, gas flaring for C credits, and a combination of these activities.

8.6.1 Covering Existing Lagoon (4,500m^3 Volume)

Table 8.16 indicates that the scenario of biogas and electricity generation from covering an existing 4,500 m^3 lagoon would become viable at an electricity price of $0.19/kwh, and is almost viable at the current estimated price of $0.18/kwh. Under a C trading scenario, the investment in biogas generation from this scenario would be viable at a C credit price of $30/t CO_{2e}. At the current C price of $40/t CO_{2e}, a FIRR of 39% would be achieved with an investment return period of 3.5 years. If the price of C increased by 10%, the FIRR would increase to 51% and return period would reduce to 2.9 years. Therefore, investment in biogas under this scenario would be economically viable under current conditions. Under this scenario, investment in both electricity generation to substitute for power from the grid combined with sale of C credits is economic at current prices.

Table 8-16: Economic Analysis Large Piggery (10,000 Head, 10 years, Covered Existing 4,500m³ Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $668,400 Operating: $82,500/yr	$0.15/kwh	0.9	-215,208	10.5	
	$0.18/kwh	8.3	-44,554	7.6	Current typical price to large farms
	$0.19/kwh	10.5	12,331	7.0	Breakeven price
	$0.21/kwh	14.6	126,100	6.1	
C credits on emission reductions Costs: Capital: $170,900 Operating: $85,500/yr	$30/t CO_{2e}	12.2	15,232	6.6	Breakeven price
	$35/t CO_{2e}	26.4	123,264	4.4	
	$40/t CO_{2e}	39.0	231,297	3.5	Current price, EU C market
	$45/t CO_{2e}	51.0	331,330	2.9	
Electricity generation and C credits on ERs Costs: Capital: $670,900 Operating: $85,500/yr	$0.15/kwh + $35/t CO_{2e}	27.6	521,990	4.3	
	$0.18/kwh + $40/t CO_{2e}	35.9	800,677	3.7	Current prices
	$0.21/kwh + $45/t CO_{2e}	43.9	1,079,364	3.2	

Table 8-17: indicates that the economic viability of biogas capture for electricity generation is cost-sensitive around current prices, and estimated capital and operation and maintenance costs. If costs decrease by 10%, biogas generation for electricity generation by covering an existing lagoon becomes economically viable at current electricity prices ($0.18/kwh). An increase in costs of 10% further decreases economic viability at current electricity prices. Biogas generation for C credit sale and combined electricity and C credit sale remain viable with cost variations of +/-10%, although FNPV and payback period varies accordingly.

Table 8-17: Cost Sensitivity Analysis (Capital and Operating Costs) Large Piggery (10,000 Head, 10 years, Covered Existing 4,500m³ Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity generation Costs: Capital: $668,400 Operating: $82,500/yr Price NZ$0.18/kwh	-10%	13.5	84,638	6.3	
	Current Cost	8.3	-44,554	7.6	Current costs
	+10%	4.4	-151,402	8.9	
C credits Costs: Capital: $170,900 Operating: $85,500/yr C price: NZ$40/t CO_{2e}	-10%	47.8	279,512	3.0	
	Current Cost	39.0	231,297	3.5	Current costs
	+10%	30.0	168,001	4.1	
Electricity generation and C credits Costs: Capital: $670,900 Operating: $85,500/yr Prices: $0.18/kwh, $40/t CO_{2e}	-10%	41.9	909,428	3.3	
	Current Cost	35.9	800,677	3.7	Current costs
	+10%	30.8	691,923	4.0	

8.6.2 New Covered Lagoon (4,500m³ Volume)

Table 8-18 indicates that the scenario of biogas and electricity generation from constructing and covering a new 4,500m³ lagoon would become viable at an electricity price of $0.21/kwh. It is not viable at the current estimated price of $0.18/kwh. This requirement for a higher electricity price to break even compared to covering an existing lagoon results from higher capital construction costs in the new lagoon scenario. Under a C trading scenario, the investment in biogas generation from this scenario would be viable at a C credit price of $35/t CO_{2e}. At the current C credit price of $40/t CO_{2e}, a FIRR of 18% would be achieved with an investment return period of 5.4 years. If the price of C credits increased by 10% to $45/t CO_{2e}, the FIRR would increase to 26% and return period would reduce to 4.5 years. Therefore, investment in biogas under this C credit trading scenario would be economically viable under current conditions. Under this scenario, investment in electricity generation to substitute for power from the grid combined with sale of C credits is economic at current prices.

Table 8-18: Economic Analysis Large Piggery (10,000 Head, 10 years, New Covered 4500m³ Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $804,400 Operating: $82,500/yr	$0.15/kwh	-2.4	-33,481	12.4	
	$0.18/kwh	4.3	-167,827	9.0	Current typical price to large farms
	$0.21/kwh	10.1	2,828	7.1	Breakeven price
	$0.23/kwh	13.6	116,597	6.3	
C credits on emission reductions Costs: Capital: $306,500 Operating: $85,500/yr	$35/t CO_{2e}	10.0	-8	7.1	Breakeven price
	$40/t CO_{2e}	18.4	108,024	5.4	Current price, EU C market
	$45/t CO_{2e}	26.0	216,057	4.5	
Electricity generation and C credits on ERs Costs: Capital: $806,500 Operating: $85,500/yr	$0.15/kwh + $35/t CO_{2e}	21.6	398,717	5.0	
	$0.18/kwh + $40/t CO_{2e}	28.8	677,404	4.2	Current prices
	$0.21/kwh + $45/t CO_{2e}	35.7	956,091	3.7	

Table 8-19 indicates that the capital and O&M cost changes of +/-10% do not result in economic viability of new lagoons for biogas capture and electricity generation at current electricity prices ($0.18/kwh). However, electricity generation is close to being economically viable (FIRR 8.2%) if costs decrease by 10%. Biogas generation for C credit sale and combined electricity and C credit sale both remain viable with cost variations of +/-10%, although FNPV and payback period varies accordingly. If costs increase by 10%, biogas generation for C credit sale just remains viable with a FIRR of 12.5%.

Table 8-19: Cost Sensitivity Analysis (Capital and Operating Costs) Large Piggery (10,000 Head, 10 years, New Covered 4,500m³ Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity generation	-10%	8.2	-48,978	7.6	
Costs:	Current Cost	4.3	-167,827	9.0	Current costs
Capital: $804,400 Operating: $82,500/yr Price NZ$0.18/kwh	+10%	0.8	-287,402	10.6	
C credits	-10%	25.2	182,934	4.6	
Costs:	Current Cost	18.4	108,024	5.4	Current costs
Capital: $306,500 Operating: $85,500/yr C price: NZ$40/t CO_{2e}	+10%	12.5	33,115	6.6	
Electricity generation	-10%	34.0	798,155	3.8	
and C credits	Current Cost	28.8	677,404	4.2	Current costs
Costs: Capital: $806,500 Operating: $85,500/yr Prices: $0.18/kwh, $40/t CO_{2e}	+10%	24.4	555,926	4.6	

8.6.3 Tank Digestion (10,000 Head, 20 Years, 3,000m³ Volume)

Table 8-20: indicates that the scenario of biogas and electricity generation from tank digestion (3,000 m³) would require an electricity price of $0.35/kwh to become viable. It is not economically viable at the current price of $0.18/kwh. Under a C trading scenario, tank digestion would require a C credit price of about $78/t CO_{2e} to become viable. These requirements for higher electricity and C credit prices to break even compared to the lagoon scenarios result from higher capital and annual operating costs with the tank digestion scenario even though the asset life is longer (20 years compared to 10 years for lagoons). Combining electricity generation and sale of C credits from tank biogas generation is close to being viable at current prices, but would require prices of $0.20/kwh for electricity and about $44/t CO_{2e} to become viable. With possibility of rising electricity prices and if C credit prices increase, then this scenario could become viable in the near future.

Table 8-20: Economic Analysis Large Piggery (10,000 Head, 20 years, 3,000m³ Tank Digestion)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs:	$0.18/kwh	-4.3	-1,333,119	36.3	Current typical price to large farms
Capital: $1,943,400 Operating: $128,200/yr	$0.35/kwh	10.2	28,024	9.5	Breakeven price
C credits on emission	$40/t CO_{2e}	-	-1,132,419	62.5	Current price, EU C market
reductions Costs: Capital: $1,445,900 Operating: $131,200/yr	$78/t CO_{2e}	10.1	5,179	9.5	Breakeven price

<table>
<tr><th>Biogas Use</th><th>Unit Price (NZD)</th><th>FIRR (%)</th><th>FNPV (10%), 20 years (NZD)</th><th>Payback period (Years)</th><th>Comment</th></tr>
<tr><td rowspan="4">Electricity generation and C credits on ERs
Costs:
Capital: $1,945,900
Operating: $131,200/yr</td><td>$0.15/kwh + $35/t CO_{2e}</td><td>4.1</td><td>-622,343</td><td>13.4</td><td></td></tr>
<tr><td>$0.18/kwh + $40/t CO_{2e}</td><td>7.7</td><td>-257,547</td><td>10.4</td><td>Current prices</td></tr>
<tr><td>$0.20/kwh + $44/t CO_{2e}</td><td>10.0</td><td>4,506</td><td>9.0</td><td>Break even prices</td></tr>
<tr><td>$0.21/kwh + $45/t CO_{2e}</td><td>10.9</td><td>107,250</td><td>8.6</td><td></td></tr>
</table>

Table 8-21: indicates that tank digestion for electricity generation and sale of C credits remain uneconomic with capital and O&M cost changes of +/-10% at current electricity and C credit prices. Biogas generation for combined electricity and C credit sale just becomes viable (FIRR 10.2%) with a cost decrease of 10%. Results in Tables 8-20 and 8-21 indicate that tank digestion is close to being viable for combined electricity generation and C credit sale, and viability could be achieved if small cost reductions and small increases electricity and C credit prices occurred.

Table 8-21: Cost Sensitivity Analysis (Capital and Operating Costs) Large Piggery (10,000 Head, 20 years, 3,000m^3 Tank Digestion)

<table>
<tr><th>Biogas Use</th><th>Unit Price (NZD)</th><th>FIRR (%)</th><th>FNPV (10%), 20 years (NZD)</th><th>Payback period (Years)</th><th>Comment</th></tr>
<tr><td rowspan="3">Electricity generation
Costs:
Capital: $1,943,400
Operating: $128,200/yr
Price NZ$0.18/kwh</td><td>-10%</td><td>-1.8</td><td>1,056,013</td><td>26.8</td><td></td></tr>
<tr><td>Current Cost</td><td>-4.3</td><td>-1,333,119</td><td>36.3</td><td>Current costs</td></tr>
<tr><td>+10%</td><td>-</td><td>-1,610,952</td><td>51.6</td><td></td></tr>
<tr><td rowspan="3">C credits
Costs:
Capital: $1,445,900
Operating: $131,200/yr
C price: NZ$40/t CO_{2e}</td><td>-10%</td><td>-5.0</td><td>-900,467</td><td>36.7</td><td></td></tr>
<tr><td>Current Cost</td><td>-</td><td>-1,132,419</td><td>62.5</td><td>Current costs</td></tr>
<tr><td>+10%</td><td>-</td><td>-1,364,371</td><td>-</td><td></td></tr>
<tr><td rowspan="3">Electricity generation and C credits
Capital: $1,945,900
Operating: $131,200/yr
Prices: $0.18/kwh, $40/t CO_{2e}</td><td>-10%</td><td>10.2</td><td>15,369</td><td>9.0</td><td></td></tr>
<tr><td>Current Cost</td><td>7.7</td><td>-257,547</td><td>10.4</td><td>Current costs</td></tr>
<tr><td>+10%</td><td>5.5</td><td>-530,462</td><td>12.0</td><td></td></tr>
</table>

8.7 Poultry

For a large poultry farm of about 50,000 head (layer hens), economic analysis was conducted based on three biogas capture scenarios: a) covering an existing anaerobic lagoon, b) construction and covering of a new lagoon, and c) tank digestion. Estimated costs of these two scenarios are given in Annex 2. It was assumed that 100% of the waste is treated in the biogas system.

For each of the biogas systems, economic analyses were conducted for electricity generation, gas flaring for C credits, and a combination of these activities.

8.7.1 Covered Existing Lagoon (330m^3)

Table 8.22 indicates that biogas capture and use from covering an existing anaerobic lagoon of 330m^3 is economically viable at current prices for electricity and C credits from gas flaring. Gas capture, flaring and sale of C credits would be economic at current prices. If electricity is generated for grid substitution and C credits are sold, then the combined economic return would be economic at current electricity and C credit prices. Viability of electricity production for grid substitution is price sensitive around the current price. If the electricity price decreased to $0.15/kwh, then generation for grid substitution would not be economic. Viability of biogas production for C credit sale and combined C credit sale and electricity substitution remain positive if prices decreased by 12 and 16%, respectively.

Economic viability of poultry wastes for biogas production compared to dairy cows and pigs results from their high total solids content per kg of manure, and smaller amounts of wash water used relative to the other animal types.

Table 8-22: Economic Analysis Poultry (50,000 Head, 10 years, Covered Existing 330m^3 Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $274,000 Operating: $22,100/yr	$0.15/kwh	7.3	-28,480	7.9	
	$0.17/kwh	11.6	17,395	6.7	Breakeven price
	$0.18/kwh	13.6	40,332	6.3	Current typical price to large farms
	$0.21/kwh	19.4	109,144	5.3	
C credits on emission reductions Costs: Capital: $36,500 Operating: $25,100/yr	$35/t CO_{2e}	93.1	157,020	2.1	
	$40/t CO_{2e}	116.4	204,222	1.9	Current price, EU C market
	$45/t CO_{2e}	140.0	251,423	1.7	
Electricity generation and C credits on ERs Costs: Capital: $276,500 Operating: $25,100/yr	$0.15/kwh + $35/t CO_{2e}	32.5	282,899	3.9	
	$0.18/kwh + $40/t CO_{2e}	40.7	398,913	3.4	Current prices
	$0.21/kwh + $45/t CO_{2e}	48.7	514,927	3.0	

8.7.2 New Covered Lagoon (330m^3)

Table 8-23 indicates that electricity generation and gas flaring for C credits are both economically viable at current purchase prices based on capture from a new covered and lined anaerobic lagoon (330m^3). However, if the electricity price decreases by $0.03/kwh to $0.15/kwh, electricity generation would not be viable. Viability of gas flaring for C credits is not affected by a decrease in C credit price to $35t/tCO$_{2e}$, although the FNPV would decrease considerably. Combining both electricity generation and C credits is also economic at current prices and at reduced prices of electricity of $0.15/wkh and a C credit price of $35/tCO$_{2e}$. Although, biogas generation from covering an existing lagoon and constructing a new covered lagoon are both viable at current prices, the difference in financial return results in higher initial capital costs of new lagoon establishment.

Table 8-23: Economic Analysis Poultry (50,000 Head, 10 years, New Covered 330m^3 Lagoon)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 10 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $302,100 Operating: $22,100/yr	$0.15/kwh	5.2	-54,025	8.6	
	$0.18/kwh	11.2	14,787	6.8	Current typical price to large farms, breakeven price
	$0.21/kwh	16.7	83,599	5.7	
C credits on emission reductions Costs: Capital: $64,600 Operating: $25,100/yr	$35/t CO$_{2e}$	51.9	131,475	2.9	
	$40/t CO$_{2e}$	65.4	178,676	2.5	Current price, EU C market
	$45/t CO$_{2e}$	78.6	225,878	2.3	
Electricity generation and C credits on ERs Costs: Capital: $304,600 Operating: $25,100/yr	$0.15/kwh + $35/t CO$_{2e}$	28.9	257,354	4.2	
	$0.18/kwh + $40/t CO$_{2e}$	36.5	373,368	3.6	Current prices
	$0.21/kwh + $45/t CO$_{2e}$	43.8	489,381	3.2	

8.7.3 Tank Digestion (20 Years, 220m^3 Volume)

Neither electricity generation nor sale of C credits from tank digestion (220m^3) is viable at current prices (Table 8-24). To achieve viability, prices of electricity and C credits would need to rise to $0.32/kwh and $49/t CO$_{2e}$, respectively. These requirements for higher electricity and C credit prices to break even compared to the lagoon scenarios result from higher capital and annual operating costs with the tank digestion scenario even though the asset life is longer (20 years compared to 10 years for lagoons). Combining electricity generation and sale of C credits from tank biogas generation is viable at current prices, with breakeven prices of about $0.14/kwh for electricity and $33/t CO$_{2e}$ for C credits.

Table 8-24: Economic Analysis Poultry (50,000 Head, 20 years, 220m3 Tank Digestion)

Biogas Use	Unit Price (NZD)	FIRR (%)	FNPV (10%), 20 years (NZD)	Payback period (Years)	Comment
Electricity Generation Costs: Capital: $490,500 Operating: $49,250/yr	$0.18/kwh	-10.9	-308,145	20.9	Current typical price to large farms
	$0.32/kwh	10.7	12,978	7.0	Breakeven price
C credits on emission reductions Costs: Capital: $253,000 Operating: $52,250/yr	$40/t CO_{2e}	1.9	-111,197	17.5	Current price, EU C market
	$45/t CO_{2e}	7.0	-45,797	11.6	
	$49/t CO_{2e}	10.4	6,522	9.3	Breakeven price
Electricity generation and C credits on ERs Costs: Capital: $493,000 Operating: $52,250/yr	$0.14/kwh + $33/t CO_{2e}	10.8	23,992	9.1	Break even prices
	$0.15/kwh + $35/t CO_{2e}	12.6	81,933	8.2	
	$0.18/kwh + $40/t CO_{2e}	17.4	242,675	6.5	Current prices
	$0.21/kwh + $45/t CO_{2e}	21.9	403,416	5.5	

8.8 Summary of Economic Analysis

The economic analysis above is based on various assumptions (Annex 1, Section 2.4) and the results will vary widely depending on the characteristics of each farm and the validity of the assumptions made.

However, a number of general findings can be drawn from the economic analysis. The analysis indicates that viability of biogas investment varies among farm types according to the following factors:

- Livestock type and waste management system. Results indicate that poultry manure for biogas generation produces larger quantities of methane per kg of manure, resulting in better economic returns than biogas generation from pig or dairy wastes. For dairy cows, biogas generation for electricity substitution and C credit sale is not economically viable under the assumptions and scenarios used in this study. However, increasing the amount of dairy manure collection through herds spending longer periods on feeding pads or hard surfaces does improve the economic returns, although these are still significantly negative under the assumptions used in the study.
- Farm size (number of head). The farm scenarios with larger livestock numbers were generally closer to economic viability for the same management and biogas technology compared to smaller livestock numbers.
- Biogas technology used (e.g. covering of existing anaerobic lagoon, construction and covering of new lined lagoon, tank digestion), which in turn is partly related to farm size, livestock type and manure volumes. For example, biogas generation by covering existing anaerobic lagoons or construction of a new covered lagoon is viable for electricity generation or C credits at current prices for a 50,000 head poultry farm. However, tank digestion is not viable for electricity generation or sale of C credits alone.

If 60% of manure from the 900 head dairy cow scenario can be collected, then covering of existing lagoons or building new covered lagoons are viable for combined electricity generation and C credit sale. However, tank digestion would not be viable for the same herd size at current electricity or C credit prices.

- Under the assumptions of this study, **electricity generation** (e.g. substitution of electricity purchased from the grid) would be viable at current prices only for poultry using biogas captured from covering an existing lagoon or a new covered lagoon. None of the other farm scenarios are viable for electricity generation at current prices. Economic viability of electricity generation from poultry-sourced biogas from lagoons is sensitive to electricity price, with small price reductions (of $0.03/kwh) making this uneconomic. Different farmers receive different electricity prices depending on their volume of usage and electricity contracts negotiated. As a result, economic viability will vary according to the electricity purchase price of different farms, especially where economic viability of biogas for electricity generation is marginal.
- Investment in biogas for **gas capture and flaring for earning of C credits** is also sensitive to livestock type and waste management system used, farm size, biogas technology used, and C credit price. For example, biogas capture for sale of C credits using existing or new covered anaerobic lagoons for a 10,000 head pig farm would be viable at current C credit prices, but tank digestion would not. In some cases, the C credit price would need to rise significantly for biogas investment to be viable (especially dairy farm scenarios) for C credit sale.
- **Cost sensitivity analysis** conducted on the 10,000 head pig farm indicates that economic returns for electricity generation and C credits is relatively sensitive to changes in capital and operating costs. For example, the FIRR from electricity generation for a 10,000 head piggery by covering an existing anaerobic lagoon ranges from 4.4% to 13.8% depending on whether costs change by +/- 10%. Where biogas generation is marginal at current prices, cost sensitivity can be important in determining economic viability.
- Many pig and some poultry producers currently use **anaerobic lagoons** for waste management. Covering of existing lagoons is more economic in both cases than construction of new, lined and covered lagoons due to the lower capital costs for covering existing lagoons. In the case of a 10,000 head piggery, covering an existing lagoon is close to being economically viable at current electricity prices, and would be if costs reduced by 10%. However, construction of a new, lined and covered lagoon would not be viable for electricity generation even if costs decreased by 10%. Covering an existing lagoon or constructing a new lagoon is viable for biogas generation and C credit sale at current C credit prices. Use of either anaerobic lagoon technology is viable for a 50,000 head poultry farm at current electricity and C credit prices.
- **Labour costs** are a significant component of operation and maintenance costs (Annex 2) for all biogas capture technology types. The need to regularly desludge anaerobic lagoons also adds significant O&M costs for lagoon capture of biogas.

In summary, future analysis of biogas viability will need to take into account all of the above factors. It is emphasised that economic viability is dependent on the characteristics of each individual farm, waste management system, the type of biogas system used, and the prices of items such as electricity, C credits or other resource inputs that the biogas system is substituting for.

9 Issues Related to Technology Application

There are a variety of critical technical issues relevant to application of on-farm biogas technology. These include:

9.1 Livestock Management and Waste Systems

The type of livestock management and waste collection system is a critical factor in viability of biogas generation. Livestock management systems where animals are housed either permanently (e.g., pigs) or for long periods (e.g., housing or hard standing concept for dairy cows) are necessary so that a large proportion of the manure generated can be efficiently collected and stored anaerobically for the digestion process to occur.

The biogas plant should be constructed near the source of manure and other digester feed material to minimise manure transport costs. The biogas plant should also be located close to the main farm buildings to permit easy maintenance when malfunctions occur. The biogas plant should not produce odours and a sheltered location is preferable to reduce risk of damage by wind, especially to flexible gas storage bags. Three-phase electricity supply will be required at the site to power the machinery of the biogas plant. A water supply will also be required for washing of animal sheds or pads, operation of anaerobic lagoons, tank digestion units and scrubbing of the biogas.

9.2 System Design, Operations and Maintenance

The type of gas collection and digestion system used (e.g. covered lagoon, tank digestion) is an important factor in biogas viability. Choice of system will depend on scale of the farm operation and manure able to be processed for biogas, as well as economic viability related to its use (e.g. electricity price, C credits, cost of other types of energy substitution).

Local characteristics must also be taken into account in the design of anaerobic digesters and power generation system operations. These include climate and temperature conditions, the required scale of plant and equipment, characteristics of the manure, and expected treatment effects. The biogas system requires a management and monitoring plan with operational monitoring parameters to maintain system performance levels. As scale and complexity of the system increases so do the operation and maintenance requirements and on-farm expertise required to maintain the system. This is often limited at the farm level.

Good access to repairs and spare parts is also required to support a sustainable operation. World wide, few anaerobic digesters with co-generation for electricity have achieved long term operation due primarily to inappropriate operations and maintenance.

There are few commercially active on-farm biogas systems in New Zealand at present. This is partly due to the considerable upfront costs of tank digestion, limited technical expertise, and limited economic viability (Section 8) in the presence of relatively cheap electricity prices to large farm users, and the absence (to date) of C credits and an Emissions Trading Scheme. However, the introduction of the ETS in the agriculture sector in 2013 may have significant implications for biogas development if C credits for on-farm livestock waste management can be included in the ETS (on-farm waste management is not included at present).

Choice of biogas capture technology is important in relation to on-farm use of the biogas product. Covering of unheated existing lagoons or building new lagoons is cheaper than tank digestion, but biogas production from such lagoons is temperature dependent and seasonal in nature. Lagoons would be more suitable where gas flaring for C credits is the proposed economic use (assuming the economics are viable). Tank digestion is more expensive, but provides the ability to control digestion temperature and obtain more regular biogas production across seasons if this meets the requirements of the farm management system.

9.3 Efficiency of the Digestion Process and Electricity Generation

In pig farms, a major use of on-farm energy is to keep animal sheds warm (e.g., through use of heat lamps) during winter to promote animal growth. An important issue for using biogas to generate electricity (or use of surplus exhaust heat from the cogeneration engine) for substitution of grid electricity is that energy demand is usually highest in winter when biogas production is lowest. For example, using biogas to generate electricity for heating livestock sheds in winter coincides with lowest levels of biogas production due to cool air temperatures (especially in covered anaerobic lagoon systems). Similarly, more energy is needed to heat biogas tank digesters in winter to maintain optimal tank temperature for digestion efficiency leaving less biogas-sourced electricity for other uses. Seasonal variation in biogas production from unheated lagoons or seasonal variation in energy availability following digester heating are important issues to consider when integrating biogas into the overall farm operations and management systems.

9.4 Economic Efficiency

As indicated in the economic analysis, choice of technology, electricity price, access to C credits, and plant and equipment, and operation and maintenance costs all affect economic viability of on-farm biogas generation. Use of biogas is sensitive to each of these factors, both singly and in combination. Careful system design and research into appropriate technology for each particular farm situation is necessary, coupled with careful economic analysis of each farm situation, biogas system options, electricity contracts and possibility of on-farm livestock waste management benefits being included in the agriculture ETS in 2013.

10 Conclusions

The results of this study indicate that capture and management of methane from collection and management of animal waste using biogas systems have potential to reduce greenhouse gas emissions from livestock farms. For example, potential net emission reductions of about 3,868 t CO_{2e} could be achieved from a 10,000 head pig farm by capturing methane from animal wastes through use of anaerobic digestion (either covered lagoons or tank digestion) and conversion to CO_2 by combustion.

Introduction of a biogas system to a farm operation for reduction in methane emissions from animal waste may require changes in animal management to maximize waste collection. This is especially the case for dairy cows, where currently only about 10% of total manure produced is able to be collected because typically the only time cows spend on hard surfaces is in the dairy shed during milking. If manure collection for dairy cows could be increased significantly (e.g. through feeding on hard standing pads, or animal housing for longer periods) greater potential exists for methane capture and management in a biogas system. For example, potential annual net emission reductions from biogas digestion of wastes for a 900 head dairy herd is about 217t CO_{2e} based on 10% manure collection compared to about 1,305 t CO_{2e} based on 60% manure collection.

While there is potential for biogas systems to reduce on-farm methane emissions, the scenarios analysed under this study indicate that such systems are generally not economically viable at present (poultry and some pig farm scenarios excepted). Analysis for farm scenarios in Section 8 indicates that use of biogas for on-farm electricity generation and C credits is non-economic for most dairy and some pig farm scenarios at current prices and costs under the assumptions made in the study. However, economic viability does vary according to a wide range of factors, including livestock type and number of head per farm, manure management systems used, biogas technology used, electricity price (where electricity generated from biogas is used to substitute for grid supplied electricity), C credit price (if methane emissions reductions from biogas can be eligible under the Emissions Trading Scheme), and capital and operating and maintenance costs. Due to these many variables affecting biogas viability in New Zealand, it is recommended that detailed analysis (with steps similar to those used in Section 8 of this study) should be conducted by all farms considering investment in biogas because viability will be farm specific.

Biogas technology is still relatively new in New Zealand, with few systems currently operating despite a number of large biogas investments in the 1980s and 1990s. The lessons learned from these earlier investments and also current biogas investments should be collated so that new entrants to biogas in New Zealand have access to the full range of knowledge generated in this area. Given the changing energy situation and potential ETS in New Zealand, it is timely for MAF Policy to consider drawing this experience together for the benefit of rural sector investors considering biogas development in the future.

This work has developed and presented a detailed model, encompassing a series of variables, and with a significant degree of associated necessary complexity, to investigate possible scenarios for methane generation from animal wastes on dairy, pig and poultry farms. For optimum utility it will be necessary to produce a simplified version of the model, probably with an associated “User Guide”, to lead farmers through the practical application of the model to their particular animal waste management circumstances.

It is therefore recommended that the results of this work and, in particular, the mechanics of application of the economic model, be simplified and consolidated into a user-friendly package that farmers can adapt to the circumstances of their individual operations. This would enable them to assess the physical and economic viability of collecting wastes and carrying out anaerobic digestion to produce biogas, with that biogas either utilised for electricity generation (and possibly waste heat usage) or simply flared, in each case with associated carbon credits.

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The intensive pig farming operations of N & EE Reid Farms, Carterton, Wairarapa was the subject of a field visit associated with this project. We gratefully acknowledge the generous assistance of Noel Reid, Steve Shivas and Andrew Hosken of N & EE Reid Farms in terms of discussions held and detailed data provided on manure management, anaerobic digestion and biogas generation associated with a large-scale piggery operation.

A further field visit in relation to this research was made to Landcorp's dairy farm at Eyrewell, Waimakariri District, North Canterbury. Discussions on manure management, biogas generation and associated utilisation at this intensive dairying operation were held with Ian Yeh, Landcorp's Farm Manager; Ian Bywater of Natural Energy Systems and Peter Stevens of Spanwood Building Systems. We gratefully acknowledge these informative discussions and the data shared with us during this visit.

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Annex 1: Methane Calculation and Economic Analysis Model

1. Model Overview

The modelling comprised four sets of calculations:

1. Manure Generation
2. Biogas Generation
3. Baseline Methane Emissions Prior to Biogas
4. Economic Modelling of Various Livestock Types, Farm Sizes, and Biogas Applications

2. Model Calculations

2.1 Manure Generation

Manure generation was calculated for each livestock type using the following equations:

Total raw manure (kg/day) = No. of animals (head) X Raw manure per animal per day (kg) (1)

Manure total solids (kg/day) = Total raw manure (kg/day) X Per cent total solids (%) (2)

Collectible manure total solids (kg/day) = Manure total solids (kg/day) X % collectible (3)

Input data for the above equations are given in Table A2.1. It was assumed that the percent collectible dairy cow manure under typical management is 10%, but under a herd home scenario where cows might be housed for up to 16 hours/day, it was assumed that 60% might be collectible.

Table A2.1: Input Data for Manure Calculations

Livestock Type	Head (no.)	Raw Manure / head (kg/day)[1]	Total Solids (% of fresh manure)[1]	% Collectible
Dairy cows (10% manure collectible)	500	35	13	10
Dairy cows (60% manure collectible)	500	35	13	60
Dairy cows - large herd (10% manure collectible)	900	35	13	10
Dairy cows - large herd (60% manure collectible)	900	35	13	60
Pigs	1,000	5	9	100
Pigs - large piggery	10,000	5	9	100
Poultry	50,000	0.12	25	100

[1] Data from New Zealand Ministry of Agriculture and Fisheries AgLink FPP603 (1985)

2.2 Biogas Generation From Anaerobic Digestion

Daily potential for biogas generation was calculated using the following equations:

Potential Volume of Biogas (Litres/day) = Collectible manure total solids (kg/day) X typical volume of biogas produced per kg total solids (L/kg TS) (4)

Potential Volume of Methane (L CH_4/day) = Potential Volume of Biogas (L/day) X % Methane in Biogas (5)

Weight of Methane produced per day (Kg CH_4/day) = Potential Volume of Methane (L CH_4/day) X Density of Methane (Kg/L) (6)

Kg CH_4/year (kg) = Weight CH_4 produced per day X 365 days (7)

t CH4/year (tonnes) = Kg CH4/year /1,000 (8)

t CO2 equivalent/year (tonnes) = t CH4/year X GWP_{CH4} (9)
where GWP_{CH4} = Global Warming Potential for CH_4 (t CO_2/CH_4) = 21 (IPCC 2006).

Alternatively, conversion to m^3 biogas/methane figures:

Potential Volume of Biogas (m^3/day) = Potential Volume of CH_4 (L CH_4/day)/1000 10)

Potential Volume of Biogas (m^3/year) = Potential Volume of Biogas (m^3/day) X 365 days (11)

Potential Volume of Methane (m^3/day) = Potential Volume of Biogas (m^3/day) X % Methane in Biogas (%) (12)

Potential Volume of Methane (m^3/yr) = Potential Volume of Methane (m^3/day) X 365 days (13)

Table A2.2: Input Data for Biogas Calculations

Livestock Type	Typical Volume Biogas Produced (L/kg TS) [1]	Methane in Biogas (%)[1]	Density of CH4 (kg/L)[2]
Dairy cows - 500 head (10% manure collectible)	Common range: 190-220 Used: 205	68	0.00067
Dairy cows – 500 head (60% manure collectible)	Common range: 190-220 Used: 205	68	0.00067
Dairy cows – 900 head (10% manure collectible)	Common range: 190-220 Used: 205	68	0.00067
Dairy cows – 900 head (60% manure collectible)	Common range: 190-220 Used: 205	68	0.00067
Pigs – 1,000 head	Common range: 170-450 Used: 310	55-65 Used: 60	0.00067
Pigs – 10,000 head	Common range: 170-450 Used: 310	55-65 Used: 60	0.00067
Poultry	Common range: 300-450 Used: 375	57-70 Used: 65	0.00067

1 Data from New Zealand Ministry of Agriculture and Fisheries AgLink FPP603 (1985)
2 Data from IPCC (2006)

Biogas Digester Volume required is based on a 20-day retention time, volume (m^3/day) = 20 X Total Collectible Manure volume (kg/d) /1,000 (14)

Covered Lagoon Volume required is based on a 30-day retention time, volume (m^3/day) = 30 X Total Collectible Manure volume (kg/d) /1,000. (15)

2.3 Baseline Methane Emission Calculations for CER Calculations

2.3.1 General

The calculation of baseline methane emissions is required to calculate Carbon Dioxide Emission Reductions as a result of investment in biogas. The baseline emission calculations for each of the three major livestock types (pigs, dairy cows, poultry) are based on the procedures given in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

These procedures are based on a) manure characteristics and b) manure management system characteristics.

Manure characteristics: This includes the amount of volatile solids (VS) produced in the manure and the maximum amount of methane able to be produced from that manure (B_0). Production of manure VS can be estimated based on feed intake and digestibility or calculated by scaling default IPCC values adjusted for site specific average animal weight (see formula below). B_0 varies by animal species and feed regime and is a theoretical methane yield based on the amount of VS in the manure.

Manure management system characteristics: This includes the types of systems used to manage manure and a system-specific methane conversion factor (MCF) that reflects the portion of B_0 that is achieved. A description of manure management systems for which the models were run is given in Table A2.4. The system MCF varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100%. Both temperature and retention time play an important role in the calculation of MCF. Manure that is managed as a liquid under warm conditions for an extended period promotes methane formation. Such manure management conditions can have high MCFs of 65 to 80%. Manure managed as dry material in cold climates does not readily produce methane and consequently has an MCF of about 1%. The optimal temperature to be maintained in biogas digesters is about 35 ^{0}C in order to maintain high MCFs, with heating to maintain this temperature required in cooler months or cooler climates to obtain optimum digestion rates.

In New Zealand, MCFs vary from 75% in Whangarei to 66% in Invercargill, based on mean annual temperature (see Table 4.3 in main text).

In assessing biogas potential for all livestock types, calculation of baseline methane emissions under current management is required to allow for the scenario of calculating potential Carbon Emission Reductions (CERs) as a result of biogas investment. The potential for this will vary among livestock types and waste management systems.

2.3.2 Methane Emissions from Uncovered Anaerobic Lagoon

For modelling purposes, it was assumed that the baseline livestock waste management system was initial treatment in an uncovered anaerobic lagoon, with water from the lagoon used to irrigate and fertilise fields. For pig farm analyses, input data for the model was based on data provided from a large pig farm in the Wairarapa.

Under this management method, the baseline methane emissions (BE_y) are calculated using the amount of pig manure that decays anaerobically in the absence of oxygen. The baseline is calculated based on the IPCC Tier 2 approach (IPCC, 2006). Volatile solids (VS) produced are calculated based on weight using the IPCC default values and adjusted based on actual data from sample farms in New Zealand. For pig analyses, two sets of model runs were conducted based on a large pig farm (approximately 10,000 pigs) and a typical pig farm of 1,000 standard pig units. The sample animal populations for each category are based on the data in Table A1.1 below.

Table A1.2: Pig Numbers Used in Model Applications

Piggery Type	Sows	Boars	Piglets	Nursery	Growing and Finishing	Total
Large	1,000	40	1,272	3,505	4,183	10,000
Average	104	4	120	348	424	1,000

Methane generated under anaerobic conditions was calculated as:

$$BE_y = GWP_{CH4}\ X\ D_{CH4}\ X\ UF_b\ X \sum_{j,LT} (MCF_j\ X\ B_{0,LT}\ X\ N_{LT,y}\ X\ VS_{LT,y}\ X\ MS\%_{BL,j}) \qquad (1)$$

Where:

Table A2.2: Baseline Methane Generation (Emission) Formula

Parameter	Value	Unit	Description
BE_y		tCO_{2e}	Baseline emission in year "y"
GWP_{CH4}	21	tCO_{2e}/tCH_4	Global Warming Potential (GWP) of CH_4
D_{CH4}	0.00067	$tCH_4/m^3\ CH_4$	CH_4 density (0.00067 t/m^3) at room temperature (20^0C) and 1 atmosphere pressure
UF_b	0.82-0.87		Model correction factor to allow for model uncertainties. Standard IPCC (2006) guidelines followed according to knowledge of manure characteristics.
LT			Index for all types of livestock
J			Index for animal waste management system
MCF_j	Dairy cows, pigs 0.71, poultry 0.73. Range is 0.66-0.75 for NZ		Annual methane conversion factor (MCF) for the baseline animal waste management system (assumed to be open anaerobic lagoon for pigs). Values from IPCC 2006 Table 10A7, 8, 9.
$B_{0,LT}$	Pigs 0.45 Poultry 0.39 Dairy cows 0.24	$m^3\ CH_4$/ kg dm VS	Maximum methane producing capacity of the volatile solids generated by each livestock type. Default value from IPCC Tier II (2006).
$N_{LT,y}$		Head	Annual average number of livestock type in year "y".
$VS_{LT,y}$		Kg dm/head /y	Volatile solids for livestock type entering open lagoon in year "y".
$MS\%_{BL,j}$	100%	Per cent	Fraction of manure handled by open lagoon

$VS_{LT,y}$ was determined by scaling default values as per IPCC (2006). $VS_{default}$ was used to adjust for a site-specific average animal weight as shown below:

$$VS_i = (W_{site} / W_{default}) \, X \, VS_{default} \times nd_y \qquad (2)$$

Where, definitions are given in Table A2.3.

Table A2.3: Volatile Solids Calculation

Parameter	Value	Unit	Description
W_{site}		Kg/head	Average animal weight of a defined livestock population at the project sites (kg)
$W_{default}$	Market pigs 45kg Breeding pigs 180kg Dairy cows 500kg Poultry 1.8kg	Kg/head	Default average animal weight from IPCC (2006) Oceania region
$VS_{default}$	Market pigs 0.28 Breeding pigs 0.5 Dairy cows 3.5 Poultry 0.02	Kg dm/head/day	IPCC (2006) default value for the volatile solid excretion rate per day on a dry matter basis for a defined livestock population (kg dm/animal/day), Oceania region
nd_y	365	Day	Number of days in year "y" where the management system was operational.
W_{sow}	225	Kg/head	Average sow weight, Site data (Wairarapa farm)
W_{boar}	215	Kg/head	Average boar weight, Site data (Wairarapa farm)
$W_{piglets}$	6.5	Kg/head	Average piglet weight, Site data (Wairarapa farm)
$W_{nursery}$	19	Kg/head	Average nursery (weaner) pig weight, Site data (Wairarapa farm)
$W_{growing\ \&\ finishing}$	65	Kg/head	Average growing and finishing pig weight, Site data (Wairarapa farm)
W_{dairy}	500	Kg/head	Average dairy cow weight (IPCC 2006),
$W_{poultry}$	1.8	Kg/head	Average poultry (chicken) weight (IPCC 2006)
VS_{sow}	0.63	Kg dm/head/day	Volatile solids for sow per day. Default data from IPCC 2006 Tier II scaled with site sow weight data.

Parameter	Value	Unit	Description
VS_{boar}	0.60	Kg dm/head/day	Volatile solids for boar per day. Default data from IPCC 2006 Tier II scaled with site boar weight data.
$VS_{piglets}$	0.04	Kg dm/head/day	Volatile solids for piglet per day. Default data from IPCC 2006 Tier II scaled with site piglet weight data.
$VS_{nursery}$	0.12	Kg dm/head/day	Volatile solids for nursery (weaner) pig per day. Default data from IPCC 2006 Tier II scaled with site nursery (weaner) pig weight data.
$VS_{growing\ \&\ finishing}$	0.40	Kg dm/head/day	Volatile solids for finishing pig per day. Default data from IPCC 2006 Tier II scaled with site finishing pig weight data.
$VS_{dairy,\ y}$	0.35	Kg dm/head/y	Collected volatile solids for dairy cow per day. Default data from IPCC 2006 Tier II scaled with site dairy cow weight data. 10% manure collection.
VS_{dairy}	2.1	Kg dm/head/day	Collected volatile solids for dairy cow per day. Default data from IPCC 2006 Tier II scaled with site dairy cow weight data. 60% manure collection.
$VS_{poultry}$	0.02	Kg dm/head/day	Volatile solids for poultry (layer hen) per day. Default data from IPCC 2006 Tier II.

Equation 1 can also be used for aerobic conditions or for various combinations of anaerobic and aerobic management systems by adjusting $MS\%_{BL,j}$ accordingly. For a mainly aerobic situation (e.g. some poultry farms), MS would be set to a small percentage figure. If the system was completely aerobic, MS% would be set to 0 and there would be no CH_4 emissions.

Allowance for Leakage

Application of the model assumes that 100% of the Baseline Emission (BE_y) is captured by the biogas system. However, a factor should be allowed for physical leakage. Biogas project emissions due to physical leakage of biogas from digesters used to produce, collect and transport the biogas to the point of combustion (flaring, engine for electricity generation) is estimated as 10% of the maximum methane producing potential of the manure fed into the biogas digester. Annual leakage is estimated as:

$$PE_{PL,y} = 365 \times 0.10 \times GWP_{CH4} \times D_{CH4} \times UF_b \times MCF_j \times \sum_{i,LT} (B_{0,LT} \times N_{LT,y} \times VS_{LT,y} \times MS\%_{i,y}) \quad \text{(Equation 3)}$$

Where:

i Index for animal waste management system, here assumed to be biogas digester

$MS\%_{i,y}$ Fraction of manure handled in biogas digester in year "y".

For economic model run calculations, the MS% is assumed to be 100%.

Total Emission Reduction
The total emission reduction is:

$ER_t = BE_y - PE_{PL, y}$

2.4 Economic Modelling Calculations

Economic analysis of investment in the capture and use of biogas for economic activities was conducted for a range of farm types and sizes under the scenarios in Table A2.4. For each farm size and type, analysis was conducted for electricity generation, process waste heat for energy substitution (assuming replacement of diesel as energy sources), and the potential scenario of methane capture and combustion for carbon credits.

Basic assumptions in the economic analysis included:

- Values are expressed in current year constant prices (2008) and exclude inflation
- NZ dollar is the unit of account.
- A wide range of biogas technologies and combinations of biogas use are possible. In order to limit the scope of the analysis, the following three types of biogas technology were assumed:
    - a) Covering of anaerobic lagoon for biogas capture
    - b) New lined anaerobic lagoon
    - c) Tank biogas digester.
- Modelling scenarios: 1) electricity generation using co-generation engines (7-195kw); 2) flaring for C credits; and 3) combinations of these.
- Gas-electricity conversion ratio: 2.0
- Heat value of biogas: 20MJ/m3 (4780 Kcal/m3)
- 1 m3 biogas = 0.5 kg diesel heat energy. Used to express potential for process heating cost savings in terms of diesel heat energy equivalent (Table 7-5).
- Diesel cost/litre: four scenarios were analysed: current price (NZ$1.84/litre), -10% (NZ$1.66/litre), +10% (NZ$2.02/litre) and +25% (NZ$2.30/litre) of current price.
- Percentage of biogas used by the system for generation of heat energy for maintaining digestate at 350C in tank digestion: dairy 40%, pigs 15%, poultry 8%.
- Electricity price/kwh: Scenarios analysed for each farm type included current electricity price ($0.18/kwh) and price at which electricity generation was economic, where this price was higher than the current price. Price sensitivity was also conducted for +/-16% of current price, i.e. $0.15/kwh (-10%); $0.21/kwh (+16%).
- C credit price: current price in European C markets approximately €20/t CO2e (NZ$40/t CO2e). Standard analysis was conducted for prices $35, $40, $45/t CO2e and in some cases for higher prices to determine at which C price, the biogas investment would become economic.
- For tank digestion, a 20 year economic life was applied. A 10 year economic life was assumed for biogas capture by anaerobic lagoon (covering existing, and new lined lagoon).
- Waste residence time was assumed to be 20 days for tank digesters, and 30 days for anaerobic lagoons.
- A discount rate of 10% was used.
- Capital costs and annual operating and maintenance costs assumed are given in Annex 2 for tank and anaerobic lagoon digestion.

- Cost sensitivity of +/-10% was conducted for the large (10,000 head) pig farm scenario.
- For analyses related to C credits, the following due diligence, monitoring and verification costs were assumed.
  - Year 1 due diligence by ETS $2,500
  - Annual monitoring costs $1,500/year
  - Annual verification costs (compliance): $1,500/year.

The computer models used are not included in this report, but can be provided.

Table A2.4: Biogas and Economic Modelling Scenarios

Livestock Type	Livestock Numbers	Current Waste Management Practice	Biogas Digestion	Baseline Emissions	Biogas Generation and Emission Reductions	Sources of Revenue/Cost Savings from Biogas		
						Electricity Generation	C Credits ERs Flaring	Electricity and C Credits
Dairy Cows – average farm size	500 milking cows	10% manure collection, anaerobic lagoons	Baseline	√				
		10% manure collection and all used for biogas	Yes		√	√		
					√		√	
					√			√
		60% manure collection, anaerobic lagoon	Baseline	√				
		60% manure collection & all used for biogas	Yes		√	√		
					√		√	
					√			√
Dairy Cows – Large farm	900 milking cows	10% manure collection, anaerobic lagoons	Baseline	√				
		10% manure collection and all used for biogas	Yes		√	√		
					√		√	
					√			√
		60% manure collection, anaerobic lagoon	Baseline	√				
		60% manure collection & all used for biogas	Yes		√	√		
					√		√	
					√			√
Pigs –	1,000	100% manure	Baseline	√				

Livestock Type	Livestock Numbers	Current Waste Management Practice	Biogas Digestion	Baseline Emissions	Biogas Generation and Emission Reductions	Sources of Revenue/Cost Savings from Biogas		
						Electricity Generation	C Credits ERs Flaring	Electricity and C Credits
average farm size	combined sows and breeding pigs	collection, anaerobic lagoons						
		100% manure collection, biogas	Yes		√	√		
					√		√	
					√			√
Pigs – large farm size	10,000 combined sows and fattening pigs	100% manure collection, anaerobic lagoons	Baseline	√				
		100% manure collection, biogas	Yes		√	√		
					√		√	
					√			√
Poultry	50,000 laying hens	100% manure collection into anaerobic lagoons	Baseline	√				
		100% manure collection all used for biogas	Yes		√	√		
					√		√	
					√	√		√

Annex 2: Typical Cost Data for Two Types of Biogas Systems

1. Tank Digestion and Co-generation Plant

The following schedule of costs was used in the economic analysis for the biogas plants of various capacities calculated in Table 7-4.

Capital Costs:

Item	Materials	Estimated cost ($)						
		Dairy 500 Head, 10% Collection	Dairy 900 Head, 10% Collection	Poultry 50,000 Head	Pigs, 1000 Head	Dairy 500 Head, 60% Collection	Dairy 900 Head, 60% Collection	Pigs, 10,000 Head
		85m³	150m³	220m³	300m³	510m³	920m³	3,000m³*
Digester tank	Bolted steel, epoxy lined Tectank	48,000	52,000	65,000	78,000	102,000	154,000	450,000
Digester roof	Steel frame, butynol liner	10,000	11,000	12,000	14,000	20,000	34,000	100,000
Digester insulation	Fibreglass batts	1,800	2,000	2,200	2,800	5,000	8,000	24,000
Insulation outer skin	Vertical colour steel	4,600	5,400	6,000	7,000	9,000	13,500	40,000
Digester base	Reinforced concrete	12,000	14,800	16,000	18,000	25,000	33,000	99,000
Heat exchanger(s)	HDPE/steel	3,400	5,000	6,000	7,000	10,000	16,000	48,000
Digester mixing	Gas recirculation	3,000	4,000	4,100	4,600	6,800	10,000	30,000
Loading sump	Precast concrete 22 m³	3,800	3,800	3,800	3,800	3,800	3,800	11,400
Loading pump	Mono, 4.8kW motor	4,600	4,600	4,600	4,600	4,600	4,600	13,800
Sump mixer		1,200	1,200	1,200	1,200	1,200	1,200	3,600
Gas storage bag	Butynol rubber #	4,000	8,000	8,000	8,000	10,000	14,000	30,000
Gas sulphide filter		600	800	800	1,000	2,000	4,000	10,000
Effluent storage tank	Plastic 25 m³	3,600	3,600	3,600	3,600	7,200	7,200	21,600
Gas water boiler	Rheem gas or equiv.	2,800	2,800	2,800	3,400	6,000	8,000	24,000
Hot water tank	Glass-lined steel	1,200	1,200	1,200	2,000	4,000	8,000	24,000
Water pump		1,200	1,600	1,600	1,600	2,400	4,000	12,000

Item	Materials	Estimated cost ($)						
		Dairy 500 Head, 10% Collection	Dairy 900 Head, 10% Collection	Poultry 50,000 Head	Pigs, 1000 Head	Dairy 500 Head, 60% Collection	Dairy 900 Head, 60% Collection	Pigs, 10,000 Head
		85m^3	150m^3	220m^3	300m^3	510m^3	920m^3	3,000m^3*
Valves		8,000	10,000	13,000	16,000	26,000	34,000	48,000
Pipes		6,000	8,000	8,000	10,000	16,000	24,000	60,000
Construction labour		46,000	50,000	53,000	66,000	78,000	100,000	250,000
Electrical		20,000	24,000	24,000	26,000	34,000	44,000	100,000
Gas meter		1,600	1,600	1,600	1,600	2,200	3,400	8,000
Biogas flare solar/ battery operated		12,000	12,000	12,000	12,000	18,000	18,000	36,000
Sub total		199,400	227,400	250,500	292,200	393,200	546,700	1,443,400
Gas engine	Including heat recovery, paralleling equipment, and contingency	21,000	36,000	240,000	60,000	120,000	200,000	500,000
Total		220,400	263,400	490,500	352,200	513,200	746,700	1,943,400

* Based on three 920m^3 volume digesters
#Volumes 100-800m^3
Costs exclusive of GST.

Annual Operating Costs:

The following schedule of operating costs was used in the economic analysis for the biogas plants of various capacities calculated in Table 7-4. The operating cost schedule assumes:

- all digester heating from biogas
- power from electricity @ 18c/kWh
- effluent management remains the same (i.e. irrigated to pasture or discharged to surface water).

Item	Estimated cost ($/year)						
	Dairy 500 Head, 10% Collection	Dairy 900 Head, 10% Collection	Poultry 50,000 Head	Pigs, 1000 Head	Dairy 500 Head, 60% Collection	Dairy 900 Head, 60% Collection	Pigs, 10,000 Head
	$85m^3$	$150m^3$	$220m^3$	$300m^3$	$510m^3$	$920m^3$	$3,000m^3$*
Power for digester mixing	1,000	1,000	1,000	1,400	1,800	2,600	9,000
Power for pumps	330	580	850	1,165	1,980	3,570	11,650
Power for sump mixer	330	580	850	1,165	1,980	3,570	11,650
Power for water pump	1,050	1,050	1,050	1,200	1,200	1,800	5,000
Replacement of sulphide filter	200	300	400	500	600	800	2,600
Gas water boiler maintenance	500	500	500	1,000	1,000	2,000	3,500
Machinery maintenance	800	800	800	1,200	1,200	2,400	4,800
Operating and maintenance labour @ $40/h	29,200	43,800	43,800	43,800	58,400	58,400	80,000
Total	33,410	48,610	49,250	51,430	68,160	75,140	128,200

* Based on three $920m^3$ volume digesters

2. Covered Anaerobic Lagoon and Gas Flaring Costs

For the smaller farm types where a tank digestion process and electricity generation was unlikely to be financially viable, analysis was conducted assuming that the biogas system comprised a covered anaerobic lagoon and gas flaring to obtain C credits. Options including a cogeneration unit were also included.

Analysis was conducted for two types of covered anaerobic lagoon:
1) Existing lagoon, unlined, and
2) New lined lagoon with subdrains.

Capital Costs

Covering Existing Anaerobic Lagoons

Estimated schedule of costs for covering existing anaerobic lagoons of capacities as shown in Table 7.4:

Item	Estimated cost ($)						
	Dairy 500 Head, 10% Collection	Dairy 900 Head, 10% Collection	Poultry 50,000 Head	Pigs, 1000 Head	Dairy 500 Head, 60% Collection	Dairy 900 Head, 60% Collection	Pigs, 10,000 Head
	128m^3	225m^3	330m^3	450m^3	765m^3	1,380m^3	4,500m^3
P&G	2,000	3,000	3,800	4,500	5,500	7,000	10,000
HDPE cover	1,200	1,500	2,400	3,000	3,600	6,800	30,000
Anchor trench for cover	2,000	2,400	2,800	3,300	4,700	6,000	11,400
Surface water control	1,000	1,200	1,600	1,900	2,400	3,000	6,000
Gas collection pipes	500	600	800	1,000	13,000	16.000	24,000
Biogas flare solar/battery operated	12,000	12,000	12,000	12,000	18,000	18,000	36,000
Construction labour	5,000	7,000	9,000	12,000	17,000	21,000	43,000
Electrical	1,200	1,400	1,600	2,000	3,000	3,400	8,000
Sub total	24,900	29,100	34,000	39,700	67,200	65,216	168,400
Gas engine (including heat recovery, paralleling equipment, and contingency)	21,000	36,000	240,000	60,000	120,000	200,000	500,000
Total	45,900	65,100	274,000	99,700	187,200	281,200	668,400

Costs exclusive of GST

New Covered Anaerobic Lagoons

Estimated schedule of costs for new covered anaerobic lagoons of capacities as shown in Table 7.4:

Item	Estimated cost ($)						
	Dairy 500 Head, 10% Collection	Dairy 900 Head, 10% Collection	Poultry 50,000 Head	Pigs, 1000 Head	Dairy 500 Head, 60% Collection	Dairy 900 Head, 60% Collection	Pigs, 10,000 Head
	$128m^3$	$225m^3$	$330m^3$	$450m^3$	$765m^3$	$1,380m^3$	$4,500m^3$
P&G	2,000	3,000	3,800	4,500	5,500	7,000	10,000
Earthworks	3,000	5,000	8,000	10,000	16,000	20,000	36,000
HDPE liner	1,600	2,000	2,600	3,600	4,600	7,000	20,000
HDPE cover	1,200	1,500	2,400	3,000	3,600	6,800	30,000
Under-liner drains	6,400	8,000	9,500	11,250	15,750	20,000	38,000
Inlet and outlet pipes	1,000	1,200	1,800	2,000	3,000	5,000	10,000
Surface water control	1,000	1,200	1,600	1,900	2,400	3,000	6,000
Gas collection pipes	500	600	800	1,000	13,000	16.000	24,000
Biogas flare solar/battery operated	12,000	12,000	12,000	12,000	18,000	18,000	36,000
Construction labour	10,000	14,000	18,000	24,000	34,000	42,000	86,000
Electrical	1,200	1,400	1,600	2,000	3,000	3,400	8,000
Sub total	39,900	49,900	62,100	75,250	118,850	132,216	304,000
Gas engine (including heat recovery, paralleling equipment, and contingency)	21,000	36,000	240,000	60,000	120,000	200,000	500,000
Total	60,900	85,900	302,100	135,250	238,850	332,216	804,000

Costs exclusive of GST

Operating costs for covered anaerobic lagoons (existing and new)

The following schedule of operating costs was used in the economic analysis for the biogas plants of various capacities calculated in Table 7-4. The operating cost schedule assumes:

- Power from electricity @ 18c/kWh
- Effluent management remains the same (i.e. irrigated to pasture or discharged to surface water)
- Sludge is pumped out every 3 years and irrigated onto pasture. Estimate includes machinery, power and labour.

Item	Estimated cost ($/year)						
	Dairy 500 Head, 10% Collection	Dairy 900 Head, 10% Collection	Poultry 50,000 Head	Pigs, 1000 Head	Dairy 500 Head, 60% Collection	Dairy 900 Head, 60% Collection	Pigs, 10,000 Head
	128m^3	225m^3	330m^3	450m^3	765m^3	1,380m^3	4,500m^3*
Power for pumps*	330	580	850	1,165	1,980	3,570	11,650
Power for sump mixer	330	580	850	1,165	1,980	3,570	11,650
Machinery maintenance	400	400	400	600	600	1,200	1,200
Operating and maintenance labour @ $40/h	5,000	6,500	8,000	10,000	14,000	18,000	20,000
De-sludging	8,000	10,000	12,000	14,000	18,000	20,000	38,000
Total	14,060	18,060	22,100	26,930	36,560	46,340	82,500

*Lagoon loading pump, water control pump

3. C Credit Due Diligence, Monitoring and Verification Costs

For analyses related to C credits, the following due diligence, monitoring and verification costs were assumed to be additional for both tank and anaerobic lagoon digestion, and were included in the costs used for economic analysis:

- Year 1 due diligence by ETS $2,500 (classed as a one-off capital cost)
- Annual monitoring costs $1,500/year (annual operating cost)
- Annual verification costs (compliance): $1,500/year (annual operating cost).

Annex 3: Biogas Plant Construction: Design and Operation

Farm Production & Practice

Ministry of Agriculture and Fisheries

Energy Biogas Plant Construction

Design and Operation

Other index entries: methane; digesters.

The design of a biogas plant, especially that of the digester, depends on the operation method (batch or continuous) and the material to be digested.

Biogas is a mixture of 50–70% methane and 50–30% carbon dioxide. It is produced from organic matter by bacteria which act only in the absence of air (anaerobic bacteria) and act fastest at about blood temperature.

A biogas plant is a collection of components necessary for the production of biogas from organic matter. A typical plant is shown in fig. 1.

The main component of a biogas plant is the digester, which is designed to provide the conditions required by the bacteria. It consists of a closed tank fitted with a heating system to maintain the digesting organic matter at 30–37°C, a mixing system to promote heat transfer and circulation of bacteria as well as preventing accumulation of solid organic matter, and insulation to minimise heat loss.

Construction of a digester, its mixing system and heating is described in other AgLinks.

A means of loading organic matter into the digester must be provided as well as storage for the biogas produced and for the digested organic matter (effluent) until it can be used as a fertiliser.

Design and Operation

The design of a biogas plant, especially that of the digester, depends on the operation method and the material to be digested.

Specialised designs of digesters and methods of operation have been developed to utilise and treat liquids containing mainly dissolved solids, but they are not directly applicable to high-solids materials like farm manures, crops, and crop residues. Only conventional biogas plant construction and operation are described here. A simple tank is used for the digester, suitable for farms, and uses any high-solids materials.

Conventional biogas plants can be operated either by batch loading or continuously.

Batch digestion: In batch loading the digester is filled with organic matter, and a slurry of sludge containing suitable bacteria is added.

The bacteria feed on the organic matter, producing biogas at an increasingly rapid rate as their numbers increase (fig. 2).

After about 15 days (depending on the material being digested) the bacteria will have converted nearly all of the digestible organic matter into biogas, and the digester will have to be emptied and refilled. Some of the residue is kept to provide bacteria for restarting.

The digestion time of 15 days is called the retention time.

Batch digestion does not produce a steady biogas output from the digester (fig. 2) because of the varying proportions of bacteria and organic matter. The bacterial balance needs to be maintained by neutralising any acidity.

It may be inconvenient to have to empty and restart the digester every 2 or 3 weeks.

Continuous digestion: Continuous digestion is more convenient because the digester does not have to be

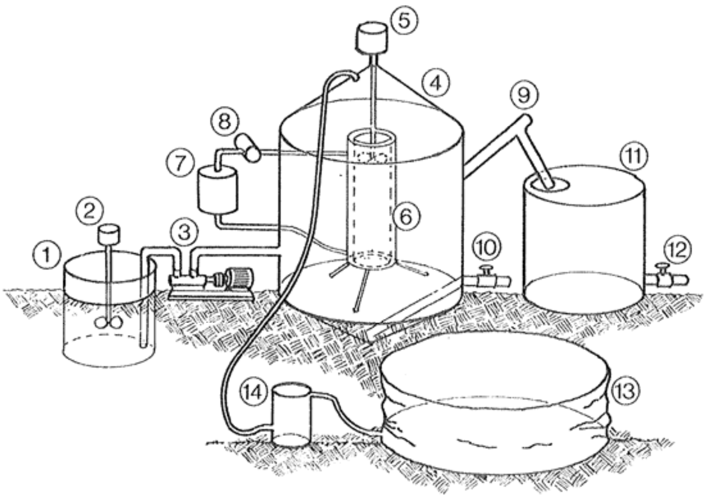

Fig. 1 : Components of a biogas plant. (1) Pre-mix tank; (2) Mixer; (3) Loading pump; (4) Digester; (5) Digester mixer; (6) Heat exchanger/eductor tube; (7) Water heater; (8) Circulating pump; (9) Effluent overflow pipe; (10) Sludge drain; (11) Effluent storage tank; (12) Effluent tank outlet; (13) Biogas storage bag; (14) Biogas filter to remove sulphides.

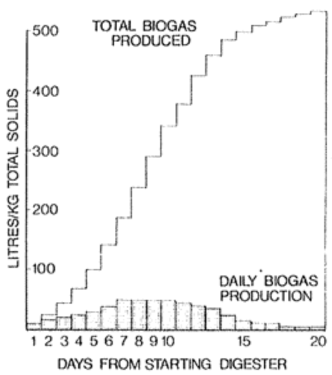

Fig. 2 : Production of biogas from a batch loaded digester over a 20-day period after start-up.

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1st ed. 1985

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emptied, there is a regular output of biogas and, once started, the population of bacteria and the proportions of bacteria and organic matter are always in balance.

Continuous digester operation requires daily loading for full biogas production.

If a retention time of 15 days is chosen, sufficient organic matter is added each day to replace 1/15th of the digester contents. Thus digester contents are then effectively replaced every 15 days, but the biogas plant never has to be stopped or restarted.

Uses of a Biogas Plant

The bacterial process of anaerobic digestion that takes place in a biogas digester has been used for many years to reduce the polluting strength of wastes. Most sewage works use large digesters to treat the solids that are settled out from the raw sewage. The biogas produced is used to heat the digesters and to fuel pumps and generators.

A biogas plant can therefore be used to treat wastes like manures, reducing their biological oxygen demand (BOD), or as a fuel producing system, or a combination of both.

If a biogas plant is to be an economic source of fuel, the plant must be fully utilised to maximise return on the capital invested.

A biogas plant is not well suited to such purposes as producing gas for grain drying over only a few months of the year or heating greenhouses during the winter, unless some other use can be made of the plant over the rest of the year.

Uses such as producing biogas for cooking pig food or compressed methane for fuelling vehicles are ideal in that demand is steady throughout the year.

Materials for Biogas Production

Anaerobic digestion will decompose most organic matter and produce biogas, but has little effect on wood or woody shrubs because they contain a high proportion of lignin, which is not digested by the bacteria. Lignin in other materials, e.g. straw, tends to protect cellulose and prevent bacteria from digesting it.

Other components of a material can affect its digestibility, the amount of biogas that it will produce, and the proportion of methane in the biogas. Such information can only be obtained from experiments in the laboratory. The results of such tests at Invermay are given in table 1.

Some materials can contain chemicals that are toxic to the bacteria, so any prospective material should be tested before it is used in a full-sized biogas plant.

Gas quantity: Different materials produce different amounts of gas. This is important if the plant is to be used to produce biogas for fuel.

If the quantity of biogas that a material can produce is high, the total gas output of the plant will be high. Thus the return on capital invested in the plant will be higher than if a material producing less gas were used.

The net energy produced will also be higher because more biogas will be produced for the same energy input required to run the plant.

A short retention time is also desirable — material will be digested quickly and so passes through the plant quickly. This gives a higher gas output from the plant and a higher return on capital invested than for material requiring a longer retention time.

If the biogas plant is to be used for waste treatment the total biogas yield obtainable is less important, although the gas can be valuable in meeting the costs of operating the waste treatment system.

Solids content: Only the solids sustain bacteria and produce biogas. Any waste liquid or slurry must contain at least 5% solids to be suitable for digestion in a conventional biogas plant digester.

If the solids content is less than 5% the biogas plant must incorporate a settling tank to concentrate the solids (as is used in sewage works).

The settled solids are pumped to the digester and the liquid disposed of separately. Effluents like dairy shed washings or thin piggery manure can be handled in this way, or they can be mixed with drier solids to produce a slurry with more than 5% solids.

If the solids content is low, there will also be insufficient bacteria to cope with different solids fed to the digester. This results in an unstable operation and possible washout of the bacteria if the thin waste is fed too quickly.

Heating: The water and solids of the waste must be heated to blood temperature but this water eventually goes to waste.

TABLE 1 : PRODUCTION OF BIOGAS FROM DIGESTION OF VARIOUS MATERIALS AT 35°C AND SUITABLE RETENTION TIMES WITH A LOADING CONCENTRATION OF 5% TOTAL SOLIDS
(from experiments conducted at Invermay)

Material	Biogas produced (litres/kg total solids)	% Methane in biogas	Suitable retention time (days)
Banana (fruit and stem)	940	53	15
Potato (tuber)	880	54	15
Sugarbeet (root)	620	60	15
Meat waste (paunch, offal)	600	59	25
Lucerne	450–600	56–64	20
Kale	440–560	47–58	20
Grass	450–530	55–57	20
Maize (whole plant)	350–500	50	20
Oats (whole plant)	450–480	51–55	20
Hay	350–460	54–65	20
Straw (ground)	350–450	54–58	25
Poultry manure (fresh)	300–450	57–70	20
Pig manure (fresh)	170–450	55–65	20
Sugarbeet (leaves)	380	66	20
Garbage (organic fraction)	380	48	25
Lakeweed (*Lagarosiphon*)	380	56	20
Straw (chopped)	250–350	58	30
Newspaper	240	52	30
Cattle manure	190–220	68	20
Sheep manure	180–220	56	20

TABLE 2 : DAILY QUANTITIES OF WASTE PRODUCED BY VARIOUS ANIMALS AND BIRDS

Animal/bird	Fresh manure/ day (kg)	Total solids* (%)	Total solids/day (kg)
Dairy cow (500 kg)	35	13	4.5
Beef steer (400 kg)	25	13	3.2
Breeding sow	16	9	1.4
Fattening pig (50 kg)	3.3	9	0.3
Turkey (5.5 kg)	0.4	25	0.09
Layer hen (2 kg)	0.12	25	0.03
Meat chicken (1 kg)	0.10	21	0.02
Sheep	3.9	32	1.25
Fitch	0.12	25	0.03

* Varies with diet, etc.

A thin waste with little solid material requires a high energy input for heating but fuel output is low. In the worst case there may be no net fuel produced.

Diluting wastes: To be suitable for digestion, a material does not have to be a liquid or a slurry, but it must become a slurry within the digester because the bacteria require a liquid in which to move about.

A slurry of 5–15% solids is suitable for bacterial mobility, but usually the mixing system of a digester will not cope with a slurry of more than 10% solids. Material containing more than 10% solids, such as silage or straw, can still be fed directly into the digester, so long as the loading system can handle it because it will become diluted by the slurry within the digester.

If the feedstock must be diluted to enable the loading pump or other machinery to handle it, either water can be added or slurry can be drawn from the digester for mixing. An outlet to draw off the slurry from the digester must be provided (fig. 1), and a pre-mix tank is needed for mixing the slurry with the feed material.

Size of a Biogas Plant

The required size of a biogas plant will depend either on the amount of waste to be treated or on the amount of fuel to be produced. Once these amounts are decided, a suitable size for the digester can be calculated and the rest of the biogas plant can be sized accordingly.

To calculate a suitable digester volume for waste treatment it is necessary to know the average daily waste produced, or the number of animals or birds producing the waste. From this the waste quantity can be estimated using the data in table 2.

If the consistency of the waste is above 10% solids, the size of the digester should be calculated from the daily quantity of total solids (TS) produced, as shown in the following example:

What size of digester would be needed to treat the manure from 5600 layer hens and how much biogas is likely to be generated?

Calculation:

Step 1 — 5600 layer hens would be expected to produce 0.03 kg TS each/day (table 2)
= 5600 × 0.03
= 168 kg TS in total.

Step 2 — 168 kg TS made to a 10% TS slurry weighs 168 × 10
= 1680 kg and has a volume of 1680 litres.

Step 3 — A retention time of 20 days should be used (table 1) so that the digester volume should be 1680 × 20 = 33 600 litres.

Step 4 — From table 1, 300–450 litres of biogas should be generated from each kg TS of poultry manure.
Therefore, the daily biogas production should be between 168 × 300 = 50 400 and 168 × 450 = 75 600 litres.

If the waste is produced as a slurry at 10% TS or less, the volume of the slurry produced should be used in Step 3 to calculate the digester volume, with the corresponding weight of total solids being used to calculate the biogas yield as in Step 4.

If the biogas plant is intended primarily to provide fuel, it should be designed to meet the average demand. It is uneconomic to build a plant to meet short-term peak demands, such as grain drying or spring cultivation.

It is worthwhile building a digester up to 50% larger than necessary because the additional cost is likely to be small. This can allow some additional capacity for peak demands, and for short periods production can also be boosted to up to double the usual by loading more material into the digester each day.

The most economical way to meet the balance of any peak fuel demand is by supplementing with fossil fuels, perhaps by running vehicles on petrol or diesel instead of biogas when grain is being dried with the biogas.

Once the average daily fuel demand has been estimated, it is necessary to consider the materials that are already available or could be grown for producing biogas.

Table 1 can then be used to calculate how much material (kg TS or DM) must be digested each day to produce the required gas. From this figure the appropriate digester size can be calculated by Steps 2 and 3 above.

If the fuel demand (litres of petrol or diesel) is known, these figures can be converted to litres of methane using the following conversions (based on higher calorific values of 36 MJ/litre for premium petrol, 38 MJ/litre for diesel, and 37 MJ/m^3 for methane):

1 litre of premium petrol = 918 litres of methane or 1670 litres of biogas at 55% methane.

1 litre of diesel = 1011 litres of methane or 1838 litres of biogas at 55% methane.

If some of the biogas is to be used for heating the digester allowance should be made for this additional demand when estimating the total fuel requirement.

When a mixture of materials is to be digested and the materials need different times for digestion, the longest retention times (RTs) should be used to calculate the necessary digester volume in Step 3. A longer RT reduces any odours in the effluent from the biogas plant.

Storage of Effluent

When fresh material is added to the digester an equivalent volume of slurry from within the digester is displaced. It is convenient to provide several days' storage for this effluent, so that it can be disposed of or used as fertiliser in suitable weather. In this way it does not have to be handled every day.

Pre-cast water tanks or small lagoons are most economic. Their volume will depend on how the digester is operated and what storage time is chosen.

If fresh material is added directly as a slurry of 10% solids or less, the volume of effluent displaced will equal that of the fresh material loaded. If drier material is used and either added directly or diluted with slurry drawn from the digester, the volume of effluent discharged will be equal to the effective volume of the dry feed material.

Siting the Biogas Plant

To minimise transport costs, a biogas plant should be built near the source of manure or other feed material. However, if the biogas is to be used for fuelling vehicles, it may be convenient to locate the compressor, biogas scrubber, and refuelling station separately, perhaps near the farmhouse or implement sheds. A PVC or alkathene pipeline can be laid to transfer the raw gas.

The biogas plant should be sited near enough to the farmhouse to permit easy maintenance, because malfunctions can occur. If the plant is close to the house alarm bells can be used to indicate some malfunctions.

The biogas plant should not produce odours, but manures or crops stored as silage can cause an unpleasant smell. If this is a possibility, the plant should be sited further from the house, or be suitably screened with trees or by buildings.

A sheltered location is preferable to reduce the risk of damage by wind, especially to flexible gas storage bags.

Three-phase electricity will be needed at the site to power the motors of the biogas plant and at the compressor/scrubber/refuelling site if separate.

A water supply will also be required for scrubbing the biogas.

Acknowledgement

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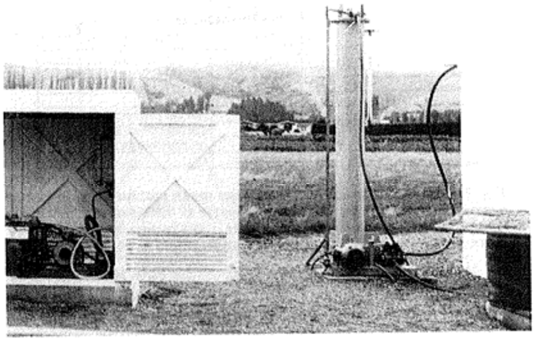
Annex 4: Biogas Scrubbing: Providing Methane for Vehicle Fuel

Farm Production & Practice

Ministry of Agriculture and Fisheries



Energy Biogas Scrubbing

Providing Methane for Vehicle Fuel

A scrubber that can remove most of the carbon dioxide is an essential part of any biogas plant intended to produce fuel for vehicles.

In the system established at the Invermay Energy Farm and illustrated above the scrubber tower and water pump (centre) operate in conjunction with a 4-stage compressor (left) and a water tank (right).

Raw biogas contains 50 to 70% methane and 50 to 30% carbon dioxide (CO_2) with trace impurities of sulphide gases. Although the raw gas can be used in boilers, space heaters, cooking stoves, and the stationary engines that drive pumps, blowers, or electricity generators, removal of the sulphides is advisable (to avoid the possibility of the burner elements and controls of the engine-exhaust system corroding).

Biogas that contains a large proportion of CO_2 is not suitable for fuelling vehicles. The CO_2 has no fuel value therefore space it occupies in the vehicle storage tank is wasted, and the distance the vehicle can travel is reduced. Moreover, if the biogas is to be interchanged with petrol in a standard petrol-engine vehicle, it will not produce an acceptable power output unless its CO_2 content is reduced to less than 5% by volume. Finally, CO_2 in compressed biogas can cause problems with freezing at valves or at other points where expansion occurs.

Keywords: **Energy; biogas; scrubbing; vehicle fuel; methane; carbon dioxide; sulphide.**

Carbon-dioxide removal

There are many ways of removing CO_2 from biogas, most of which have been designed to perform the same function with natural gas. However, the only method that is suitable for small-scale operations is washing with water under pressure.

Pressurised water washing: This method takes advantage of the fact that CO_2 dissolves easily in water under pressure (as in the manufacture of carbonated drinks), whilst methane is only slightly soluble. The process is very simple, and the pressurising of the biogas for scrubbing can be part of its overall compression for storage in the vehicle.

In Fig. 2 the process is shown schematically, with one four-stage compressor being used both to scrub and to com-

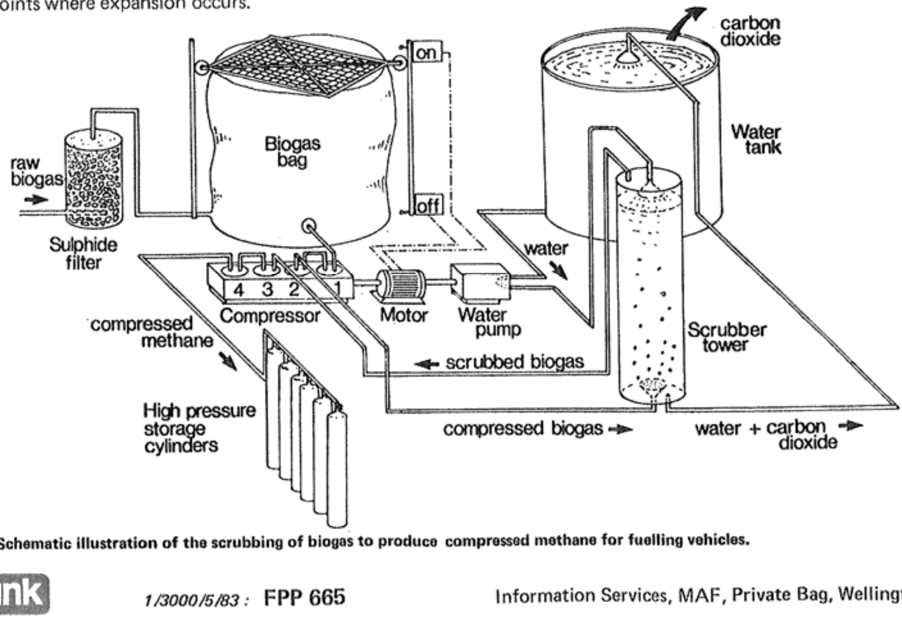


Fig. 1: Schematic illustration of the scrubbing of biogas to produce compressed methane for fuelling vehicles.

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press the biogas. A separate compressor for the scrubbing may be used in some situations.

Operation: The operation of scrubbing and compressing the biogas is controlled automatically by the switches on the gas bag. As the bag inflates with biogas, it lifts a stabilising frame above it until, when the bag is full, the frame trips a switch that activates the motor(s) to drive the water pump and compressor. The compressor draws the raw biogas from the bag and pumps it into the bottom of the scrubber tower under pressure, for the removal of the CO_2 by the water.

The water is pumped to the top of the scrubber tower at the same pressure by the water pump. It then flows down through the tower, dissolving the CO_2 and carrying it out through the exit at the bottom. The rate at which the water leaves the tower is governed by a level control device which maintains the desired water level in the scrubber.

The scrubbed biogas is now largely methane. It emerges from the top of the scrubber tower, and passes to the final compression stages of the compressor and thence to the high-pressure storage cylinders. An adjustable pressure-relief valve on the scrubber gas exit maintains the inside pressure by allowing the methane to escape only when it reaches the preset discharge pressure. The water that has been used in the scrubbing is discharged into the water reservoir tank, where it returns to atmospheric pressure. The dissolved CO_2 is released into the atmosphere, as happens when the cap is removed from a bottle of soft drink. The water can then be reused to scrub more biogas. The compression and scrubbing operation is automatically shut down when the gas bag deflates and the stabilising frame activates a lower-limit switch.

Efficiency: The water scrubbing method is capable of removing virtually all the CO_2 content of the biogas, if the scrubbing pressure, water flow rate and purity, and the scrubbing towers dimensions (especially its height) have all been correctly calculated for the given gas-flow rate. Increasing any of these variables will increase the purity of the scrubbed gas. In practice, 100% removal of the CO_2 is unnecessary – most vehicles perform satisfactorily on scrubbed biogas whose methane content is 95 or more percent.

Design calculations

There is no simple formula for choosing the appropriate combination of scrubbing pressure and water and gas-flow rates to produce scrubbed gas of an acceptable purity. However the deciding factor is the degree of solubility of CO_2 in the water under the proposed conditions.

Carbon-dioxide solubility: The solubility of CO_2 in clean water at the normal temperatures (about 15°C) is known to be (0.87 x the partial pressure of the CO_2) litres per litre of water. The partial pressure of CO_2 in biogas is given by the total pressure of the biogas x the fraction of CO_2 in it, so that for biogas containing 65% methane (35% CO_2) at atmospheric pressure the partial pressure of the CO_2 would be 1 x 35/100 = 0.35 atmospheres. Under these conditions 0.87 x 0.35 = 0.30 litres of CO_2 should dissolve in each litre of water. At 10 atmospheres partial pressure (147 psi), 3.0 litres of CO_2 should dissolve in each litre of the water used for scrubbing the biogas.

Unfortunately, the full amount of CO_2 that should dissolve in the water does not do so in practice. This is largely because all the CO_2 does not have time to dissolve on its passage through the scrubbing tower. An even lower solubility must be expected if the scrubbing water is re-used as it will already contain some CO_2 that has not had time to escape back into the atmosphere.

Performance graph: The uncertainties just mentioned make it more practical to base the design of a scrubbing system on the performance of the actual scrubbers – the graph in Fig. 3 has been drawn from such data.

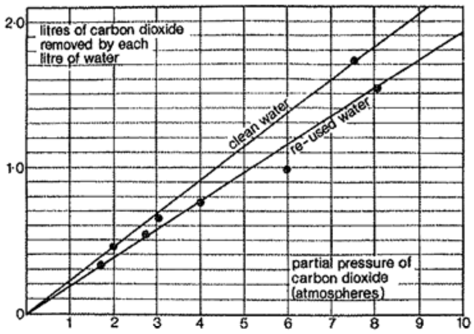

Fig. 2: Correlation graph, showing how much carbon dioxide can be washed from biogas by each litre of water at different scrubbing pressures and carbon-dioxide contents – the points are taken from working scrubber systems. (Note: 1 atmosphere = 14.69 psi).

To use the graph it is necessary to be able to measure the composition of the raw biogas – in general, it can be expected that biogas from manures will contain about 65% methane, while crops and other vegetable matter produce a biogas that contains about 55% methane. The graph can be used to read off the volume of CO_2 that should be removed from the biogas by each litre of water that is pumped through the scrubber tower for whatever partial pressure of CO_2 is produced by the compressor.

This figure and the volume of CO_2 pumped through the scrubber per minute by the compressor enable calculation of the flow rate that the water pump must deliver at the predetermined scrubbing pressure. A working example follows.

Working example: The biogas produced from poultry manure is known to contain 65% of methane and 35% of carbon dioxide. The specifications for the compressor to be used to scrub it state that it will compress 133 litres of biogas per minute (8 m^3/hour) to 14.3 atmospheres (210 psi). What specifications must the water pump have if recycled water is to be used for scrubbing?

- The partial pressure of CO_2 supplied to the scrubber will be 14.3 x 35/100 = 5.0 atmospheres.
- From Fig. 3 it is seen that at 5.0 atmospheres, 0.9 litres of CO_2 can be dissolved in each litre of water.
- The compressor will pump 133 litres/min of biogas which corresponds to 133 x 35/100 = 46.6 litres/min of CO_2.
- Therefore, to remove 46.6 litres of carbon dioxide from the biogas each minute it will be necessary to pump 46.6/0.9 = 51.7 litres of water. A suitable water pump should therefore provide a flow rate of about 52 litres/min at 14.3 atmospheres (210 psi).

Choosing the compressor

If the scrubbed biogas is to be used to fuel vehicles, it must be compressed to about 272 atmospheres (4 000 psi) for storage in the refuelling cylinders. A suitable

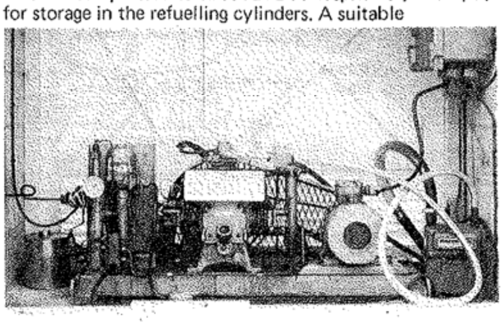

Fig. 3: A four-stage compressor (Luchard HBE 8, marketed in New Zealand by Compair Ltd) being used both for scrubbing and for compressing biogas.

compressor needs to be capable of handling the daily production of biogas in about 12 hours of running time.

If several makes or models of a suitable size are available, the choice should be made on their cost and reliability, and on the availability of servicing. Compressors may be three or four-stage types, but they should be fitted with stainless-steel piping. They must not have any copper piping or gaskets, because copper is rapidly attacked by both the sulphides in the raw gas and carbonic acid that is formed by any moisture in contact with the CO_2 in the compressed gas.

Provision should be made for bleeding gas from the compressor stages whenever it shuts down, so that it will not restart under load. Where the continuous running time is likely to exceed an hour, a timing device should be installed that will allow condensed moisture and oil contamination to be vented at about hourly intervals.

Lubricating and cooling: Whatever the compressor, it is important to use a synthetic oil, designed for use with methane — otherwise a chemical reaction between the oil and the methane can occur, causing the oil to degrade to a black sludge. Most compressors will be provided with a thermal sensor to detect a failure of the oil or the cooling system and some may have an oil-level warning indicator. Air-cooled compressors are simpler than the water-cooled models, but when the compressor is being operated in conjunction with a biogas plant, a water-cooled model allows the cooling water to be used for digester heating, enabling a more efficient utilisation of energy.

How many compressors: For smaller operations, it is more economic to use a single compressor for the scrubbing and the compressing — the capital costs are lower, the electrical installation is simpler and less costly, and there are fewer items to require regular maintenance. In larger plants however, it can be more economic to use a separate compressor for the scrubbing after which the gas is returned to a second, flexible storage bag that is fitted with limit switches to control the high-pressure compressor. The reduced volume of the scrubbed biogas (without the CO_2) allows the high-pressure compressor to be of smaller capacity than if it were used to scrub as well. This reduces its cost and can offset the added costs of the scrubbing compressor and the second gas bag with its electrical system.

Choosing the water pump

Once the compressor has been chosen, the scrubbing pressure and the gas-flow rate through the scrubber tower have been fixed. The only flexibility is in whether to direct gas to the scrubber from the first or from the second stage output of the compressor. The water pump must be able to work with water that is at or above the chosen scrubbing pressure — and at a suitable flow rate to clean the biogas to the desired degree of purity. (The choice of rate can be made from experience or, as described previously, by using a graph such as Fig. 3).

In order to provide for a possible increase in the scrubbing efficiency, it is wise to choose a pump whose flow rate does not depend too closely on the pressure — otherwise any attempt to increase the purity of the scrubbed gas by increasing the scrubbing pressure will be offset by a corresponding reduction in the flow rate from the pump. If the scrubbing system is to operate automatically, it is essential to have a pump that is easily maintained and reliable under extended usage. Water that contains dissolved CO_2 is acidic and thus corrosive to steel and copper — if the scrubbing water is to be re-used, a pump with a stainless-steel impeller or with rubber diaphragms is needed to avoid any possibility of corrosion.

Designing the scrubber tower

The scrubber tower is the vessel in which the raw biogas comes in contact with the scrubbing water. The taller the

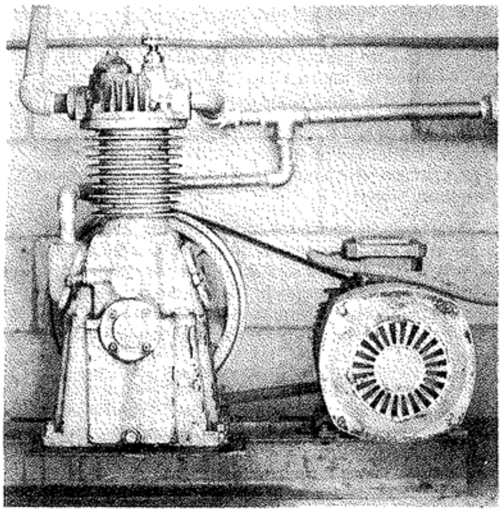

Fig. 4: A two-stage compressor (Kellogg 321 TV, marketed in New Zealand by Compair Ltd) being used to scrub biogas. A second compressor compresses the scrubbed gas.

vessel, the further the gas bubbles must travel through the water and the greater the efficiency of the gas washing. A vertical tower is therefore an appropriate shape for a scrubber.

Dimensions: The actual dimensions are not as important as are the water and gas flow-rates and pressure in determining the purity of the scrubbed gas. A 6 m length of 200 mm diameter pipe will make a scrubber tower able to handle as much as 2 000 m^3 of raw biogas per day if the other parameters are chosen correctly. A standard 6 m length of 200 mm diameter PVC irrigation pipe can be used to make an inexpensive and corrosion-free scrubber tower for smaller operations where the scrubbing pressure is below 1 200 kPa (174 psi), as shown in Fig. 6. Steel pipe must be used for higher pressure scrubbing.

Packing: The efficiency of scrubbing in any tower can be further improved by packing it with cascade minirings No. 1 (available in New Zealand from AHI Chemical Engineering Services, Private Bag, Auckland) or with nylon pot mitts, either of which will obstruct the gas flow and force it to

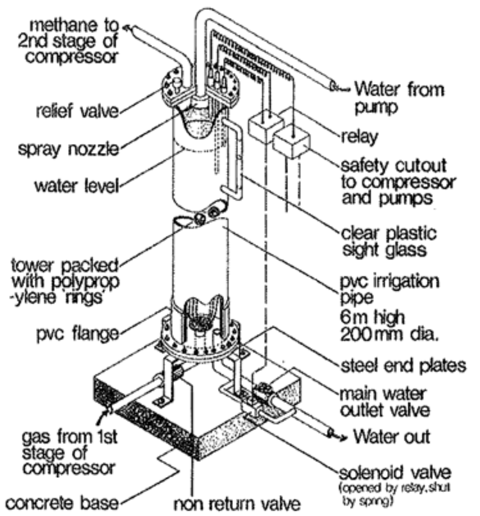

Fig. 5: Design of a water scrubber suitable for removing carbon dioxide and hydrogen sulphide from biogas.

travel further. Packing is very important in a tower that is operated as a spray tower with very little water in it – the contact between the gas and the water is made in the film on the surface of the packing. If a flooded tower almost filled with water is used, the nature of the packing is less critical.

All the information in this AgLink relates to flooded towers, which have a number of operational advantages over spray towers.

Water level: A device for controlling the level of the water in its tower is essential if the scrubber is to operate automatically. Without such a control, the water level could rise too high and water could flow through the gas outlet into the compressor. If the level dropped too low, the gas would not be scrubbed and might even escape through the water outlet.

There are a number of ways of monitoring and controlling the water level, but the least expensive and most robust is to use conductivity probes. These are two lengths of stainless-steel rod that either enter the tower through the top and descend to the desired water level, or are fitted in the walls of the tower at that level. If the tower is of steel the rods are insulated from it by an insulating seat. When the water level in the tower rises so that it covers both probes a current can travel between them through the water. It is used to operate a relay that opens a solenoid valve which releases more water from the tower.

The main water-outlet valve is adjusted so that the water level will normally rise slowly during scrubbing, and the control maintains the level after it has reached the desired height. When the water is re-used, it could eventually become contaminated with solid particles and it is advisable to instal a water filter in front of the solenoid valve to ensure that its fine bleed holes do not become blocked.

As a further precaution, a third conductivity probe should be installed at the top of the scrubber tower so that if the water level does rise too far it will cause a current to flow between the upper and the lower probes and thus activate a safety shut-off of the water pump and compressor.

Water re-use: Some water-scrubbing systems use a second tower to assist the release of CO_2 from the water before it is re-used. However, this has not been found necessary with the scrubbers in use in New Zealand – so long as the water reservoir is large enough to allow sufficient time for the water to have lost most of its CO_2 content before it is used again. An open 13.6 m^3 (3 000 gal) concrete tank is suitable in most cases. It should be painted on the inside with a water-based epoxy paint to prevent erosion by the acidic content (carbon dioxide) of the water.

Electrical wiring

The operations of the scrubber are controlled by the limit switches on the biogas storage bag, which control the motor that drives the compressor and water pump. However, a number of other switches must be 'on' for the scrubbing and compression operation to take place (this is shown schematically in Fig. 7).

The high-pressure cut-out switch prevents overfilling of the high-pressure storage cylinders and also limits the operating pressure of the compressor. A gas-release valve is required to allow biogas to escape from the storage bag when this switch is 'off'. The vent-cycle timer may shut

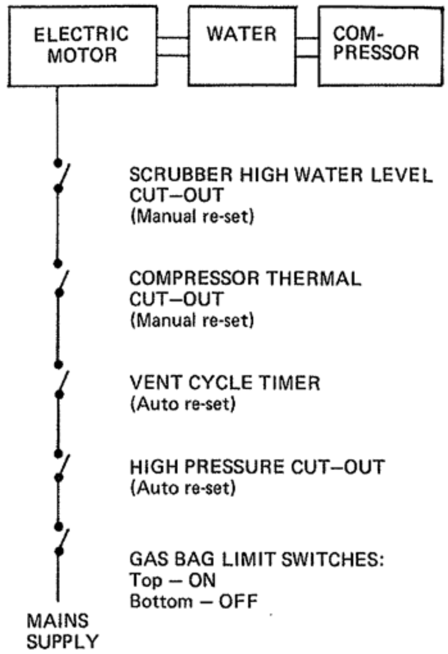

Fig. 6: Schematic electrical wiring of a scrubbing/compression system for biogas.

down the compressor for a short period to allow its normal shut-down bleed system to vent collected moisture and oil. Or, it may simply open the vent valve without stopping the compressor motor (if this valve is electrically operated).

The compressor thermal cut-out switch and the scrubber high-water-level switch are safety devices which must be re-set after the fault is corrected. When thrown to the 'off' position, they can also ring a warning bell to draw attention to the fault.

Insulation

In areas that are subject to freezing temperatures, it is essential to insulate any water pipes and valves that may freeze. Where extremely low temperatures are common this may necessitate locating the water pump, solenoid valve and even the bottom part of the scrubber tower, inside a building such as the biogas plant control shed.

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