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Rural Industries Research and Development Corporation

Assessment of Methane Capture and Use from the Intensive Livestock Industry

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Foreword

The intensive livestock industry accounts for about 12% (methane from livestock) of Australia's total GHG emissions (Hegarty, 2001). Significant reductions in methane emissions from the intensive livestock industry will therefore have a major impact on reducing Australia's overall GHG emissions on a CO_2-e basis.

This report explores the viability of methane capture and use systems for the Australian intensive livestock industry. A review of existing manure methane systems from intensive livestock industries operating within Australia and overseas is presented and the technologies that are best suited for capturing methane in the Australian context are identified.

The findings of this report revealed that the intensive livestock industry in Australia presents a diverse range of issues and the assessment of viability of methane capture and use must be assessed on a site specific basis. It is clear, however, that transport cost for wet wastes is a key variable in the financial viability of these systems. Other factors that affect the viability of methane capture and use are the amount of energy the system would produce and the recovered form of the energy (i.e. as heat or electricity). The available literature suggests that the viability of some projects may rely heavily on the ability to sell the dewatered digested solids produced as a by-product of energy production.

This report also discusses how government aids and incentives can be economically beneficial by reducing the payback period for methane capture capital investments. However, the impact of incentives on the economics or return of investments on bioenergy projects in Australia are often insufficient to allow viable projects to proceed.

This project was funded by RIRDC Core funds, which are provided by the Australian Government.

This report, an addition to RIRDC's diverse range of over 1600 research publications, forms part of our Methane to Markets R&D program.

Most of our publications are available for viewing, downloading or purchasing online through our website:

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Acknowledgments

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Abbreviations

ADAS	Agricultural Development and Advisory Service
AGO	Australian Greenhouse Office
AMH	Australian Meat Holdings
APL	Australian Pork Limited
BOO	Build Own Operate
CAL	Covered Anaerobic Lagoons
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
DAF	Dissolved Air Floatation
DEUS	Department of Energy, Utilities and Sustainability
DPI	Department of Primary Industries
EU	European Union
GEC	Gas Electricity Certificate
GHG	Greenhouse Gas
HSCW	Hot Standard Carcass Weight
HRT	Hydraulic Retention Time
MAD	Completely Mixed Mesophillic Anaerobic Digesters
NGAC	NSW Greenhouse Abatement Certificate
NSW	New South Wales
ORT	Organic Resource Technologies
QLD	Queensland
REC	Renewable Energy Credit
RIRDC	Rural Industries Research and Development Corporation
SEDA	Sustainable Energy Development Authority
SPU	Standard Pig Unit
SRT	Solids Retention Time
TS	Total Solids
TWMS	Total Waste Management System
UASB	Upflow Anaerobic Sludge Blanket
UNEP	United Nations Environmental Program
UK	United Kingdom
US	United States
VREC	Victorian Renewable Energy Credit
VS	Volatile Solids
WA	Western Australia

Contents

Table Index

Figure Index

Executive Summary

What this report is about?

This report assesses the viability of producing and capturing methane from manure for conversion into energy within the context of the Australian intensive livestock industry. The key technology used for conversion of manure into methane is anaerobic digestion. This report therefore focuses on the historic and current use of anaerobic digesters in the livestock industry in Australia and overseas. It also investigates the viable project scale by estimating project costs, the transport costs for feed material associated and the current incentives available for industries to convert/ modify their current waste processing systems into anaerobic digesters.

Who is the report targeted at?

This report is targeted at two groups:

- Individual farmers who need to understand the reasons for methane capture, the available technologies, the current use of these technologies in Australia and overseas and the financial incentives available; and.
- Decision makers and extension officers from government and industry bodies who need to understand Australia's current situation on methane capture and use from the intensive livestock industry.

Background

Methane capture and use from the intensive livestock industry has been reasonably well established in the European Union (in countries such as Denmark, Germany and UK), as well as the United States. However, this process is used rarely in the Australian industry. With the increasing focus on minimising emissions of greenhouse gases, it is expected that the application of capture and reuse technologies can help significantly reduce methane emission from the intensive livestock industry. This report therefore focuses on establishing the financial credentials of methane capture and use for the Australia intensive livestock industry.

The aims of the research project

This report aims to allow:

- An individual farmer to be able to make an initial assessment on the viability of anaerobic digestion for their operation based on their location, the proposed technology, the use of the energy, and the incentives available; and
- Organisations and the government to determine whether more support for the industry is required if there is intention to encourage the growth of methane capture and use technology in Australia.

Method

The first step of this research study was to understand the technologies available to produce methane from organic wastes produced by the intensive livestock industry and conversion of the methane into energy. This was achieved through a literature review to identify historic Australian and international work in the area of methane capture and use technology. An assessment was then carried out on the systems that best identify with and suit the characteristics of the Australian intensive livestock industries.

A further review of the literature was conducted to determine the best available method(s) for establishing the organic loads (tonnes per day) required from piggeries, dairy free-stalls and beef feedlots that would provide for economically viable capture and use of methane.

An assessment of the potential for cross-sectoral and/or cross-enterprise methane capture and use projects was undertaken to understand if project viability was enhanced through economies of scale. This was achieved by obtaining information from the relevant industry sectors.

Capital cost estimates for methane capture and use facilities were prepared for each intensive livestock industry sector i.e. piggeries, dairy free-stalls, and beef feedlots. The cost data used was based on in-house experience with similar anaerobic pond systems. An estimate of the potential economics for each of the options was also prepared showing possible payback periods.

As part of the cost analysis, determination of viable transport distances for crop stubble and liquid manure (dairy or piggery sludge at 1%, 5%, 10% TS) and the dry manure from deep-litter piggeries and beef feedlots (TS 60%) was also performed.

Results

The literature review revealed that the viability of anaerobic digesters in the intensive livestock industries is very site specific. It is dependent on:

- The type of "digester" that will be used (i.e. if there are any lagoons present to convert into digesters or new equipment will be required);
- The amount of energy produced and the potential uses of this energy;
- The location of the farm;
- The possibility of sale of the dewatered digested solids;
- Which state the farm is in; and
- The incentives available for the use of gas produced from anaerobic digesters in Australia.

Much of the literature reviewed reported manure production rates for livestock as "rules of thumb" (kg manure (TS, VS, etc)/animal/day). This approach is considered sufficiently robust to estimate manure production rates for evaluating the economic viability of projects.

The payback period for a piggery of size 20,000 SPU for a methane capture facility that involves covering existing lagoons and a cogeneration unit is approximately 1.5 years for a site using a diesel generator and approximately 6 years for a site connected to the grid. This would be significantly reduced if government incentives were introduced.

The feasibility for transporting manure (liquid or solids) to a centralised methane capture facility was investigated and was found to be unfeasible if transportation distances exceed 5 km. Even for distances <5 km, transportation, costs are significant relative to the available energy value.

Based on the transportation cost of straw per tonne per km, cost of straw per tonne and the energy available ($) in the straw when anaerobically digested, it is not financially viable to purchase and transport crop stubble to a farm for the specific reason of digesting it with manure to produce biogas.

Implications and Recommendations

This report will allow individual farms and organizations to make a preliminary assessment of the viability of methane capture and use in the Australian context. Based on the information presented, government and non-government organisations will be better positioned to determine if they are satisfied with Australia's position on cleaner production in the livestock industry or whether provision of incentives or subsidies are required to stimulate the introduction of methane capture and use technologies.

1.0 Introduction

1.1 Background

The Australian Greenhouse Office (AGO) has estimated that on-farm activities produce about 18% of national Greenhouse Gas (GHG) emissions (excluding energy use). Methane is the dominant GHG, with this sector's methane emissions accounting for about 12% of Australia's total GHG emissions. Significant reductions in methane emissions from Australia's intensive livestock industry will therefore have a major impact on reducing Australia's overall GHG emissions on a CO_2-e basis.

In 2004, the international "Methane to Markets Partnership" was launched and this program now has 19 international partners, including Australia. The Rural Industries Research and Development Corporation (RIRDC) is the manager of the "Methane to Markets in Australian Agriculture Program". One of the objectives of this program is to reduce GHG emissions from agricultural industries. The current report assesses the opportunities for GHG emission reductions through methane capture and use systems associated with the intensive livestock industry.

1.2 Scope of Works

While methane capture and use from intensive livestock industries is fairly well established in the European Union (EU) and the USA, it is still in its infancy in Australia. The Australian intensive livestock industry displays different characteristics to those in the EU and USA, where facilities are typically much larger or more densely located than Australian operations. Consequently, the terms of reference for this study are to:

1. Review previous Australian and overseas work in the area of methane capture and use technology and assess the systems that best identify with and suit the characteristics of the Australian intensive livestock industries (*vis a vis* piggeries, beef feedlots and dairy free-stalls).
2. Review the best systems to determine organic loads required from piggeries, dairy free-stalls and beef feedlots to provide for economic capture and use of methane.
3. Assess the potential for cross-sectoral or cross-enterprise methane capture and use projects to achieve economies of scale.
4. Make recommendations as to the requirements necessary to implement viable methane capture and use systems within the Australian intensive livestock industry, including:
    a. Determination of the project scale required to be viable. i.e. What is the project scale, MWe or tonnes of CO_2-e abatement required for external build-own-operate (BOO) projects in Australia; and
    b. Determination of viable transport distances for crop stubble and liquid manure (dairy or piggery sludge at 1%, 5%, 10% TS) and the dry manure from deep-litter piggeries and beef feedlots (TS 60%).

2.0 Review of Existing Methane Capture / Use Systems

2.1 Overview

There are a variety of processing routes available to convert Biomass to energy. Figure 1 provides an overview of the pathways that can be followed.

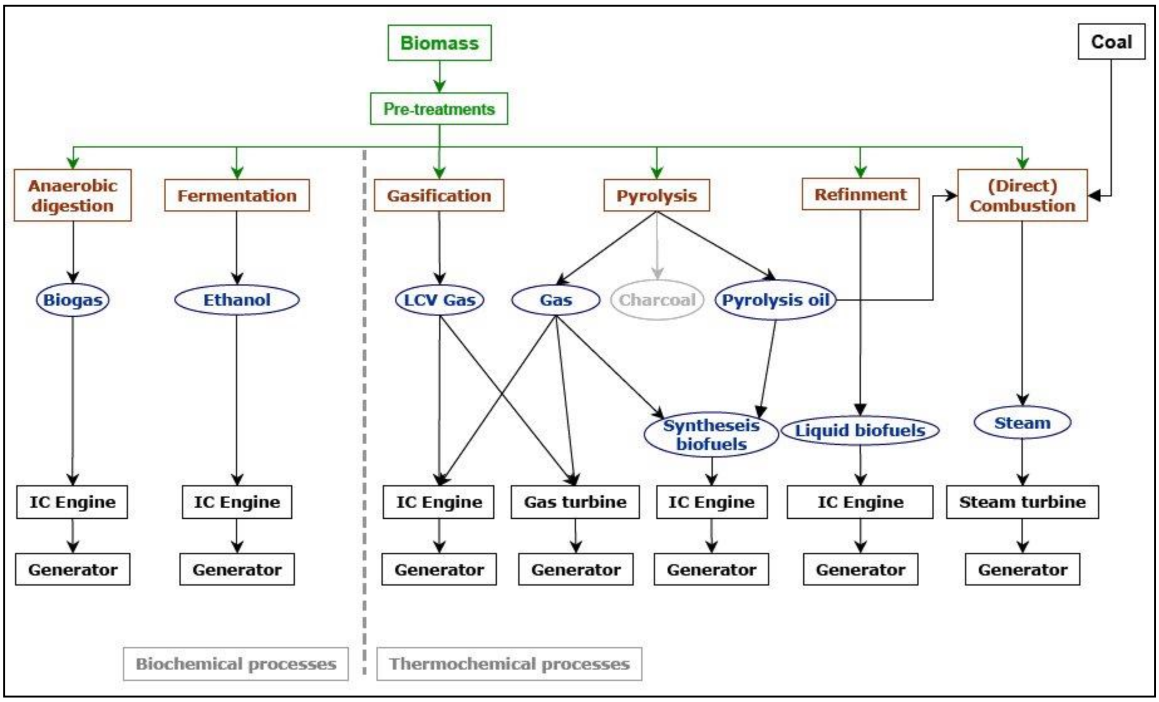

Figure 1 *Biomass Waste-to-Energy Pathways (GHD, 2007)*

2.1.1 Anaerobic Digestion

Anaerobic digestion relies on microbes to convert organic material to a combination of the most reduced and most oxidised forms of carbon; methane and carbon dioxide respectively. This mixture of methane and carbon dioxide is also known as biogas and consists of 60 – 80% methane, carbon dioxide and other compounds in trace amounts e.g. hydrogen sulfide and hydrogen gas. Biogas capture and use has been found to be the most useful method for recovering energy from "wet" waste streams (Lake *et al*., 1999), with the water content of wet waste streams typically >70%.

Anaerobic digestion systems are installed principally to:

- treat wastewater streams containing organic solids and sludge;
- reduce sludge volumes; and/or
- stabilise organic sludge prior to disposal.

Many operations, including piggeries, abattoirs, food manufacturers and municipal sewage treatment plants currently use anaerobic digestion for this purpose (Lake *et al*., 1999).

Biogas produced from anaerobic processes is often released to atmosphere and in some instances flared or combusted to provide heat and/or power. Within Australia, biogas capture and use schemes have been uncommon in the past, however, there is an increasing trend in developing these projects for beneficial reuse of the produced biogas.

2.1.2 Thermal Processes

Thermo-chemical processes used on wet waste streams are hampered by the water content. The energy available from the organic content in the waste is generally low compared with the energy needed to drive off the water associated with the waste (Lake *et al*, 1999). Thermo-chemical processes are more likely to be financially feasible for waste streams containing higher solids percentages, e.g. from deep litter housing from piggeries.

Co-combustion is the single largest energy recovery route for management of biomass in Europe. Within Australia, this approach could be an option in areas where large intensive livestock industries are located near coal fired power stations or cement works. Co-combustion has been used at Millmeran, Kogan Creek, the Hunter Valley, the Latrobe Valley and Collie (GHD, 2007).

Co-combustion includes advantages such as higher efficiencies at large scale, lower investment costs if current facilities can be adapted and biomass burning can lead to lowering sulphur and nitrogen oxide and other emissions compared to coal only. Chloride and alkaline rich straw can cause corrosion and slagging in conventional combustion systems. A two-stage process can avoid this when straw is used to raise low temperature steam, which is then superheated with a conventional fuel (GHD, 2007).

Gasification systems are not generally considered to be reliable technologies at present. One of the main issues is the cost of thermal gasification compared to anaerobic digestion. It has been estimated that a full-scale plant must have a daily capacity of at least 250 tons of manure (wet) to be financially viable (Stoholm 2005). This corresponds to production from 650,000 pigs, which should be located near the plant to minimise transport costs. . There are a number of beef feedlots in Australia close to this scale that produce a dry waste. However, gasification systems are not explored in any detail in this report as it is beyond the scope of this work but should be considered in future investigations.

Pyrolysis is even less developed than gasification, and while there are some demonstration plants operating, actual market penetration is in its infancy (GHD, 2007). However, it should be investigated further as an option for beef feedlots as dry organic wastes suits this technology best. Although, significant energy requirements and costs are involved in drying the material prior to processing. Woody garden organics that are relatively dry have been successfully processed using this technology. The gases produced can be used to generate electricity (GHD, 2007).

Thermo-chemical processes are relatively new technologies (for manure) that are complex and capital intensive to implement. For these reasons, they have not been considered further in this report.

Based on the above, this study has focused solely on anaerobic digestion for methane generation and the various alternatives available for using the biogas produced as an energy source.

2.2 Australia

A review of the livestock industry literature revealed that while much work has been done at desk-top, laboratory and pilot scale, only one commercial-scale methane capture and use system is currently operating in Australia within the intensive livestock industry. This facility was installed at the Berribank Farm in Ballarat, Victoria (Australian Centre for Cleaner Production, 2001).
Another commercial facility is planned for Rockdale Beef Pty Ltd in Yanco, NSW. However, details on this facility are still “commercial-in-confidence”. The NSW Government, through DEUS has provided a $2 million grant for this facility. Rockdale plans to process 160,000 tonnes of wet manure per annum

(600 ML/yr) and produce at least 16 MWh/a of electricity (Rockdale Beef). Preliminary projects costs are estimated to be $20M (2007) which equates to ~$400/head for a 50,000 head facility.

2.2.1 Berribank Farm

Berribank Farm is a piggery operated by Charles I.F.E Pty Ltd. In June 1989, they commenced installation of a Total Waste Management System (TWMS) to handle all the waste liquid manure from the piggery, which houses 14,730 Standard Pig Units (SPUs). The TWMS comprises the following major units:

- A grit removal system;
- A high-efficiency DAF to increase manure total solids (TS) to about 4%;
- A dual-stage engineered anaerobic digester system, the first operating mesophilically (37^0C) and the second at ambient temperature, with biomass recycle;
- Digested sludge dewatering; and
- A combined heat and power (CHP) system.

Based on a 2001 audit of the facility (Australian Centre for Cleaner Production, 2001) the following information was noted:

- The capital cost of the facility, in 1991, was $2.3 million (equivalent to about $4M in today's dollars);
- The facility processes 320 kL/d of manure at a nominal 1.6% TS;
- The facility recovers 140 kL/d of water from the DAF which is recycled for nutrient reuse;
- The facility recovers 7.2 tpd of digested solids at a TS of 25% which is sold as fertiliser;
- The facility produces 1,700 Nm3/d of biogas which is used to generate 120 kW of electricity; and
- The estimated annual savings are $425,000, providing a 6-year payback on investment.

This data indicates that the unit capital cost per MW of power generated is $33 million/MW (in today's dollars). The annual saving includes $250,000 per annum for sale of dewatered digested solids, $125,000 per annum for electricity savings and $50,000 per annum for water savings (Australian Centre for Cleaner Production, 2001).

2.2.2 United Nations Environmental Program (UNEP) Case Studies

In 1998, UNEP carried out a study for the Sustainable Energy Development Authority (SEDA) to explore the potential for co-generation using wet wastes. The study included wastes from animal farming and processing, and food and beverage processing (Lake, 1999). For the sake of simplicity, this study focused on biogas generation and use of any energy generated on site. The study did not extend to examination of electricity export to the grid or the sale of digested sludge as a by-product.

Wet wastes from intensive livestock industries (piggeries, dairies, feedlots and poultry farms) consist of animal manure, which is generated in an effluent, slurry or semi solid form. Animal manures are an excellent source of nutrients and organic carbon that are often applied to land as a soil additive and fertiliser. However, once these biosolids are anaerobically digested, the by-product can be used as a superior quality fertiliser (Lake, 1999).

Large-scale processing activities, such as abattoirs, poultry processing and dairy products processing were considered to produce sufficient biosolids to sustain economically viable methane recovery projects. In order to determine the feasibility of anaerobic digestion in Australian industries, six companies were chosen to assess whether energy recovery from wet wastes was viable in the Australian context. The six companies were (Lake, 1999):

- Parkville Piggery
- Scone Fresh Meat
- Toohey Brewery
- Bartter Enterprises Poultry Processing Plant
- Australia Meat Holdings
- Streets Ice Cream Factory

In the current report, only two of these case studies have been detailed, as this report primarily explores the viability of methane capture and use from the intensive livestock industry. It should be noted that all of these companies bar the Parkville Piggery incur significant costs for the treatment and disposal of their wet waste streams (Lake, 1999). Furthermore, due to the high water content of all the waste streams considered, anaerobic digestion to produce biogas was considered the most appropriate treatment technology.

Parkville Piggery– Case Study

UNEP (Lake *et al*., 1999) conducted a case study on Parkville Piggery in 1999, however it was closed a few years later. Parkville piggery was a medium-sized piggery located in the Upper Hunter Valley of New South Wales. It housed approximately 1,200 sows. The total number of piglets per sow is approximately 10, hence there was approximately 24,000 pigs. The calculated number of standard pig units (SPUs) was 15,500 SPU (Lake *et al*., 1999).

The piggery was divided into two areas; the breeding sheds and the growing sheds. Each of the production areas had a set of effluent treatment lagoons that treat the effluent before it was irrigated to land on the property. The pig housings were made of slatted or concrete floors that were flushed with water to remove manure (Lake *et al*., 1999).

The Parkville Piggery did not incur costs for disposal of their wet waste stream. Instead, they received some financial return from their waste stream by worm composting of the solids in the effluent that produced a soil-conditioning product. The benefit from worm composting would potentially be lost if the piggery was to capture methane and use it, although it was expected that the digested biosolids would also have some value. In addition to the above, the piggery did not use a large amount of electricity, hence part of the gas that would be produced would have been flared unless it was sold to the grid (which was not considered in this study).

The liquid manure was screened and then processed via two parallel trains, each comprising an uncovered anaerobic lagoon followed by two aerobic lagoons. This is shown schematically in Figure 2 (Lake, 1999).

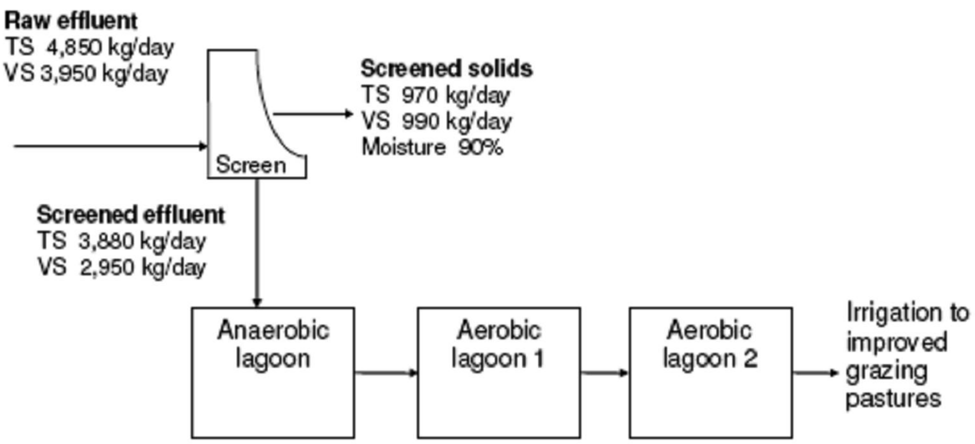

Figure 2 *Treatment Flowsheet for Parkville Piggery*

Three options to capture methane for energy generation were considered:

- Option 1 - Covering one of the existing anaerobic lagoons to collect biogas;
- Option 2 - A new, centralised anaerobic lagoon specifically designed for biogas collection; and
- Option 3A and 3B - In vessel digestion for screened solids to produce biogas.

The infrastructure requirements for these options were:
- Option 1 – Included the infrastructure to collect biogas from an existing anaerobic lagoon and piping it to the farrowing and weaner sheds for heating purposes.
- Option 2 – Included construction of a new centralised anaerobic lagoon with a HDPE floating cover, biogas treatment and conveyance systems and a generator set with heat recovery equipment. The cost of constructing a new lagoon was estimated at $\$2/m^3$.
- Option 3A – Included the provision of a digester vessel, equipment for treating the biogas to reduce moisture and H_2S, and associated pipework. The gas would be used for heating purposes.
- Option 3B – Included the works as outlined in Option 3A plus additional capital expenditure associated with a Dissolved Air Flotation (DAF) unit and a generator set for electricity generation.

The details of these methane capture and use options, along with an assessment of the economic viability of these options, is detailed in the Table 1 below. The data presented is based on dollars as estimated in 1998.

Table 1 Economic Viability of Methane Capture and Use at Parkville Piggery:

	Option 1: Covering 1 of the existing anaerobic lagoons	**Option 2:** New centralised anaerobic lagoon	**Option 3A:** Solids digester using rundown screens	**Option 3B:** Solids digester using DAF unit
Capital Cost [1]	\$410,000	\$680,000	\$1,150,000	\$1,370,000
Energy Saving	560,000 kW.h/yr	660,000 kW.h/yr	560,000 kW.h/yr	660,000 kW.h/yr
Payback Period	11 years	13 years	45 years	80 years
Net Reduction in tonnes of CO_2/yr	2,962	5,482	??	??

1. All costs have been converted to today's dollars using inflation rate.

This case study showed that:
- None of the energy recovery systems could be justified on economic grounds alone, since the payback periods for all the options were greater than 10 years. One of the key reasons for these lengthy payback periods is the relatively low wet waste treatment and disposal cost at this site.
- Of the options available, the construction of a new anaerobic lagoon appears to be the most suitable option, as it would digest the entire effluent stream from the piggery to produce biogas.

Bartter Enterprises Poultry Processing Plant – Case Study

The Bartter Poultry Processing plant (Griffith, NSW) covers all stages of poultry, meat and egg production including hatcheries, broiler farms for meat bird production, layer farms for egg production, feed mills and the poultry processing plant. The processing plant slaughters 30 million birds/year or 100,000 birds/day. The plant also includes a rendering plant that processes inedible by-products into a meat and bone meal, and tallow products.

Currently, the site's energy needs are met by electricity from the grid and natural gas, with LPG stored on site as a back-up energy source. The average annual consumption and costs for each of these sources are outlined in Table 2.

Table 2 *Average Annual Costs and Consumption for Electricity and Natural Gas*

	Consumption		**Cost** [1]	
	Annual	Daily	Average Unit Cost	Annual
Electricity	17,000 MWh	65,000 kWh	10 c/kWh	$1,700,000
Natural Gas	105,850 GJ	407 GJ	$10/GJ	$1,060,000

1. The costs have been adjusted from 1998 to 2007.

Two processing options were considered in this case study:

- Options 1A - Anaerobic digestion of the effluent stream in a covered anaerobic lagoon accepting the total load, with bypass of the existing Dissolved Air Flotation (DAF) unit;
- Options 1B - Anaerobic digestion of the effluent stream in a covered anaerobic lagoon accepting wastewater from the existing DAF unit;
- Option 2 - Anaerobic digestion of the DAF flotation sludge in a vessel digester.

The estimated capital expenditure for these options were:

- Option 1A – Includes infrastructure to convert an existing turkey's nest dam into an anaerobic lagoon with the provision of lining it with high density poly ethylene (HDPE), providing effluent feed lines, and possibly reinforcement of the banks and the provision of a floating cover. This option provides the additional benefit of increased treatment capacity, which is important as the company is considering a doubling of its production in the future.
- Options 1B – Would incur similar capital costs to Options 1A, although with additional operating costs associated with the DAF.
- Option 2 – Will continue operating the DAF unit at maximum efficiency as the primary treatment unit and includes infrastructure for a new digester, a generator set and heat recovery equipment.

The details of these methane capture and use options, along with an assessment of the economic viability of these options, is detailed in the Table 3 below. The data presented is based on today's dollars. It should be noted that this facility has an existing anaerobic lagoon and a DAF system. For this reason, the capital cost to convert the existing dam to a covered anaerobic lagoon would be lower than covering a new anaerobic lagoon.

Table 3 *Economic Viability of Methane Capture and Use at Bartter Enterprise*

	Digestion of total load effluent stream by passing the DAF (1A)	**Digestion of wastewater effluent from the DAF (1B)**	**Anaerobic digestion of DAF flotation system (2)**
Capital cost	$1,800,000 – 2,050,000	$1,800,000 – 2,050,000	
Payback Period – Natural Gas	3 years	26 years	$768,000 – 3 years

	Digestion of total load effluent stream by passing the DAF (1A)	**Digestion of wastewater effluent from the DAF (1B)**	**Anaerobic digestion of DAF flotation system (2)**
Payback Period – Elec. Generation	3 years	30 years	$960,000 - 4 years
Net Reduction in tonnes of CO_2/yr Natural Gas	2916	-	1055
Net Reduction in tonnes of CO_2/yr Coal delivered electricity	-	3568	3568

This case study revealed:

- For Option 1A, methane recovery is only feasible if the majority of the organic load is fed to the lagoon, eliminating the need for the DAF unit.
- Option 2 has the advantage of eliminating the requirement for land-based sludge disposal, but does not provide additional treatment capacity, as is the case with Option 1.
- The company utilises three natural gas fired boilers, although one was decommissioned during the study and replaced with a new unit. The biogas produced from any of these options could be fed to the decommissioned boiler with some modifications. The potential capacity of electricity generated by the company would be large enough to export into the grid. However this option was not fully explored, due to lack of information regarding electricity pricing.

From an economic perspective, both Options 1A and 2 are potentially attractive, with payback periods of around 4 years. Additionally, from a GHG emission perspective, electricity generation and displacement of coal-generated electricity provides a further benefit.

Conclusions from the Case Studies

The above case studies revealed that methane capture and use projects are economically viable, although the viability is dependent on site-specific factors. Payback periods can vary widely in the range of 1.6 to 80 years depending on the individual sites and the processing options considered. Nonetheless, based on the estimated capital costs for installing anaerobic digesters, a basic guideline was formulated to estimate the threshold scale of production above which energy recovery could be viable for the intensive livestock industries (Lake et al, 1999).

Table 4 below shows the payback periods that can be achieved for a given capital expenditure and methane generation rate.

Table 4 Thresholds for Economic Viability (derived from Lake *et al*., 1999)[1]

	Payback Period[2]		
Total Capital Expenditure	2 years	4 years	6 years
$410,000	2,330 m^3 methane	1,160 m^3 methane	780 m^3 methane
$680,000	3,880 m^3 methane	1,940 m^3 methane	1,290 m^3 methane

$1,100,000	6,200 m^3 methane	3,100 m^3 methane	2,070 m^3 methane
$1,370,000	7,760 m^3 methane	3,880 m^3 methane	2,590 m^3 methane
$2,740,000	15,520 m^3 methane	7,760 m^3 methane	5,170 m^3 methane

1. All costs (both capital and operating) and associated energy credits have been converted to today's dollars using CPI inflation figures.
2. For this assessment, it has been assumed that capital and operating costs and associated energy credits have all increased in proportion with inflation.

The study was based on the following assumptions (Lake *et al*, 1999):

- The use of biogas was only considered for on-site use (export of energy off site not assessed);
- Methane content of biogas is valued at about $8/GJ (in today's dollars);
- Usable biogas can be generated at least 300 days per year; and
- The capital expenditure thresholds are based on energy savings alone.

Table 4 above does not take into account any additional benefits such as sale of digestate as fertiliser, sale of excess electricity to grid, government incentive programs, etc, since these will be site specific.

The low-end capital expenditure ($410k-$680k) is based on providing a covered anaerobic lagoon or plug flow anaerobic digester and feeding the biogas to an existing boiler. It does not include an allowance for a cogeneration unit. This set-up would be suitable for the following sized industries (Lake *et al*, 1999):

- Piggeries with around 15,000 pigs (SPU);
- Feedlot style dairies with 2,000 head cattle; and
- Poultry processing plants processing around 10 million birds/yr.

The high-end capital expenditure ($1.4M-$2.74M) is based on providing a high-rate anaerobic digester system. Again, it does not include a cogeneration unit. This set-up would be suitable for the following sized industries (Lake *et al*, 1999):

- Piggeries with around 47,000 pigs (SPU); and
- Poultry processing plants processing around 26 million birds/yr.

2.2.3 Australian Pork Limited (APL)

APL commissioned Bob Lim and Co Ltd to prepare a report on the technical, economic and financial implications of using piggery waste to generate electricity (Lim *et al*, 2004). This economic model development study used the following input values:

- Cost basis is a 20,000 SPU piggery;
- Capital cost for a new covered anaerobic lagoon (CAL) is $55/SPU;
- Capital cost for an engineered digester is $137/SPU;
- Biogas generation rate of 0.13 Nm^3/SPU/d;
- Biogas energy density of 23 MJ/Nm^3;
- Engine efficiency of 27%; and
- Financial viability based on achieving an IRR of 15%.

Using the above inputs, the financial modelling indicated that installation of a covered anaerobic lagoon (CAL) for energy recovery was viable for farms with greater than 6,000 SPU, although this increased to 20,000 SPU when using engineered digesters.

2.2.3 Organic Resource Technology

Organic Resource Technologies Ltd (ORT) are currently in the process of design and constructing a 17,000 tonne per annum municipal solid waste demonstration DiCOM digester plant in Perth, costing in the order of A$5.6 million. This plant is a batch solid phase facility with a 7 day thermophilic anaerobic digestion of municipal solid waste. The anaerobic process is sandwiched between two aerobic processes – the first for heating, and the last for post-conditioning. This type of high capital process has more in common (and is competing with) continuous dry phase digestion (see below), and in contrast with simple, small-scale batch digestion, is probably not suitable for individual, farm-scale applications (Bioenergy Australia 2004).

2.3 International

2.3.1 European Information

The Agricultural Development and Advisory Service (ADAS) carried out a review of farm anaerobic digestion systems in the UK in the early 1990's (Energy From Biomass, 1997). Although anaerobic digestion plants have been installed on UK farms since the 1970, up-take of the technology has been slow. A total of 43 systems were installed, mostly on pig and dairy farms. Of these, only 25 were still in operation in 1993.

Most of European Plants are small or medium sized farm scale plants that use 1-20 m^3 substrate per day. Nine large farm-scale plants in Germany use more than 20 m^3 per day. There are also several plants of this size in concentrated livestock areas of northern Italy, the Netherlands, and Denmark. (Escobar *et. al*, 1999)

Centralised biogas plants (known as *Community Plants* in Europe) use manure from many farmers in a particular area. The first plant began operation around 1990 and by year 2000 there were 14 plants in operation, which used up to 80 manure deliverers and up to 440 tonnes per day of substrate (Escobar *et. al*, 1999). Community plants are especially popular in Denmark for the following reasons:

- Individual farm plants had minimal success in Denmark;
- The Danish culture stresses co-operation and community involvement; and
- Most villages have heat distribution grids with central boilers that can make use of the waste heat produced from biogas cogeneration systems.

Comparison of Anaerobic Digesters in the UK and Denmark

In Denmark, the Government embarked on a programme that installed 9 large-scale, centralised digesters that co-processed feed stocks other than manure to produce district heating and electricity supply. These facilities were provided with a 35% capital grant from the Danish government. It was concluded that only co-operative scale facilities would be able to produce electricity at competitive prices, again provided that by-product fibre sales were included (Energy From Biomass, 1997).

ADAS reviewed the performance of the anaerobic digester at the Hanford Farms piggery in Dorchester (Energy From Biomass, 1997). The main objectives were to obtain data for design of centralised facilities and to determine why British digesters traditionally produced only 0.6 m^3 of biogas per day per m^3 of digester volume, compared to typical Danish values of 1.2 to 1.6 $m^3/m^3/d$. The Hanford farm digester is a 750 m^3 unit, operating at 30 to 35^{0}C with a nominal HRT of 10 days. The feedstock is pig manure and food wastes. The design criteria for the digester were (Energy From Biomass, 1997):

- Feed rate of 70 m^3/d at a TS of 5%;
- Design gas production of 525 m^3/d or 26,250 MJ/d; and
- Electrical output of 90 kW.

ADAS conducted intensive monitoring of the facility over 3 month period in 1994, which yielded the following results (Energy From Biomass, 1997):

- Feed rate was 66 m^3/d at a TS of 2.1%;
- Biogas production of 472 m^3/d with an energy content of 25 MJ/m^3;
- Biogas methane content averaged 66%; and
- Power production of 1026 kWh/d (43 kW) at a conversion efficiency of 31.5%.

This data again confirmed that UK digesters operate at lower biogas yields than their Danish counterparts.

2.3.2 US Information

Comparison of Thermophillic and Mesophillic Reactors

While there are many technical papers on laboratory or pilot scale anaerobic digestion of manures from intensive livestock operations a paper by Sung and Santha (2001) is particularly relevant to the current study. They operated a laboratory-scale temperature phased anaerobic digestion system to treat dairy cattle manure. The first reactor was operated under thermophillic conditions and the second reactor under mesophillic conditions. The feed to the system ranged from 2.6 to 10.8% TS but optimal operations were achieved with feed TS of less than 8% TS. At a combined HRT of 14 days, the optimal loading rate was 5.8 kg VS/m^3/d, which provided a VS destruction of about 40%. Biogas yield averaged 0.55 m^3/kg VS destroyed with a methane content averaging 60%.

Although there has been success with thermophillic digesters overseas (e.g. Denmark) it is understood that there have been problems with regards to odour and failure with poor temperature control.

Based on the Australian climate, there is potential to operate thermophillic (anaerobic) digesters for the intensive livestock industry. Thermophillic digesters are worth considering especially if reliable heat sources are available (i.e. artesian bore water, waste heat from cogeneration, etc). Thermophillic systems used in Europe are designed as above ground digesters due to civil costs being high. This saves approximately 30% in capital costs. However, in Australia the same benefit would not be gained due to existing anaerobic lagoons (hole in the ground) used in the intensive livestock industry. Although, Australian farm operations are most likely not geared to operate sophisticated and complex systems such as thermophillic digesters.

Electricity Generation for Small and Mid Sized Dairy (Free-Stall Barns) Farms

In 1992 there were only 25 anaerobic digesters in operation on free-stall farms in the US (Mehta, 2002). By 2002 this had risen to 32, of which 14 were on free-stall dairy farms. Many of the digesters were built with partial funding from research agencies and there were a range of different designs employed. It was estimated that the capital cost for a digester/engine was about $US 880 to 1200 per cow, with the upper figure probably being more realistic.

The typical power generation potential per cow in the US is estimated at 0.2 kW/cow, while in the EU this appears to drop to 0.15 kW/cow, assuming an engine efficiency of 28%. On this basis, it is thus estimated that the capital cost to generate power from cattle manure in the US is $7300/kW. The power demand and power generation potential for various sized free-stall dairy farms is shown in Table 5 (Mehta, 2002).

Based on this information, Mehta (2002) concluded that:

- Power generation on free-stall dairy farms is not economic unless a reasonable amount of power export is possible, which requires a herd of at least 200 cows;
- Currently there are no digesters/engines on free-stall dairy farms in the US with herd sizes of less than 400 cows; and
- Micro-turbines are a good power generation unit, with efficiency of these units of about 25-28%. (www.capstoneturbine.com)

Table 5 Power Demand and Generation Potential (Mehta, 2002)

Dairy Farm (Free-stall) Size (No. cows)	Power Demand (kW)	Power Generation Potential (kW)
30	11	6
60	12	12
200	20	40
400	25	80

It should be noted that Australian dairies are predominantly grass fed outdoor production and that these yields will not translate.

Suitable Types of Anaerobic Digesters for the US Intensive Livestock Industry

The Dairy Handbook (Denis and Burke, 2001) provides information on waste quantities and characteristics, types of anaerobic digestion processes and costs for various processes options. Key points taken from this handbook include:

- Digesters usually operate best on "diluted" manure, with TS in the range of 6 to 7%. This differs to anaerobic lagoons in Australia where they are generally operated at a solids concentration of 1-2% solids;
- Solid retention time (SRT) for digesters needs to be at least 20 days to achieve VS destruction of greater than 45%; and
- Optimal organic loading rate is determined to be about 6 kg VS/m^3/d.

Table 6 categorises the designs of anaerobic digesters for treatment of dairy manure (Denis and Burke, 2001).

Table 6 Suitable and Unsuitable Anaerobic Digesters for Dairies in the US

SUITABLE	NOT SUITABLE
• Covered Anaerobic Lagoons (CAL)	• Fixed Film reactors
• Complete-mix reactors	• UASB reactors
• Contact reactors (with sludge recycle).	• Horizontal Baffled reactors
• Plug-flow reactors (Low rate)	

The anaerobic reactors listed as "not suitable" in Table 6 are high rate anaerobic reactors. These reactors are not suitable for digesting dairy waste (US) since they are not effective at converting particulate solids to gas and tend to clog while digesting dairy manure slurries. Instead, these reactors retain bacteria which have been developed to treat soluble organic industrial wastes (Denis and Burke, 2001).

However, there has been recent success in Australia with pilot trials at the DPI dairy research farm on dairy waste using fixed film anaerobic digestion. The preliminary results from the digester trials show that:

- Can generate enough power to run the dairy and complex at Ellinbank - need to have storage of gas to meet peak demand;
- Reduce sludge levels by 98%;
- Only need to store nutrient water which can be managed using conventional pumping equipment; and
- Water savings at the dairy of 90%.

Digester Parameters

Digestion can take place under mesophilic or thermophilic conditions and some reactor configurations employ both sets of operating conditions (Dual-stage or dual-phase reactors). Capital cost of digestion systems are reported to range from $US750 to 1200 per cow. It is reported that power generation is normally (Denis and Burke, 2001):

- 1.28 kWh/kg VS destroyed; and
- Nominal engine efficiency of 35%.

A US supplier of farm digesters (RCM, 2000) has indicated that typical power generation statistics are 0.1 to 0.15 kW/cow and 0.01 to 0.015 kW/pig.

The Dairy Handbook also comments on suitable substrates to blend with dairy manure to increase the potential for power generation and hence the economic viability of on-farm digesters. The following substrates were deemed suitable (Denis and Burke, 2001):

- Cellulosic waste;
- Food waste; and
- Organic fraction of MSW.

The manure from feedlot fed cattle, particularly in the US, has a higher methane potential due to the type of feed consumed and the high level of feeding (FAO Corporate).

3.0 Review of Methods for Determining Organic Loads

There are several methods that may be used to calculate organic loads from intensive livestock industries. These include:

- Empirically derived "rules of thumb" (e.g. kg VS or TS/annum/pig);
- Feed basis: (Mass balance: weight of animal before and after minus total mass feed manure produced); and/or
- Wastewater characterisation (e.g. by measuring COD mg/L, TS mg/L, etc).

From the literature, the most commonly and well tested methods for determining organic loads are empirical measures, which is typically kg manure/animal/day or year.

3.1 Rules of Thumb

Table 7 sets out the daily manure production and its associated characteristics for a range of animal sizes. The actual amount excreted can vary by about 25 % either side of these averages due to changes in diet, animal health, availability of water and climate. Similarly, Table 8 is another example of empirically derived manure productions rates for feedlot cattle.

Table 7 Daily manure production for beef feedlot cattle (QLD DPI & F, 2003)

Animal Size (kg)	Manure Production (kg/day)	Total Solids (kg/day)	Volatile solids (kg/day)
220	13.2	1.54	1.32
300	18.0	2.08	1.06
450	27.0	3.1	2.7
600	36.0	4.18	3.56

Table 8 Daily manure production for beef feedlot cattle (Watts, P and Tucker R, 1994)

Live weight (kg)	300	400	600	750
Total Manure Produced (t/hd/yr)[A]	6.4	9.5	12.7	15.9
Total Manure Dry Matter (t/hd/yr)[B]	0.6	1.0	1.3	1.6
Manure Removed from pens (t/hd/yr)[C]	0.5	0.8	1.1	1.3
Manure Removed from stockpile (t/hd/yr)[D]	0.2	0.4	0.5	0.6

Assumptions:
A - Total manure is 5.8% of liveweight.
B – Total dry matter assumes manure is 90% water
C – Manure removed from pens assumes 50% loss of initial dry matter and 40% moisture content on removal
D – Manure remove from stockpile assumes 70% loss in dry matter and 20% moisture content on removal

Another rule of thumb quoted in the Dairy Handbook is that an average dairy cow (635 kg) excretes 50.8 kg of wet manure per day at a TS of 12.5% and VS of 83% of TS (Denis and Burke, 2001).

3.2 Feed Basis

Beef feedlots often calculate organic loads via mass balance methods per 450 kg feedlot beast. Feed consumption is typically 2.5 % to 3 % of body weight per day depending on the type of diet (QLD DPI & F, 2003).

For example, for a 450 kg beast:

- Feed consumption will be about 13 kg of feed intake per day;
- Weight gain is only 1.0 to 1.6 kg per day;
- Hence, the remaining mass must leave the animal.

Part of the feedlot leaves as manure (manure is the combination of faeces and urine) and part via belching (as gas). However, it should be noted that this method doesn't take into account "maintenance" energy, and as a result organic loading is over estimated.

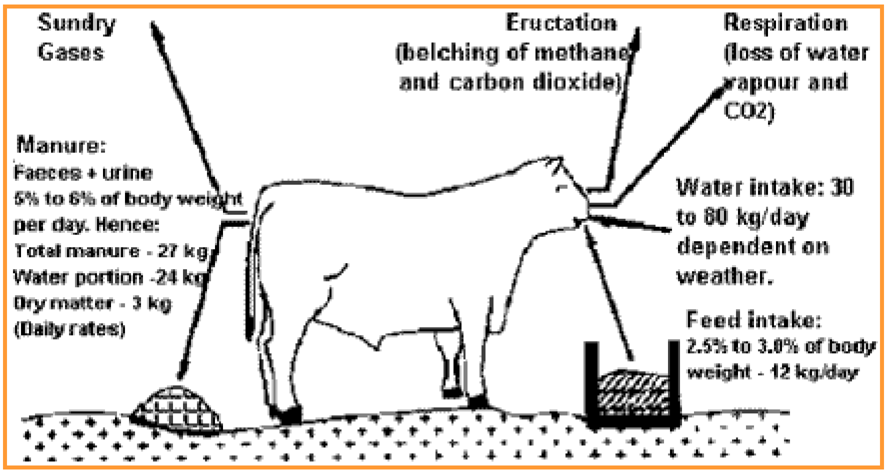

Figure 3 **Manure production from a 450 kg beast** (www2.dpi.qld.gov.au)

In addition to feed intake, cattle drink considerable quantities of water. The daily volume consumed varies and depends on body weight, diet and climatic conditions. Some water is lost to the atmosphere via respiration, however, a considerable proportion of the water is voided as part of the manure (www2.dpi.qld.gov.au).

3.3 Other Methods

The Queensland DPI have prepared comprehensive models in excel spreadsheets that perform mass balances and calculate manure production for each of the livestock industries (piggeries, beef feedlots, dairy). The user can enter farm/site specific data and the spreadsheet will calculate a nutrient mass balance as well as manure loadings. The spreadsheet takes into account climate, nutrient compositions in feed, feed mass and wastage etc. In calculating the final manure production per site, a rule of thumb parameter is used for each livestock industry.

3.4 Summary of Methods

Much of the literature reviewed reported manure production rates for livestock as "rules of thumb" (kg manure (TS, VS, etc)/animal/day). This approach seems to be a reasonable method for estimating manure production and has been practiced for many years. Although, this method should be used with caution as there are slight variations in values found in Australian and international literature. This is due to different diets/ feeding regimes etc. Based on this, it is recommended that this approach is sufficiently robust to for the purposes of estimating manure production rates for evaluating economic viability of projects. Nonetheless, a summary of the different methods is shown in Table 9 below.

Table 9 Summary of method of estimating organic loads

Manure Calculation	Pigs	Dairy	Beef
Method 1 – Rules of Thumb	1). Fresh manure production and characteristics per 1000 kg live animal mass per day: Total manure: 84kg Total solids: 11kg Volatile solids: 8.5kg (ASAE) 2). TS and VS mass per day loading rate relating to SPUs*, i.e. 1 SPU: Total solids: 0.3 kg Volatile solids: 0.25kg (Lim 2005)	1). Fresh manure production and characteristics per 1000 kg live animal mass per day: Total manure: 86kg Total solids: 12kg Volatile solids: 10kg COD: 11 kg (ASAE) 2). 46L of fresh manure (faeces and urine) per 450kg average live weight per day. The manure contains 6.54kg of total solids per AU per day. The volatile solids production is 5.4kg per AU per day. (Dairy manure production and nutrient content)	1). Fresh manure production and characteristics per 1000 kg live animal mass per day: Total manure: 58kg Total solids: 8.5kg Volatile solids: 7.2kg COD: 7.8 kg (ASAE) 2). Total manure is 5.8% of liveweight, total solids (TS) is 10% of total manure (DPI: Designing better feedlots)
Method 2 – Feed Basis			Feed consumption is typically 2.5 % to 3 % of body weight depending on the type of diet. For a 450 kg beast, this represents about 13 kg of feed intake per day.

*SPUs (Standard Pig Units) are a unit of measurement for determining the size of a pig production enterprise in terms of its waste output. One SPU produces an amount of volatile solids equivalent to that produced by an average size grower pig of approximately 40 kg (DPI, 2003).

APL's centralized scheme for sharing piggery performance suggests that feed conversion ratios improve by approximately 2% per year. This potential uncertainty is due to variations in diet and improvements in genetics, feed formulation, and phased feeding etc. . It was also noted that feed wastage is very important and is highly variable between sites. However, these variables are difficult to monitor and has not be accounted for in the loading value.

Organic Load Variability/ Uncertainty

It should be noted that various diets for livestock results in differences in manure production. It should be noted that the manure production from livestock in Australia differs from manure production in overseas countries based on feed type/deists and the level of feeding. This also affects the VS produced and therefore affects biogas yields.

Organic loads produced from intensive livestock in Australia vary to some extent from other countries due to different diets. Piggery diets in the US, Canada and South America are typically corn based (around 70%), supplemented mainly with soy meal (20%)

In Australia, the diets vary slightly from State to State. Piggery diets in NSW, Victoria and WA consists of wheat/triticale, Queensland diets are based on sorghum, while barley and wheat is more common in SA. For protein and fat, canola meal is added in the southern States (say 10% inclusion), while sunflower or cotton seed meal is added in Northern NSW and Queensland.

Beef feedlot diets in Australia are very similar to the USA. In Australia, the typical diet consists of grains such as wheat, barley and sorghum, whereas the main grain type in the USA is corn. The grain makes up about 70-80% of the feed, 10% is fodder (silage/hay/cotton seed hulls), with the remaining 5-10% consisting of vitamins, minerals and molasses.

In Queensland, the typical diet for dairy "free-stall barns" consists of barley/wheat grain (16%), whole cottonseed (6%), wheat hay (5%), barley/wheat silage (48%) and pasture (grass, sorghum forage) 25% (DPI, 2003). No diet information could be obtained for other states or overseas countries.

A series of nutrient model spreadsheets were designed by the Queensland DPI&F for each intensive livestock (Pigs, Dairy, and Beef) and shows how different diets give different result for TS and VS. Therefore, there is some uncertainty in the TS and VS values presented in the tables above. Also, seasonal changes have not been accounted for and will certainly have and effect on the biogas yield. All these variables will needs to be considered in the assessment and design of an anaerobic system.
There are also other significant issues with using Australian beef feedlot manure for anaerobic digestion as commented by James Kelly from Rockdale Beef Pty Ltd. For example;

- The manure moisture content can vary from 10% - 80% due to seasons;
- Some feedlots clean on a standard rotation and others have campaign cleaning prior to winter and spring. Thus the material is harvested erratically, and therefore the manure can also be quite old. The drop off in yield from conventional methane capture systems is marked once the material is over 2 weeks old;
- To get the desired solids for conventional digestion a significant amount of water is required during the summer months.

However, it has been demonstrated that conventional anaerobic digestion system would operate economically on beef feedlots in Australia if there was water available (J. Kelly, Rockdale Beef). The disposal of the resultant effluent is also a significant issue due to the high TDS levels.

4.0 Systems Suited to Australian Intensive Livestock Industries

4.1 Preferred System Design

Based on the information presented from the literature review of both Australia and overseas experience, the following technologies appear to be suitable for methane capture and use in the Australian intensive livestock industry.

4.1.1 Anaerobic Digesters

The following types of anaerobic digesters are considered suitable for use in Australian intensive livestock industries:

- Covered Anaerobic Lagoons (CAL);
- Enhanced Covered Anaerobic Lagoon;
- Completely-mixed mesophilic anaerobic digesters (MAD);
- Contact digesters; and
- Plug-flow mesophilic anaerobic digesters.

4.1.2 Power Generation Units

Although power generation has not been the focus of this research, the following types of power generation units are deemed suitable for use in the Australian intensive livestock industries:

- Spark-type gas engines; and
- Micro-turbines.

It is estimated that power generation will cost approximately $1.5M/ installed MW

4.2 Design Basis

Based on the information provided in Sections 2 and 3 of this report, the major process and cost parameters have been summarised in Table 10. These factors have been used for the evaluation of project viability in Section 6.

Table 10 Facility Design, Costing and Evaluation Parameters

Parameter	Units	Piggery Value[1] (40kg)*	Dairy Value[1] (635kg)*	Beef Value[1] (525kg)*
Manure Generation Rate	Wet kg/animal/d	21	31	31
	Dry kg/animal/d	0.30	3.85	3.1
	kg VS/animal/d	0.25	3.2	2.54
Manure Characteristics				
- TS	%	1.43	12.5	10
- VS	% of TS	68	83	82
- Energy Content	MJ/dry kg	19	17.5	17.5
Power Generation Potential	kW/animal	0.01[2]	0.15[3]	0.11
	kWh/t wet man.	9 (at 1.6%TS)	-	-

*Live weights
1. Source: Bob Lim spreadsheet model
2. Source: RCM (US supplier of AD)

5.0 Assessment of Cross-Sectoral and Cross-Enterprise Methane Capture & Use

For the purposes of this report, cross-enterprise has been defined as methane capture and use from combining wet wastes from the same industry, for example, combining the wet waste from numerous piggeries in one region. Similarly, cross-sectoral has been defined as methane capture and use from combining wet wastes from different industries, for example, combining the wet waste from piggeries, dairies, and/or feedlots.

There are a number of potential project and commercial issues associated with the concept of capturing methane using a cross-enterprise or cross-sectoral approach. These include:

- Infrastructure – Specific infrastructure will have to be constructed for the transport and processing of the waste and the ownership of this infrastructure will need to be defined;
- Costs – The contribution of each of the parties to capital and operating costs as associated benefits of methane capture and use will need to be negotiated. Typically, an equitable tolling arranged would need to be established; and
- Quarantine and disease control for the waste is a potential problem.

Such Project specific issues have not been addressed as a part of this report.

The potential to combine manure from beef feedlots, piggeries and intensive free-stall dairy farms depends greatly on their proximity to one another. As shown in Figure 4, 5 and 6, there are specific regions in Australia that are highly populated with intensive livestock industries, which will increase the likelihood of project viability. The particular regions of potential interest are;

- Murray-darling region - High intensity of beef feedlots, large dairies (intensive free-stalls sites situated towards the west in the Goulburn-Broken region) and piggeries in this region.
- South-East Queensland - High intensity of beef feedlots and piggeries in this region. The dairy farms are not expected to be viable as they are closer to the coast than the feedlots and piggeries and are not believed to be intensive free-stall farms.
- North of Adelaide - Close proximity of piggeries and small beef feedlots.
- Southern New South Wales – Area of a large number of feedlots and piggeries (no dairy).
- South-West WA - There is potential in this region as there are piggeries, dairies (though they are not likely to be intensive) and a large feedlot with some smaller feedlots. However, these locations appear very dispersed.
- Northern Tasmania - May have potential, as there is a single feedlot, a number of small sized piggeries and dairies (though they are not likely to be intensive)
- Near Cairns - May have potential as there are piggeries, a large feedlot and dairy (though not likely to be intensive).
- Hunter valley - May have potential, as there are a number of beef feedlots, small to medium sized piggeries and dairies (though they are not likely to be intensive).
- Central QLD – There is high intensity of beef feedlots, small to medium sized piggeries and very few dairies (though they are not likely to be intensive).

Figure 6 is a general map of dairy farms and does not indicate intensive free-stall dairy farms. However, a representative from *Dairy Australia* indicated that the most intensive (free-stall barns) areas tend to be in the irrigation areas, in particular the Goulburn-Broken region. Large farms are located in South-East SA and the Lower Lakes region in SA. There are also large operations in central and South-West NSW.

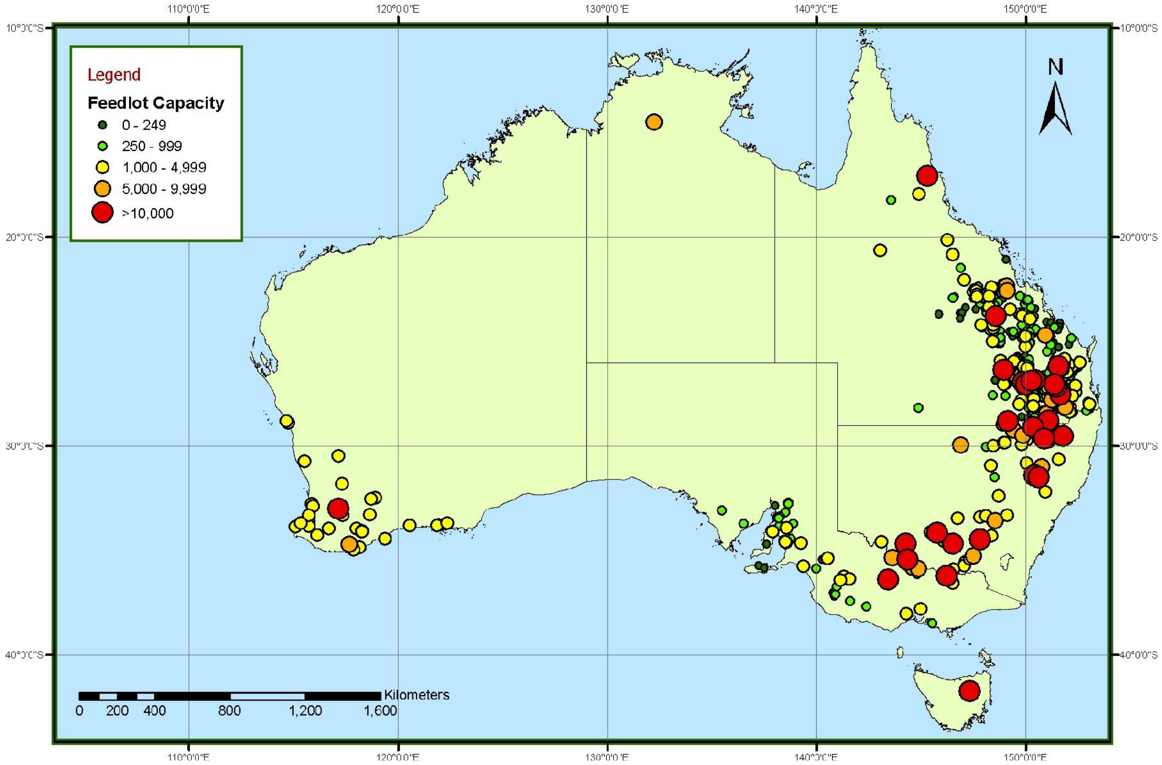

Figure 4 *Location of Feedlots in Australia (ALFA)*

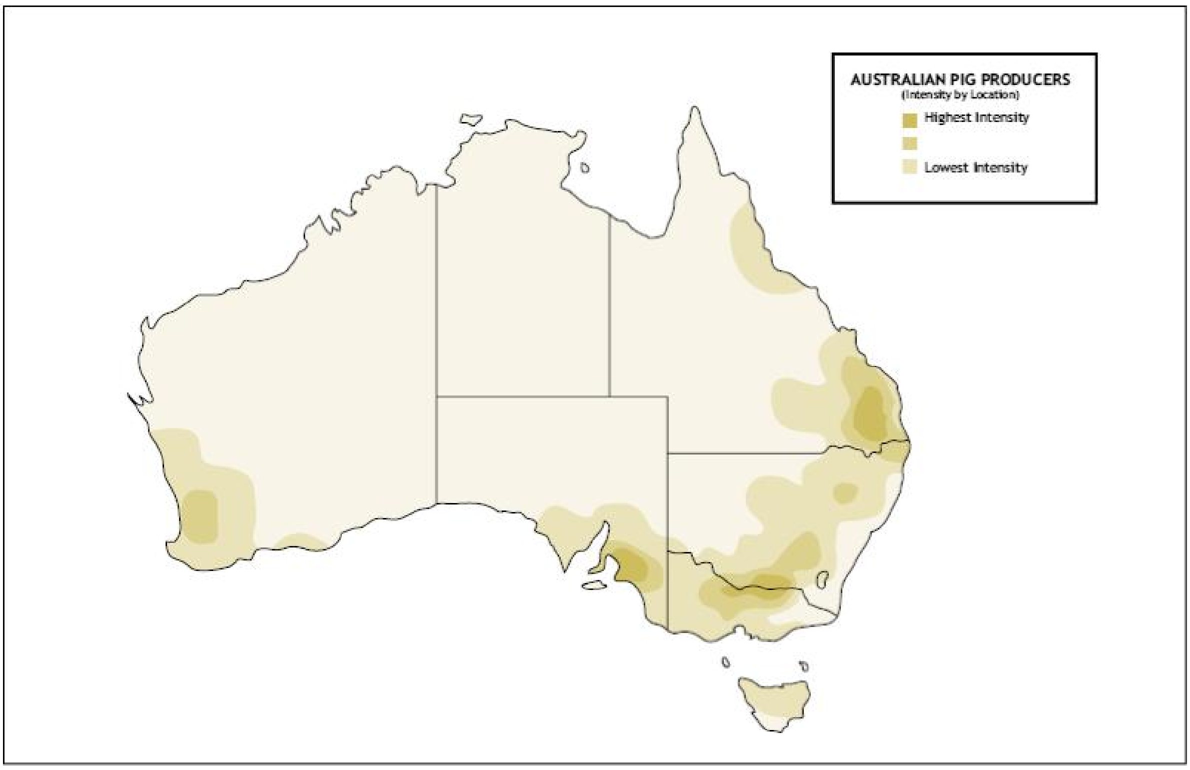

Figure 5 **Location of Piggeries in Australia (APL)**

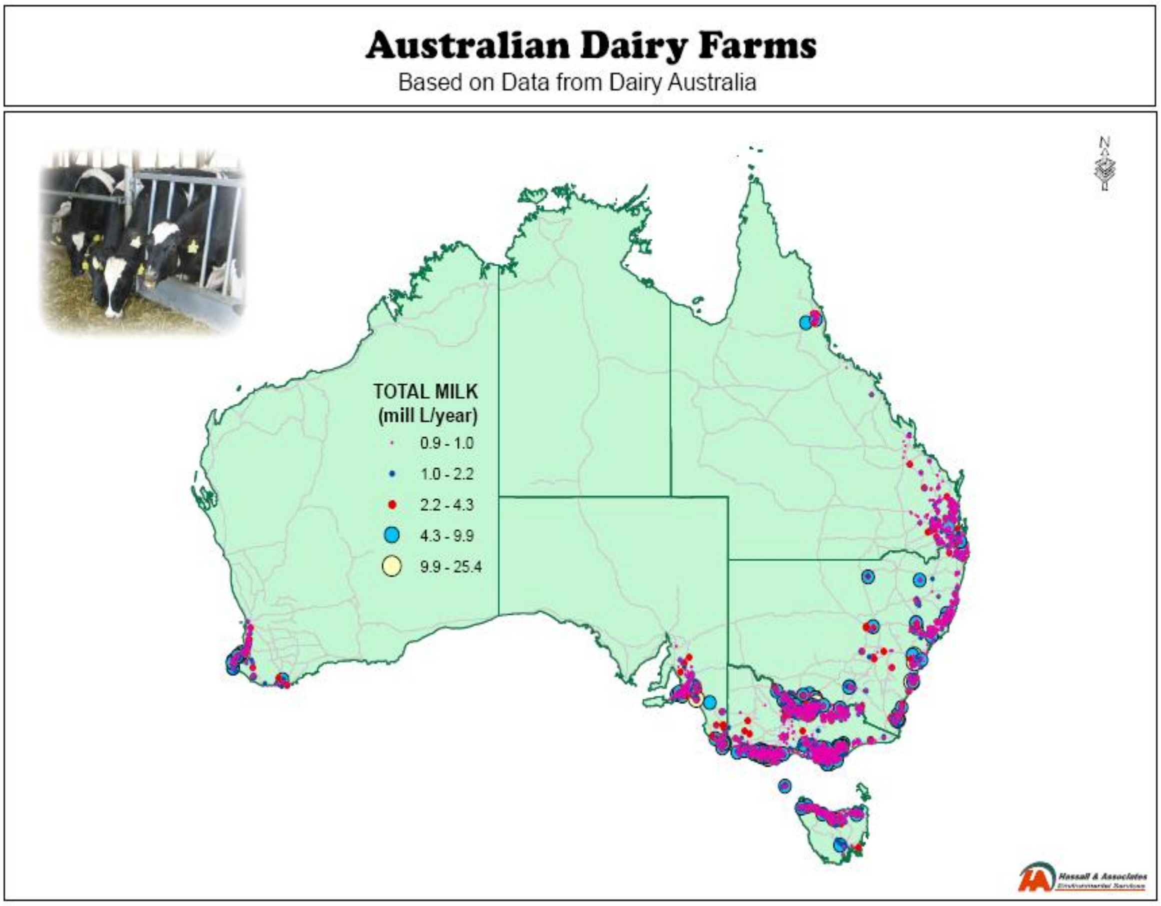

Figure 6 *Location of Dairy Farms in Australia (Dairy Australia)*

6.0 Methane Capture Infrastructure

This section of the report discusses the different steps in the process in some detail and outlines the infrastructure options available for methane capture and use projects. A basic flow diagram showing the overall process of biogas generation and energy production is shown in Figure 7.

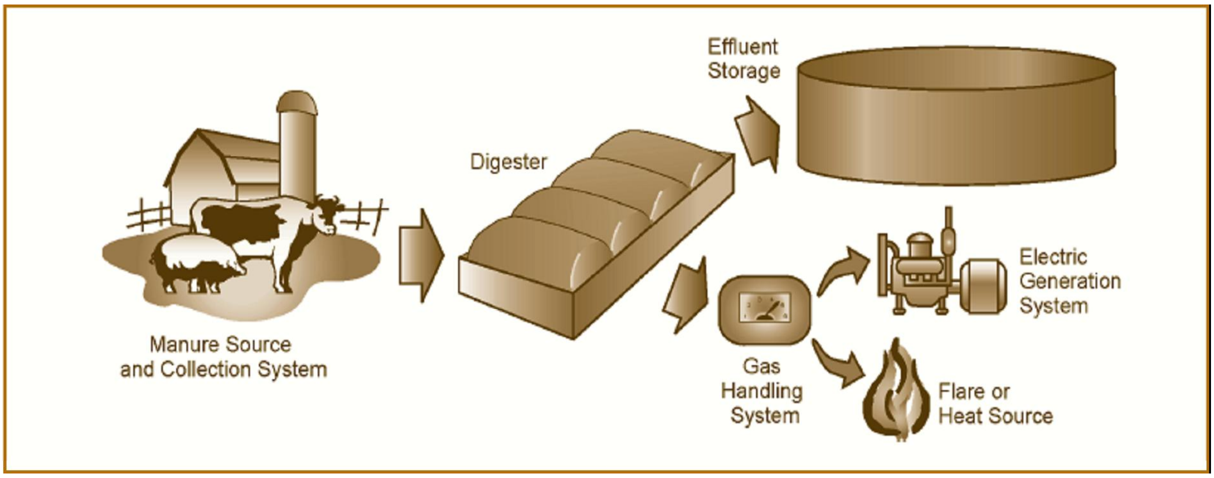

Figure 7 Process Flow Diagram illustrating the process of methane generation, capture and electricity generation (EPA, 2002)

6.1 Collection of the Waste

The organic wastes produced by the intensive livestock industry are in two forms:

- Wet waste (usually conventional piggeries and dairy); and
- Dry Waste (deep-litter piggeries, beef feedlots and poultry).

These wastes can be collected via a number of methods (Denis and Burke, 2001):

- Open lots - In this system, the manure is deposited on the ground and scraped into piles;
- Flush System - In a flush system, manure is considerably diluted. A flush system will generally reduce the concentration of manure from 12 ½ % to less than 1% solids in the flush water;
- Scrape System - Scrape systems collect the manure by scraping it to a sump;
- Front End Loader – This system stack and remove corral bedding and manure; and
- Vacuum System – Vacuum systems collect undiluted manure with a vacuum truck where it is hauled to a disposal site rather than an intermediate sump.

There are systems where bedding is used to collect the manure (typically for piggeries). The type of bedding used significantly affects the characteristics of the manure treated. Straw, wood chips, sand or compost are typically used as bedding material. The quantity of non-degradable, organic and inorganic material can significantly impact the performance of the anaerobic digester.

From the literature review, it is expected that the majority of Australian systems will be:

- Flush and deep bed litter for pigs;
- Flush and dry for dairy – most dairy in fields, only milking sheds are opportunity; and
- Dry for feedlot.

6.2 Configurations

Section 2.1 identified that anaerobic digestion is the recommended technology for methane capture from intensive livestock manure due to its water content. There are various anaerobic digestion configurations available and Table 11 summarises the advantages/disadvantages of these different anaerobic treatment technology options available for methane capture.

Table 11 Anaerobic Digestion Advantages/Disadvantages Summary

Technology	Principle	Advantages	Disadvantages
Covered Anaerobic Lagoon or CAL (very low rate)	- Total Solids content typically 0.5 – 3% - Solids settle at bottom but decomposition occurs in sludge bed. - Low reaction temp. - Low mixing energy	- Low cost - Often plants have anaerobic lagoons; hence technology is existing, and so capital cost can be low	- Little contact of bacteria with bulk liquid occurs. - Low biomass conc.= low solids conversion - Low biogas production (in winter) - Hard to heat - Cleaning requires CAL to be taken off-line - Low conversion rate
Enhanced CAL	- Incorporated sludge removal and recycle to increase utilization and mixing - Can handle varying manure flow	- Optimises manure treatment and biological stabilization for odour control - Capital cost is relatively low. - Better sludge handling	- moderate rate conversion.
Mixed Tank	- Dilution to 3-10%, and continuous feed in mixed tank. -Retention of 20 days. Used across many industries -Usually mesophillic - Requires constant conversion of feed solids to anaerobic bacteria	- Established tech - Easy to control - Continuous gas production - Good conversion of solids to gas	- High mixing cost - Poor vol. loading rate - Expensive tanks - High installation cost - High energy cost due to mixing & heating - Need dilution liquid - Bedding needs milling
Contact	- retains bacterial biomass by separating & concentrating solids in a separate reactor & returning the solids to the influent. - Thermophilic or mesophilic	- High process rate - More degradable waste can be converted to gas since substantial portion of the bacterial mass is conserved - Can treat both dilute & concentrated waste	- Very expensive
Liquid plug-flow (RCM)	- Dilution to 15%, and feed through a liquid plug-flow reactor	- Very high loading rates. - Continuous gas production. - Energy Recovery is optimized. - Digester dairy solids can be easily separated	- Need dilution liquid (Dry waste) - Poor contact with active biomass. - Bedding might require milling
Fixed film	- High rate - Fixed biofilm	- Reduced hydraulic retention time - Reduced sludge generation	- Better suited to soluble component - Fraction of available energy is captured

6.2.1 Covered Anaerobic Lagoon (CAL)

Principle of Operation

A covered anaerobic lagoon digester is an earthen lagoon fitted with either a clay or polymeric liner and a polymeric floating cover that collect biogas as it is produced from the wastes. They are extensively used for sewage treatment and methane capture.

Figure 8 *Photo of a Covered Anaerobic Lagoon (EPA, 2002)*

Key Features of CALs

- This technology and process is very well developed.
- Typical hydraulic retention times (HRT) are 40 to 60 days.
- A collection pipe transfers the biogas from the lagoon to either a gas treatment system, such as a combustion flare or to a generator or boiler to create electricity and/or heat.
- After treatment, the digester effluent usually gets transferred to an evaporative or storage pond.
- Climate has an effect on feasibility of using CALs as in cold countries, the generators to not produce sufficient waste heat to maintain adequate temperatures in the lagoon. Hence CALs are more commonly used in warm climates.

6.2.2 Enhanced CAL

Principle of Operation

An enhanced CAL is similar to a covered anaerobic lagoon, except it is fitted with pipes to collect solids and pump it back to the lagoon so that there will be an increased solids retention time and mixing within the lagoon. Often enhanced CALs have heating of the solids as an option to improve performance compared to a simple CAL.

6.2.3 Mixed Tank

Principle of Operation

Mixed tank reactors are the most common type of anaerobic digesters in the world. They normally operate on an intermittent feed basis, and require contact with biomass, retained in the digester. Slowly degradable substrates will require very long retention times. In large-scale systems, mixing normally occurs using gas recirculation whereas mechanical mixing is used for smaller systems. The feed can be continuous, but it is usually a semi-batch system (periodic feed, with simultaneous discharge).

Figure 9 *Photo of a Mixed Digester (EPA, 2002)*

Key Features of Mixed Tanks

- This technology and process is very well developed.
- In order to maintain acceptable fluid viscosity, process solids need to be maintained below 4 to 8%. Also, given 50% VS destruction (say 35% TS destruction), this means feed must be below 6-8 %
- Since the process liquid is well mixed and homogeneous, process control and monitoring is relatively straight forward.
- Analysis of a reactor fed with anaerobic wastewater (manure digestate) and straw, indicated that 4% straw in digestate, and 2% straw in digestate were the most efficient, with failure at 8% straw, and 1% straw (Masciandaro et al. 1994). However, it is understood that other systems have operated successfully below 1% straw. It can only be assumed that the failures occurred for a number of reasons, i.e. type and size of straw, type pig manure, etc.
- Analysis of a reactor fed with mixed beet tops and straw, diluted in manure digestate found a maximum effective feed of 5.6%, with 90 days hydraulic retention time (Bohn et al. 2007).
- Given that raw manure is approximately 6% solids, a codigestion process is probably not feasible, and digestate would be used mainly as carrier.
- Straw would need hammer milling to <approx 5 mm in a mixed process.
- Since straw degrades relatively slowly, and given a relatively dilute system, large process vessels are required. Given the marginal economics of biogas projects, it can be impossible to justify capital costs. As an example, The Australian Pork Limited Project 1915: Renewal Energy Industry Development Report found that in-vessel methanogenesis from manure could not be economically justified, and only low-cost covered lagoon digestion could be used (Lim 2005).

6.2.4 Liquid Phase Plug Flow

Principle of Operation

RCM digesters (http://www.rcmdigesters.com/) market a plug-flow digester designed specifically for cattle manure. The digester usually is a covered anaerobic trench with horizontal flow along the trench (Figure 10). It usually operates at the solids content of scrapped ruminant manures i.e. 11%-13%. The system is unmixed and the gas is collected from the surface of the digester.

Figure 10: Liquid phase plug-flow digesters (EPA, 2002)

Key Features of Liquid Phase Plug-Flow

- Liquid Phase Plug Flow digestersshould gain substantial benefits in degradation rates over mixed tanks due to its configuration leading to first order reaction kinetics and because it operates with higher solids concentration which also increases the rate of reaction (assuming there is no ammonia inhibition).
- This kind of digester works best for high solids content. For pig manure, it should be mixed at an approx. 7:1 ratio with straw bedding to achieve the target solids concentration, buffer capacity, and ammonia content.
- There is no real in-reactor mixing in the digester. Therefore a very good initial mixing with inoculum (manure), and straw would be needed prior to feeding to the reactor. It is also likely that the straw would need some milling or cutting.
- Buffering is vital.
- It is extremely important to have the correct straw:manure ratio.
- At present times, this technology is still new, and therefore, there is little information available about design of these systems. However, the retention time is expected be a minimum of 30 days for straw.
- Because of the relatively short retention time, and low-cost construction materials, the systems are relatively low-cost (<$US 500,000) (Moser and Mattocks 2000). The negative impact of this may be a shorter lifetime for some components (especially polyethylene covers), and higher owner-maintenance burden.
- It should be emphasized that this digester has been developed for manure, and there are additional considerations for the spent bedding application. In particular, these are proper manure: carbohydrate ratio, good mixing of feedstock, the need for milling, and evaluation of retention times.

6.3 Summary

In general, completely mixed reactors & plug flow contact process can digest entire waste stream and are not limited by the concentration of the influent waste. Plug flow will be able to process the concentrated and scraped manure but are limited to parlour waste (or a mixture of the parlour and scraped waste.) The fixed film and the plug flow are concentration limited.

Contact processes are the most effective anaerobic treatment process and can handle a wide variety of solids concentration (i.e. all manure from milk barn to free stall can be processed using the contact process). Additionally, a greater percentage of solids will be converted to energy. It also provides load flexibility, allowing for other waste materials process as well.

Also, it requires little maintenance and operation, and could be automated. Nonetheless, the contact process and the completely mixed digester do have some drawbacks. They use more energy than the plug flow process. The plug flow process is generally less expensive compared to contact process and the completely mixed reactor process as well.

All mesophillic anaerobic treatment processes are effective in reducing odours (all H_2S remains or is increased). All anaerobic processes can solubilise most of the nutrients and produce biogas. The contact process will provide the greatest solids retention time with the higher energy yield. The plug flow process has the lowest capital cost followed by the contact process and then the completely mixed digester (and vice versa with energy use). Nonetheless, the contact process has the highest operation and maintenance costs because of the reagents that are used in the biomass separation. However, overall the contact process has the largest benefits (Dennis A., Burke P.E., (June 2001).

6.4 Flaring /Generation of Electricity

There are three options for the biogas utilisation:

- Flaring (if there is no need or infrastructure to produce steam or electricity);
- Gas substitute for existing LPG/NG (i.e. boiler); or
- Generate electricity.

For power generation units the gas is usually fed into methane powered engines that generate electricity. The waste heat, which is a by-product of generating electricity, can be used to heat other industrial processes (covered lagoons, space heating, etc) ..

7.0 Assessment of Project Viability

7.1 Financial Assessment

Intensive livestock farms vary from one site to the next and hence various options have been considered for capital cost estimates and the potential associated credits. For example, one site may be connected to the electricity grid from which it sources all its energy requirements, whereas other sites may have no grid connection and rely entirely on diesel generators and/or gas for its energy requirements.

The costs presented in this section have been based on recent in-house cost data for similar anaerobic pond systems. GHD has been involved with similar type work for APL this year, providing costs for a 200,000 SPU methane capture (CAL) and electricity generation for on-site use. The piggery costs estimates presented in this report have been based on this cost data.

The same cost data has been used to estimate capital cost options for dairy and beef methane capture systems, however the costs have been adjusted to account for more dilute anaerobic pond systems. The design load for the 200,000 SPU anaerobic pond systems were designed for a VS loading of 0.46 kg VS/m^3.d, whereas dairy/beef anaerobic pond systems were designed based on 0.17 kg VS/m^3.d (McGahan *et. al*, 2003). This loading rate is for uncovered digesters to control odour, however it was used for estimating lagoon sizing and costing. The relative cost for pondage is therefore higher in the case of the dairy/beef industries compared with piggeries.

The engineered digester costs for each intensive livestock have been based on the escalated cost (in today's dollars) for Berribank Farm, i.e. $33 Million/MW.

The credits have been estimated based on the following assumptions:

- All biogas produced is used in a boiler and off-sets LPG/natural gas;
- All electricity generated from biogas is used on site and off-sets costs of electricity generation from the grid or diesel; and,
- All energy recovered from a CHP unit is usable on site and off-sets LPG/NG.

The estimated savings are indicative only and will only apply to certain intensive livestock farms. These cost estimates and associated financial assessments have been prepared for relative comparative purposes only and should not be used for budget setting purposes. Further detailed engineering and site specific assessment is required to obtain cost information of suitable quality for project budgeting purposes. Energy costs also vary significantly across Australia and this will also need to be considered in any robust assessment of site-specific project viability.

Refer to Appendix C for detailed breakdown of the costs.

7.1.1 Estimated Capital Cost Options and Potential Savings

This section summarises the estimated capital cost options for various sized facilities and is presented in Tables Table 12, Table 14 and Table 16. The options include:

- Anaerobic pond system including flare for existing lagoon (Option 1) and new lagoon (Option 2);
- Anaerobic pond system including flare for existing lagoon with electricity generation (Option 3) and heat recovery (Option 4); and
- Engineered anaerobic digester with electricity generation (Option 5).

The cost estimates presented in this section have been developed solely for the purpose of comparing and evaluating competing options. They are sufficiently accurate to serve this purpose. They cannot be used for budget-setting purposes as common elements between options may have been omitted and/or the works not fully scoped. While allowances for common elements have been made they may or may not include all the works required under this project. A functional design is recommended if a budget estimate is required. The estimates that have been prepared are not expected to be accurate to better than +/- 50% for this level of investigation.

7.1.1.1 Piggery

Table 12 Estimated Capital Cost Options for Various Sized Piggeries

Pigs (SPU)		5,000	10,000	20,000	50,000
	Volatile Solids	1,250	2,500	5,000	12,500
	Methane produced (m3/d)	400	800	1,600	4,000
No.	Anaerobic Pond				
1	Cover existing Lagoon (inc flare)	$ 90,000	$ 170,000	$ 340,000	$ 860,000
2	New lagoon and cover (inc flare)	$ 130,000	$ 260,000	$ 520,000	$ 1,300,000
	Anaerobic Pond + Power Generation				
3	Cover existing Lagoon (inc flare) + Cogeneration unit	$ 250,000	$ 500,000	$ 1,000,000	$ 2,500,000
4	Cover existing Lagoon (inc flare) + Cogeneration + Heat recovery	$ 270,000	$ 550,000	$ 1,100,000	$ 2,740,000
	Engineered Digester + Power Generation				
5	Dual-stage engineered AD system + Cogeneration + Heat recovery	$ 1,640,000	$ 3,280,000	$ 6,560,000	$ 16,400,000

The purpose for options 1 and 2 is to capture methane and use it in an existing boiler. The purpose for option 3 is to capture methane and generate electricity for use on site. The purpose for options 4 and 5 is to capture methane, generate electricity for use on site and recover heat to be used (hot water, steam, etc) on site.

Each option includes the cost of a flare for burning surplus methane (not required by boiler or electric generator) and also for emergency/bypass situations when boiler or electric generator may be down for maintenance.

As shown in Table 12, an anaerobic pond system is significantly less expensive than the infrastructure associated with an engineered anaerobic digester. For a piggery of size 20,000 SPU, an anaerobic pond system with power generation is ~$1M, compared to a $6.6M for an engineered anaerobic digester with power generation.

Table 13 summarises the potential savings associated with the installation of a methane capture and use facility. It should be noted that the actual savings will be site specific and will not apply to all sites.

Table 13 Estimated Potential Savings

Pigs (SPU)	5,000	10,000	20,000	50,000
Options 1 & 2				
Biogas (methane) Energy (GJ/annum)	5,300	10,500	21,000	52,000
LPG (savings)	$ 59,000	$ 117,000	$ 234,000	$ 585,000
NG (savings)	$ 42,000	$ 84,000	$ 167,000	$ 418,000
Options 3, 4 & 5				
Electricity Generated from Biogas (30% eff.)				
kW	50	100	200	500
MW/annum	440	870	1,740	4,360
Electricity saving (if connected to grid)	$ 44,000	$ 87,000	$ 174,000	$ 436,000
Diesel (generator 0.259L/kWh)	$ 90,000	$ 180,000	$ 360,000	$ 900,000
Options 4 & 5				
Heat Recovery				
Thermal energy (GJ/annum)	2,350	4,700	9,400	23,500
LPG (savings)	$ 26,000	$ 50,000	$ 100,000	$ 260,000
NG (savings)	$ 20,000	$ 40,000	$ 80,000	$ 190,000

Note: LPG savings are based on $14/GJ and NG savings are based on $10/GJ.

A piggery size of 20,000 SPU could potentially save ~$170k/yr if connected to the grid and ~$360k/yr if a diesel generator is used on site by installing option 3 (cover existing lagoon + electric generator unit). The savings could potentially be increased if heat is recovered (option 4) and used on site. For example, the savings would increase to ~$270k (LPG savings) if connected to the grid and ~$460k (LPG savings) if a diesel generator is used on site. Note that the LPG savings is based on all the heat being used on site.

Therefore, it is more beneficial for a farm with a diesel generator to install a methane capture and electricity generation facility than it is for a farm connected to the grid. For the example above, if considering option 3, the payback period would be approximately 3 years for a site using a diesel generator, compared with a payback period of approximately 6 years for a site connected to the grid.

7.1.1.2 Dairy

Table 14 Estimated Capital Cost Options for Various Sized Dairies

	Dairy "Free-Stall" (Head cattle)	500	1,000	2,000	5,000
	Volatile Solids	1,600	3,200	6,400	16,000
	Methane produced (m3/d)	512	1,024	2,048	5,120
No.	Anaerobic Pond				
1	Cover existing Lagoon (inc flare)	$ 140,000	$ 270,000	$ 550,000	$ 1,370,000
2	New lagoon and cover (inc flare)	$ 210,000	$ 430,000	$ 860,000	$ 2,150,000
	Anaerobic Pond + Power Generation				

3	Cover existing Lagoon (inc flare) + Cogeneration unit	$ 350,000	$ 700,000	$ 1,390,000	$ 3,480,000
4	Cover existing Lagoon (inc flare) + Cogeneration + Heat recovery	$ 380,000	$ 760,000	$ 1,530,000	$ 3,820,000
5	Engineered Digester + Power Generation Dual-stage engineered AD system + Cogeneration + Heat recovery	$ 2,100,000	$ 4,200,000	$ 8,400,000	$ 21,000,000

Similar to the piggery cost estimate options, an anaerobic pond system is significantly less expensive than the infrastructure associated with an engineered anaerobic digester. For a Dairy Free-stall barn size of 1,000 head, an anaerobic pond system with power generation is ~$700k, compared to ~$4.2M for an engineered anaerobic digester with power generation.

Table 15 Estimated Potential Savings

Dairy "Free-Stalls" (Head cattle)	**500**	**1,000**	**2,000**	**5,000**
Options 1 & 2				
Biogas (methane) Energy (GJ/annum)	7,000	13,000	27,000	67,000
LPG (savings)	$ 75, 000	$ 150, 000	$ 300, 000	$ 750,000
NG (savings)	$ 54, 000	$ 107, 000	$ 214, 000	$ 535,000
Options 3, 4 & 5				
Electricity Generated from Biogas (30% eff.)				
KW	64	127	255	636
MW/annum	560	1,120	2,230	5,580
Electricity saving (if connected to grid)	$ 60,000	$ 110,000	$ 220,000	$ 560,000
Diesel (generator 0.259L/kWh)	$ 115,000	$ 230,000	$ 460,000	$ 1,160,000
Options 4 & 5				
Heat Recovery				
Thermal energy (GJ/annum)	3,011	6,021	12,043	30,106
LPG (savings)	$ 34, 000	$ 70, 000	$ 130, 000	$ 340,000
NG (savings)	$ 24, 000	$ 50, 000	$ 100, 000	$ 240, 000

A dairy free-stall barn size of 1,000 head could potentially save ~$110k/yr if connected to the grid and ~$230k/yr if a diesel generator is used on site by installing option 3 (cover existing lagoon + electric generator unit). The savings could potentially be increased if heat is recovered (option 4) and used on site. The savings would increase to ~$180k (LPG savings) if connected to the grid and ~$300k (LPG savings) if a diesel generator is used on site. Note that the LPG savings is based on all the heat being used on site.

Similar to above, the payback period would be approximately 3 years for a site using a diesel generator, compared with a payback period of approximately 6 years for a site connected to the grid.

7.1.1.3 Beef feedlots

Table 16 Estimated Capital Cost Options for Various Sized Beef Feedlots

Beef Feedlot (Head cattle)		**500**	**1,000**	**2,000**	**5,000**
	Volatile Solids	1,270	2,540	5,080	12,700
	Methane produced (m3/d)	410	810	1,630	4,100
No.	Anaerobic Pond				
1	Cover existing Lagoon (inc flare)	$ 110,000	$ 220,000	$ 430,000	$ 1,080,000
2	New lagoon and cover (inc flare)	$ 170,000	$ 340,000	$ 680,000	$ 1,700,000
	Anaerobic Pond + Power Generation				
3	Cover existing Lagoon (inc flare) + Cogeneration unit	$ 280,000	$ 550,000	$ 1,100,000	$ 2,760,000
4	Cover existing Lagoon (inc flare) + Cogeneration + Heat recovery	$ 300,000	$ 610,000	$ 1,210,000	$ 3,040,000
	Engineered Digester + Power Generation				
5	Dual-stage engineered AD system + Cogeneration + Heat recovery	$ 1,670,000	$ 3,330,000	$ 6,670,000	$ 16,670,000

For a beef feedlot size of 1,000 head, an anaerobic pond system with power generation is ~$550k, compared to a $3.3M for an engineered anaerobic digester with power generation.

Table 17 Estimated Potential Savings

Beef Feedlot (Head cattle)	**500**	**1,000**	**2,000**	**5,000**
Options 1 & 2				
Biogas (methane) Energy (GJ/annum)	5,310	11,000	21,000	53,000
LPG (savings)	$60, 000	$120, 000	$240, 000	$600,000
NG (savings)	$40, 000	$90, 000	$170, 000	$430, 000
Options 3, 4 & 5				
Electricity Generated from Biogas (30% eff.)				
kW	50	100	200	500
MW/annum	440	890	1,770	4,430
Electricity saving (if connected to grid)	$45,000	$90,000	$180,000	$440,000
Diesel (generator 0.259L/kWh)	$90,000	$180,000	$370,000	$920,000
Options 4 & 5				
Heat Recovery				
Thermal energy (GJ/annum)	2,390	4,780	9,660	24,000
LPG (savings)	$30, 000	$50, 000	$110, 000	$270, 000
NG (savings)	$20, 000	$40, 000	$80, 000	$190, 000

A beef feedlot size of 1,000 head could potentially save ~$90k/yr if connected to the grid and ~$180k/yr if a diesel generator is used on site by installing option 3 (cover existing lagoon + electric generator unit). The savings could potentially be increased if heat is recovered (option 4) and used on site. The savings would increase to ~$140k (LPG savings) if connected to the grid and ~$230k (LPG savings) if a diesel generator is used on site. Note that the LPG savings is based on all the heat being used on site. However, heat recovery may not be an option for beef feedlots as steam is required for steam flaking, whereas the majority of the energy recovered will be in the form of hot water.

The payback period would be approximately 3 years for a site using a diesel generator compared to a payback period of approximately 6 years for a site connected to the grid.

It must be emphasised that the above analyses present a very simple financial model that does not take into consideration economies of scale and relies entirely on recent capital cost data from similar type projects. As a consequence, the cost data presented in the Tables above does not show any reduction in payback period as herd size increases, although economies of scale are expected.

There are many factors that contribute to the accuracy of the cost estimates in this report. The cost estimates are within +/-50% due to variations in:

- Diet/feed types
- Volatile solids production
- VS estimation methods and data available
- Biogas yields
- Climate
- Revenue streams (i.e. RECs, NGACs)
- Cost streams (Diesel, LPG, etc)

7.2 Financial Incentives

In the recent years, Governments have introduced incentives to drive projects such as methane capture and use to reduce the greenhouse gas emissions from industries. This section discusses the major Australian Government schemes that have been introduced to facilitate the reduction of GHG emissions, focusing on the financial incentives used to encourage generation of electricity from renewable sources.

- Mandatory Renewable Energy Target (MRET): This is a Federal Government scheme that began in 2001 and is administered by Office of the Renewable Energy Regulator (ORER). This scheme requires electricity retailers and other large electricity buyers to source renewable or specified waste-product energy sources by 2010. The objective is to contribute towards the MRET target of an additional 9,500GWh of renewable electricity per annum by 2010, with the target remaining in place until 2020. Interim targets have been set over the period 2001 to 2010 and then to continue at the 9,500 GWh level through to 2020 (Lim *et al* 2004).

  The ORER accredits renewable energy generators and determines baselines for existing generators, ensures that Renewable Energy Certificates (RECs) (see below) are validly granted, tracks the creation and trading of RECs, and assists liable parties in determining liabilities, etc.

  RECs are created by accredited generators, with each certificate equivalent to 1 MWh of renewable generation. RECs can be created at any time after eligible generation, upon provision of the required evidence. They can be traded in financial markets that are separate from physical electricity markets. RECs may be banked by eligible generators, liable parties and REC market participants and remain valid until surrendered (Lim *et al.* 2004).

In addition to the above, the States have created their own, individual schemes to encourage the reduction in GHG emissions.

- The New South Wales Government has introduced its own scheme to require electricity retailers to reduce the dependence on electricity from fossil fuels by mandating set proportions of electricity sold to be sourced from renewable energy projects. It has an incentive scheme (the

NSW Greenhouse Gas Abatement Scheme), which encourages greenhouse gas emitters to reduce their greenhouse gas emissions with a financial incentive through the issue of New South Wales Gas Abatement Certificates (NGAC's). NGACs are equal to one tonne of CO2-e emissions (Lim *et al.* 2004).

- The Queensland Government has introduced a license scheme that requires Queensland electricity retailers to source 15 per cent of electricity sold in Queensland from gas-fired or renewable generation, with 13 per cent of this electricity to be derived from gas-fired generation. The scheme commenced on 1 January 2005 and will remain in force for 15 years or until an emissions' trading scheme is introduced (Lim et al 2004)..

- The Victorian Government has developed a Renewable Energy Strategy, with a target of 10 per cent renewables by 2010 (Lim et al 2004).

To give an idea of the potential savings that might be achieved when considering renewable energy credits and greenhouse gas abatements certificates, an example, using option 3 from the piggery cost estimate in section 7.1.1.1, has been summarised in Table 18 below. This scenario assumes that the piggery site is connected to the National Electricity Market (NGACs are applicable). The use of these credits has the potential to significantly reduce payback periods.

Table 18 Potential Savings from Government Incentives

	Electrical	Electrical + RECs[1]	Electrical + RECs + NGACs[2]
Savings	$ 174,000	$ 230,000	$ 340,000
Payback Period (years)	6	4.5	3

1. For this calculation, RECs were assumed to be valued at $30/MWh
2. For this calculation, NGACs were assumed to be valued at $13/tonne CO_2-e.

7.3 Viable Transport Distances

A key cost factor in the operation of a biogas facility is the cost of collecting and transporting biomass (manure or crop stubbles) from the field or site to a centralised biogas facility.

7.3.1 Manure

Table 19 summarises the transportation cost versus the available energy ($) per tanker. This was calculated on the basis of a truck (tanker) carrying 20,000L of liquid manure (~20 tonne) being transported various distances shown in the Table 16 below. A load of 60% solid manure was assumed to be 20 tonne.

Table 19 Transportation Cost vs Energy Produced (Manure)

		Transport Costs[1] ($/truck movement)			
Total solids	Available Energy ($/tanker) [2]	5km	10km	20km	30km
1%	$0.65	$35	$70	$140	$210
5%	$3.20				

10%	$6.40				
60%	$38.00				

1. Transport costs - $7/t/20km. This is based on recent study on transportation costs for Biosolids in Sunshine Coast region (Sunshine Coast Regional Biosolids Feasibility Study, UQ (AWMC) 2006).
2. 80% of TS is VS, and 1 tonne VS = $4.80. This is based on selling electricity at a rate of $0.10/kWh.

The idea of transporting manure (liquid or solids) from a farm to a centralised methane capture facility is a very expensive exercise and is considered unfeasible. Based on a transportation rate of $7/t/20km (AWMC, 2006), it costs 5.5 times more to transport the material 5 km than the energy available in 10% solids liquid manure. It may be viable to transport 60% solids material over very short distances, although this will add significant operating costs to a centralised facility. This approach may only be viable if existing disposal options are limited or attract a significant cost.
However, there are also potential savings in transport costs by reducing the volume of solids. For example, if the manure has to be transported 80km to market from a large feedlot and there is a digester 20km away it may be economic to transport the solids to the digester to reduce the volume of solids before transporting them to market. This could potentially reduce the solids volume by +50%. This particularly makes sense for smaller feedlots near a facility with a wet waste stream that needs thickening, e.g. piggeries, which could potentially make plug-flow digesters feasible.

7.3.2 Crop Stubble

The potential viability of co-digesting crop stubbles with manure will depend mainly on their proximity to the high intensity livestock regions. Appendix A shows the various regions that are most likely to be viable for utilisation of crop stubbles.

Table 20 summarises the transportation cost of straw per tonne per km, cost of straw per tonne and the energy available ($) in the straw when anaerobically digested.

To give an indication of how much straw is required, an ecoshelter operation requires approximately 0.6-0.8 kg straw/pig/day (grower/finisher). Therefore, for a 15,000 SPU facility, approximately 12 tonnes of straw is required per day.

Square bales cost about $65 per ton stacked in a shed on farm and can be transported about 50km for $17 per ton. However, in the current drought, bales have been purchased for $120 per tonne. For the purposes of this exercise, $65/tonne has been used.

Table 20 Transportation Cost Summary – Crop Stubble

			Transport Costs[1] ($/tuck movement)			
Tonne	Energy	Cost Straw	5km	15km	30km	50km

straw (t)	per load ($2.20/t)[2]	($65/t)				
10	$22	$650	$17	$51	$102	$170
15	$34	$975	$26	$77	$153	$255
20	$45	$1,300	$34	$102	$204	$340

1. Transport costs - $17/t/50km. figures supplied by Windridge Piggery.
2. 1 tonne straw produces 180m^3 methane (D. Batstone). This is based on selling electricity at a rate of $0.10/kWh.

Based on the costs presented in Table 20, it is not feasible to purchase and transport crop stubble to a farm for the specific reason of digesting it with manure to produce biogas. The cost of straw per tonne is 30 times greater than the amount of available energy in the straw. In addition, there is the cost of transport. For example, 15 tonnes of straw will cost approx $1,000 and to transport it 30 km will cost an additional $153, giving total cost of $1,153. The available energy in the 15 tonnes of straw is only $34. Therefore, there is no benefit in purchasing straw for the specific reason of digesting it with manure, irrespective of the distance traveled.

7.4 Project Viability Assessment Tool

An example tool for initially assessing the potential viability of installing a methane capture and use facility has been included in Appendix B. It was developed by Environomics (Mattock, 1999) as a tool intended to permit animal producers/project developers an early on glance of the likelihood of success of a methane capture facility.

It works by applying a score to each assessment criteria and the tallied score gives an indication of the feasibility. However, if a "No" is circled in the critical issues column, the project may have a fatal flaw. Please refer to Appendix B for further details.

This tool could be adopted for the Australian intensive livestock industry as an initial screening process to eliminate unsuitable facilities. The sooner a project is identified as unlikely to succeed, the less time and money is spent.

Since this assessment tool is based on the US intensive livestock industry, it would need to be developed further to suit the Australian intensive livestock industry for it to be a valuable tool. The following list is an example of the criteria that would be added to the assessment tool for Australian intensive livestock industry:

- Organic loading (kg VS/day);
- Energy source used on site (i.e. Grid power, LPG, NG, Diesel, etc);
- Crop stubble used on site;
- Financial grants available; and
- Reducing GHG incentives.

8.0 Conclusions and Recommendations

8.1 Conclusions

The following conclusions have been made from assessment of available case studies:

- The economic viability of methane capture and use from the livestock industry is highly variable and dependent on site-specific issues, including the use of electricity and /or heat on site and the actual location of site. Viability is also dependent on the possibility of selling electricity to the grid, and the opportunities of selling the biogas to a nearby plant/ using it on farm. Economic viability assessments therefore need to be undertaken considering site-specific issues.
- From the case studies discussed in Australia, the cost of energy varies depending on the commercial arrangements that the companies are able to negotiate with energy suppliers. In general, the case study sites considered in this study pay between 5-8¢/kWh for electricity about $6-10/GJ for natural gas and $10-14/GJ for LPG. The cost estimates presented in this report assumed a rate of 10¢/kWh.
- In general, for sites that have gas-fired boilers, the greatest return on investment is achieved by co-firing the biogas with the primary gas supply (natural gas or LPG). This is because the infrastructure for using the biogas is already in place and only a minimal additional expenditure is required. In comparison, electricity generation generally requires additional capital expenditure in the form of a generator set and associated equipment. Additionally, if a site is not a large energy user, it is not possible to take full advantage of all the available energy, and therefore energy savings are minimal. This usually results in savings being too low to justify the investment that would be required.
- Savings should be calculated based on the full range of potential operational savings and available credits.
- Large greenhouse benefits can be obtained from converting anaerobic lagoons into CAL.
- There are a number of limiting factors associated with the use of biogas from intensive livestock industry in Australia, including:
  - The low cost of energy;
  - Lack of equipment and technology suppliers promoting energy recovery in Australia; and
  - Lack of knowledge in energy recovery.

Much of the literature reviewed reported manure production rates for livestock as “rules of thumb” (kg manure (TS, VS,etc)/animal/day). This approach seems to be a reasonable method for estimating manure production and has been practiced for many years. Although, this method should be used with caution due to slight variations in values from Australian and international sources, which is due mainly to diets/ feeding regimes etc. Based on this, it is recommended that this approach is sufficiently robust for the purposes of estimating manure production rates for evaluating economic viability of projects.

The following regions are potentially viable for combining manure due to the intensity of the industry in the region, although the cost of transportation is likely to limit transportation of material >5 km:

- Murray-darling region - High intensity of beef feedlots, large dairies (intensive free-stalls sites situated towards the west in the Goulburn-Broken region) and piggeries in a relatively close proximity
- South-East Queensland - High intensity of beef feedlots and piggeries in a relatively close proximity. The dairy farms are not expected to be viable as they are closer to the coast than the feedlots and piggeries and are not believed to be intensive farms.
- North of Adelaide - Close proximity piggeries and small beef feedlots.

- Southern New South Wales – Area of a large number of feedlots and piggeries (no dairy).
- South-West WA - There is potential in this region as there are piggeries, dairies (though they are not likely to be intensive) and a large feedlot with some smaller feedlots. However, these locations appear very dispersed.
- Northern Tasmania - May have potential, as there is a single feedlot, a number of small sized piggeries and dairies (though they are not likely to be intensive)
- Hunter valley - May have potential, as there are a number of beef feedlots, small to medium sized piggeries and dairies (though they are not likely to be intensive).
- Central QLD – There is high intensity of beef feedlots, small to medium sized piggeries and very few dairies (though they are not likely to be intensive).

The following regions are potentially viable for co-digesting crop stubble with manure due to their close proximity to intensive livestock farms, although the cost of stubble and the associated transportation cost are likely to limit the viability of this approach:

- Murray-darling region – There are low-density cereal crops through the middle of the region and increases towards the east side of the region. There are high intensity cereal crops in the west of the region.
- South-East Queensland - There is high intensity cereal crops that stretches approx 150km from Chinchilla through to Pitsworth. There are also high intensity cereal crops south of Goondiwindi to Moree.
- North of Adelaide - There is a large region north of Adelaide of high intensity cereal crops (approx. 200km long by 100km wide).
- Southern New South Wales – There is medium intensity cereal crops in this region
- South-West WA – There is high intensity cereal crops in the South-West region of Western Australia.

Based on the current cost data from similar projects, the payback period for a piggery of size 20,000 SPU for a methane capture facility that involves covering existing lagoons and a cogeneration unit (option 3) is 3 years for a site using a diesel generator and approximately 6 years for a site connected to the grid and able to use all the heat to supplant LPG heating requirements. Similarly, the payback periods for a beef feedlot and dairy (intensive free-stall) facility of size 1,000 head of cattle, for a similar set-up, is approximately 3 years for a site using a diesel generator and approximately 6 years for a site connected to the grid. These payback periods can be significantly reduced if government green energy incentives are included e.g. RECs and NGACs.

There are many factors that contribute to the accuracy of the cost estimates in this report. The cost estimates are within +/-50% due to variations in:

- Diet/feed types
- Volatile solids production
- VS estimation methods and data available
- Biogas yields
- Climate
- Revenue streams (i.e. RECs, NGACs)
- Cost streams (Diesel, LPG, electricity, etc)

The transportation of manure (liquid or solids) from a farm to a centralised methane capture facility to improve economies of scale is not considered feasible if transportation distances exceed 5 km. Even for distances <5 km, transportation costs are significant relative to the available energy value.

Based on the transportation cost of straw per tonne per km, cost of straw per tonne and the energy available ($) in the straw when anaerobically digested, it is not financially viable to purchase and transport crop stubble to a farm for the specific reason of digesting it with manure to produce biogas.

8.2 Recommendations

Based on the conclusions drawn from the literature review and the assessment of economic viability of the capture of methane and use from intensive livestock industry, it has been determined that project viability is dependent on:

- The location and size of the industry;
- The amount of energy produced and used on site; and
- They type of anaerobic digestion process used.

Based on the information presented from both international experience and the one Australian operating anaerobic digestion facility, the following anaerobic digestion technologies appear to be suitable for methane capture and use in the Australian intensive livestock industry:

- Covered Anaerobic Lagoons;
- Completely-mixed mesophilic anaerobic digesters; or
- Plug-flow mesophilic anaerobic digesters.

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b) has been prepared on the basis of information provided to GHD up to 21 August 2007;

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APPENDIX A

Crop Stubble Location

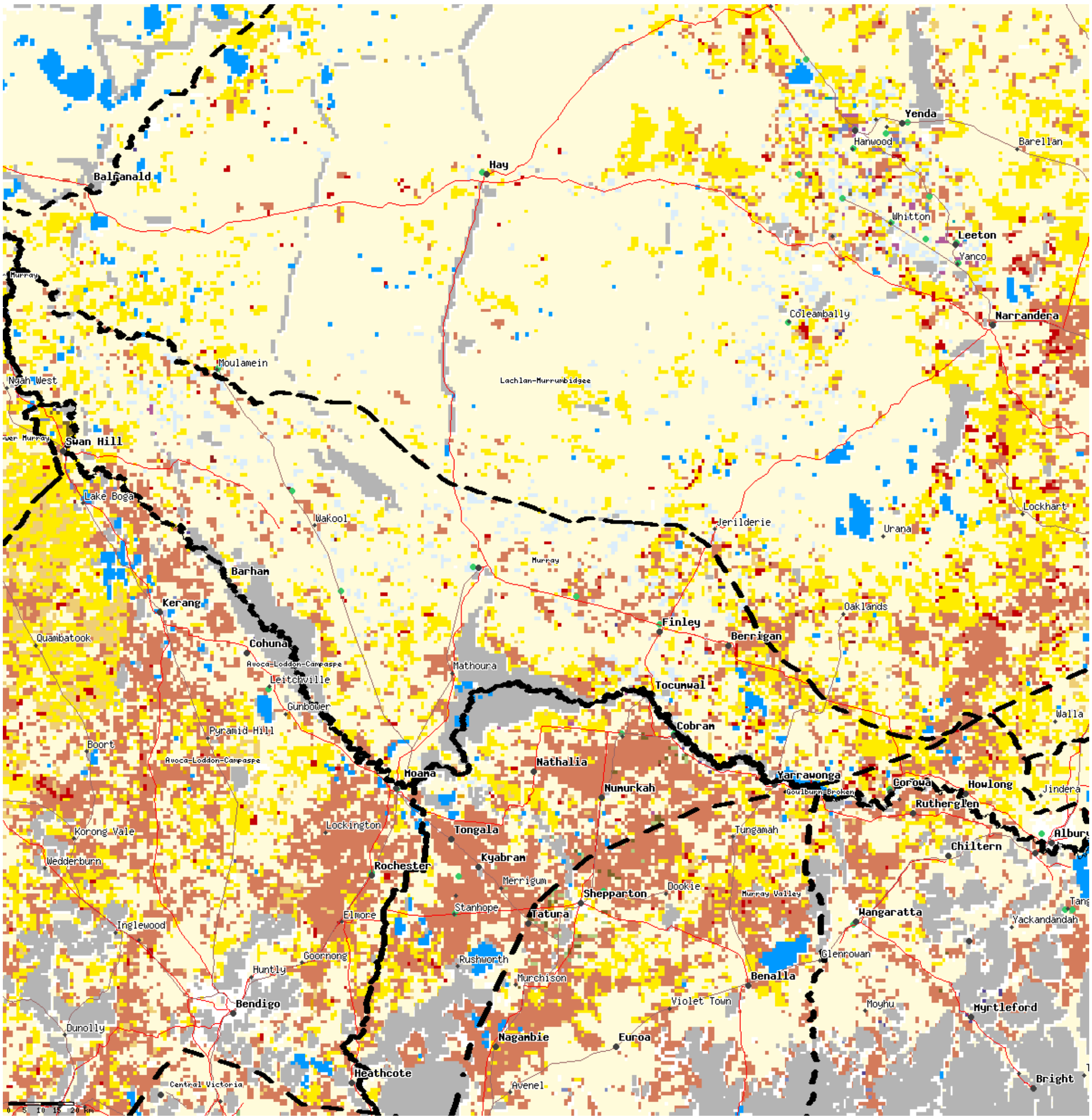

Figure 11 Murray-Darling Region – Crop (cereal) distribution (Bioenergy Atlas Australia)

Yellow shading indicates cereals (excl rice)

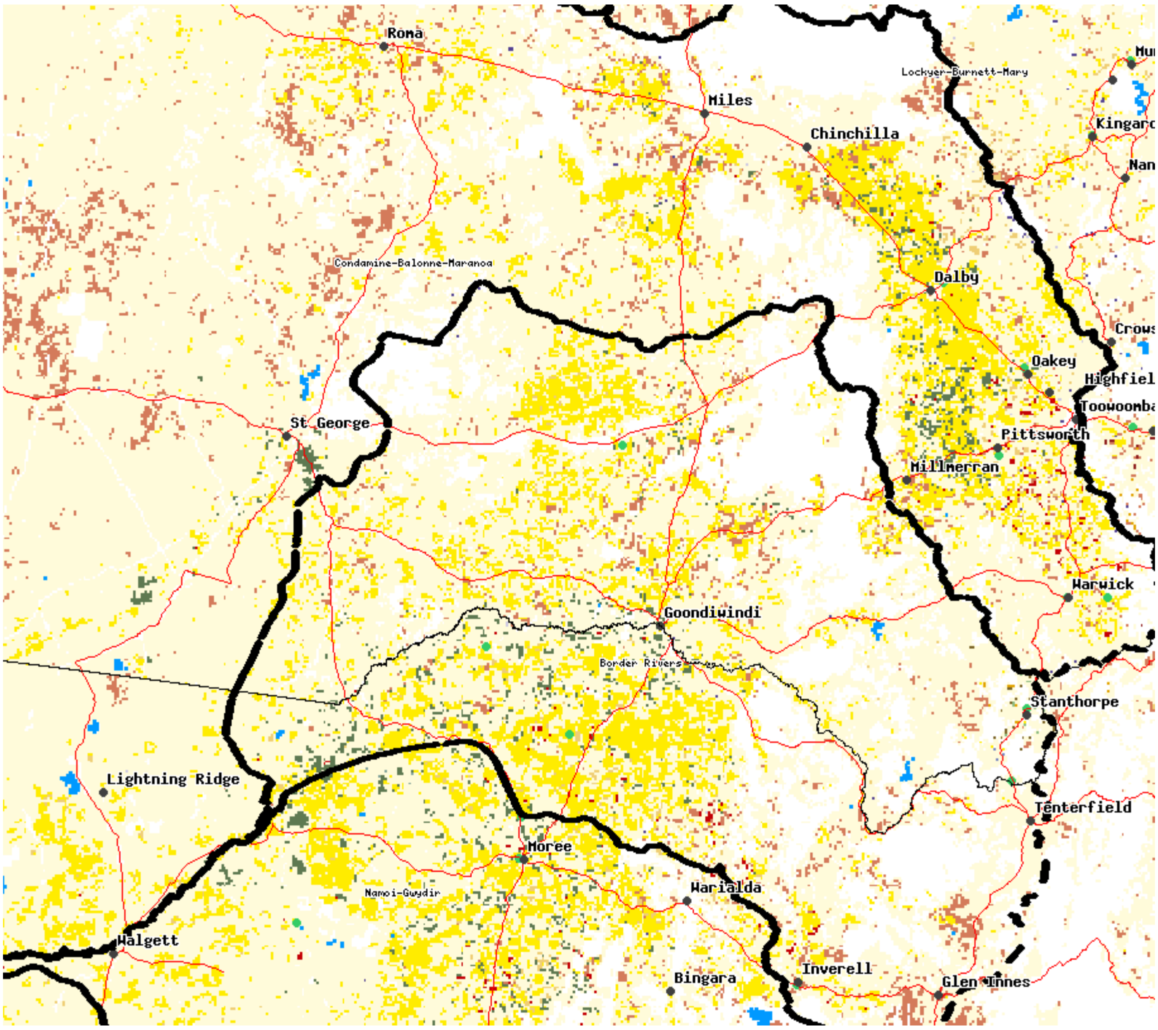

Figure 12 South-East Queensland Region - Crop (cereal) distribution (Bioenergy Atlas Australia)

Yellow shading indicates cereals (excl rice)

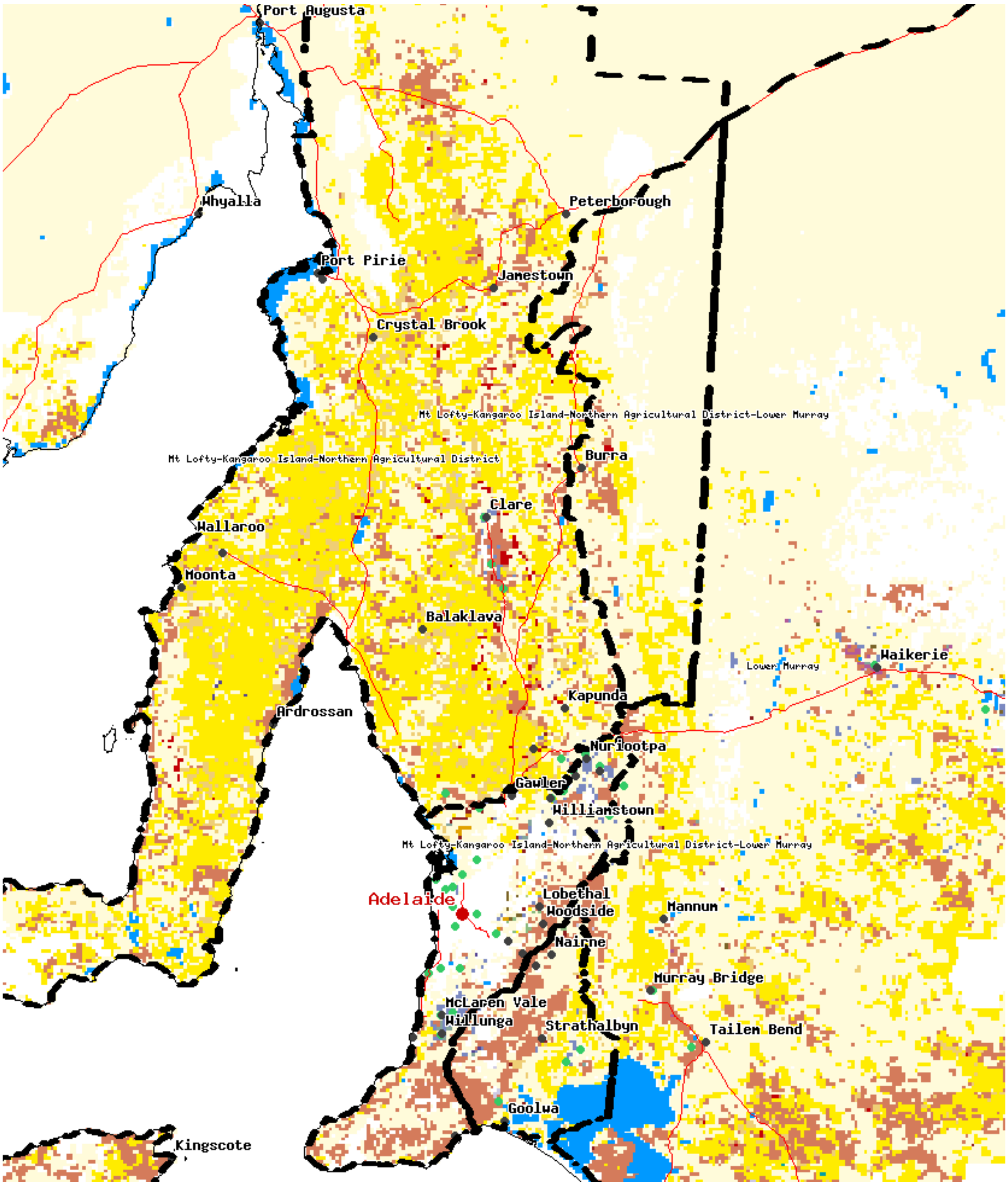

Figure 13 **North of Adelaide - Crop (cereal) distribution (Bioenergy Atlas Australia)**

Yellow shading indicates cereals (excl rice)

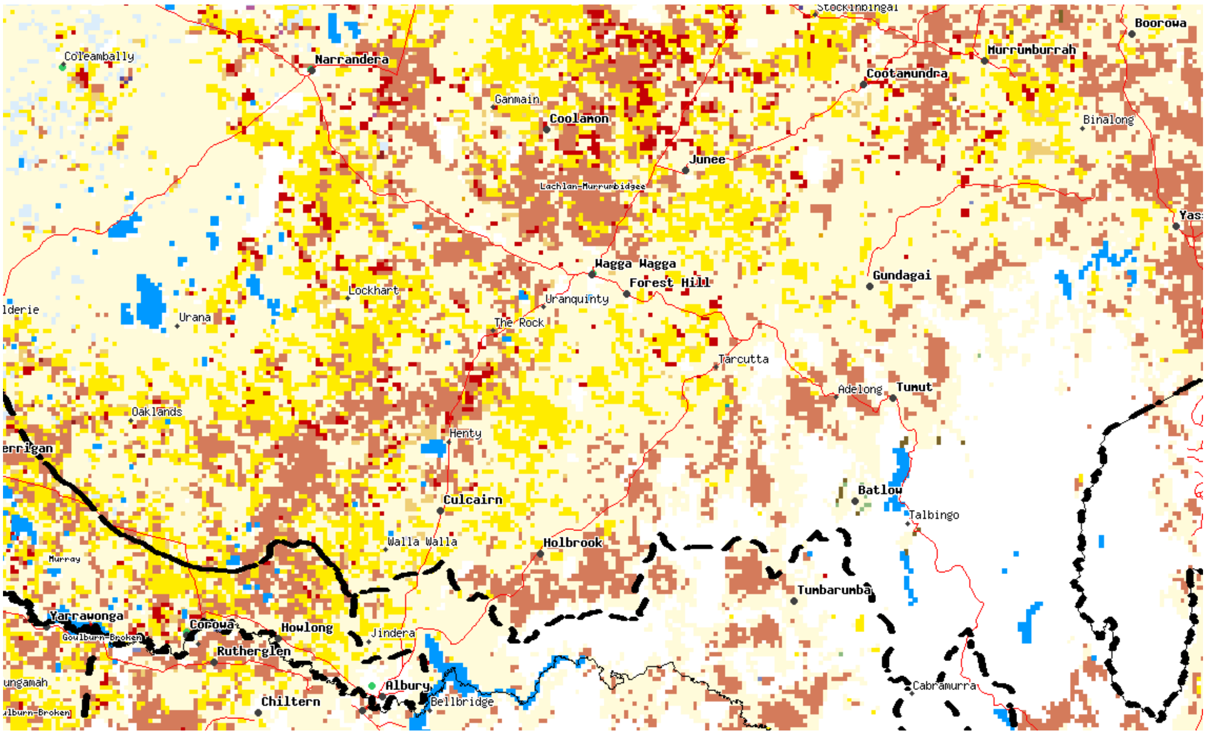

Figure 14 Southern NSW - Crop (cereal) distribution (Bioenergy Atlas Australia)

Yellow shading indicates cereals (excl rice)

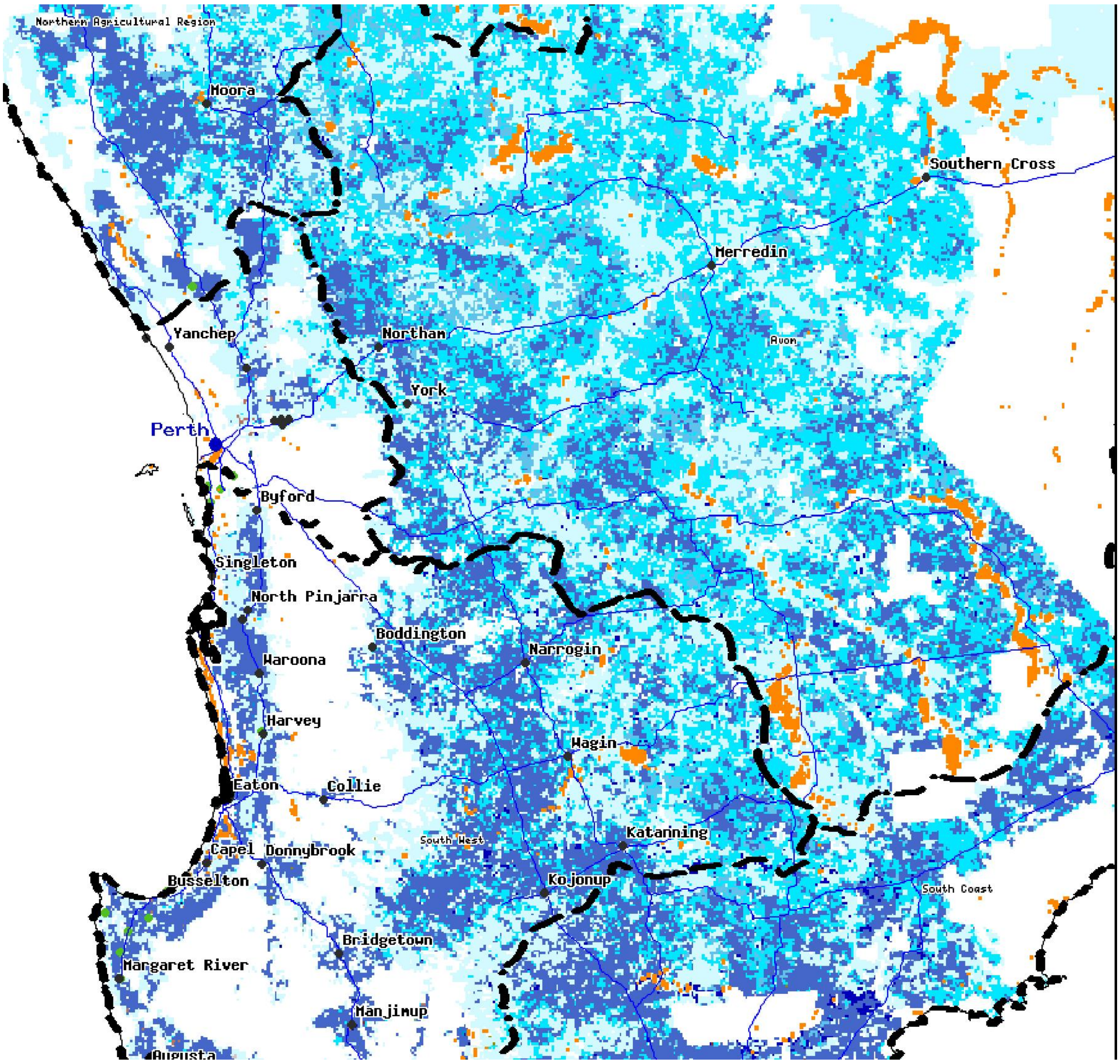

Figure 15 South-West WA - Crop (cereal) distribution (Bioenergy Atlas Australia)

Yellow shading indicates cereals (excl rice)

Appendix B

Initial Assessment Form

SELF ASSESSMENT TOOL (Mattocks, 2003)

INSTRUCTIONS:

For each question, circle the appropriate answer for the condition observed in the community. There are two responses possible for each issue under assessment; when a "No" is circled in the *Critical Issues* column, the project may have a fatal flaw; when an entry in the *Weighted Issues* column is circled, then a weight must be determined. Some weights for an assessment issue may be added together (e.g. both dairy processing wastes and other wastes may be available for processing). Write the "weight" of each answer, in the last column: *Score*. Tally all the Scores.

Very low likelihood of success	"NO-GO" Situation
Success is questionable Score of	100 - 130
Success is possible Score of	131 - 170
Greatest likelihood of success Score of	171 - 200

Issues to Assess	Critical Issues*	Weighted Issues	Weight	Score
1. To be built for other than the project being a "neat idea"?	No	Environ. Benefits Financial Benefits	5 10	
2. Pointperson/Organization in charge?	No	Yes	10	
3. Is there a "lead agency"	No	Yes	10	
4. Foodwaste-manure mixtures permitted?	No	Yes	10	
5. Is long-term storage available?	No	Yes	10	
6. Is there acreage to receive effluent nutrients?	No	Yes	10	
7. Will the industry be alive in 10 years?	No	Yes	5	
8. Are roads open for use?	No	Yes	5	
9. Experienced advisors involved?	No	Yes	5	
10. If important, are tip fees possible? (Current tip fees are?)	No	High Moderate Low	10 7 4	
11. Foodwaste proximity to the site	No	<1 mile 1-5 miles 5-15 miles	10 8 5	
12. Is the biogas usable?	No	Yes, Electric Yes, Hot Water	5 8	
13. Is manure close to the site?	No	50% is : <1 mile < 2 miles < 3 miles	10 6 3	
14. Waste available all year around?	No	7 days/wk, 52 weeks/yr Frequent	10 5	
15. Financing/grants available?	No	Yes: 100% 50% 25%	10 8 5	
16. Wastes available?	No	Dairy processing Other food process'g	5 3	
17. Waste availability		>50,000 lb. solids/day <50,000 lb. solids/day	10 5	
18. System Scaleable?		Yes	10	
19. Community support?		Yes	5	
20. Potential for byproduct sales?		Yes	5	

21. Clear facility ownership structure?		Yes	10	
22. Is there a committed facility operator?		Yes	4	
23. Legal entity identified to act?		Yes	5	
24. Formal public construction bid process		Yes	-5	
TOTAL				

* **"GO-NO GO" ISSUES**; Any "**NO**" in the critical issues column would signify the assessor should seriously reconsider going forward with the project. (Mattocks, 2003)

Appendix C

Detailed Breakdown of Financial Assessments

Piggery Cost Estimate Options

No.	Pigs (SPU)	Rate	Unit	5,000	10,000	20,000	50,000
		Rate	Unit				
	Loading - Manure						
	Total solids	0.3	kg/d	1,500	3,000	6,000	15,000
	Volatile Solids	0.25	kg/d	1,250	2,500	5,000	12,500
	Methane produced (m3/d)	0.32	m3CH4/VS kg added	400	800	1,600	4,000
	Capital Cost Options						
No.	Anaerobic Pond						
1	Cover existing Lagoon (inc flare)	Biogas to boiler		$ 85,976	$ 171,951	$ 343,902	$ 859,756
2	New lagoon and cover (inc flare)	Biogas to boiler		$ 131,098	$ 262,195	$ 524,390	$ 1,310,976
	Anaerobic Pond + Power Generation						
3	Cover existing Lagoon (inc flare) + Cogeneration unit	Generate electricity		$ 251,220	$ 502,439	$ 1,004,878	$ 2,512,195
4	Cover existing Lagoon (inc flare) + Cogeneration + Heat recovery	Generate electricity + heating		$ 274,390	$ 548,780	$ 1,097,561	$ 2,743,902
	Engineered Digester + Power Generation						
5	Dual-stage engineered AD system + Cogeneration	Generate electricity + heating		$ 1,640,833	$ 3,281,667	$ 6,563,333	$ 16,408,333
	Savings						
	Biogas (methane) Energy (GJ/annum)	35.8	MJ/m3	5,227	10,454	20,907	52,268
	LPG (savings)	14	$/GJ	$ 58,540	$ 117,080	$ 234,161	$ 585,402
	NG (savings)	10	$/GJ	$ 41,814	$ 83,629	$ 167,258	$ 418,144
	Electricity Generated from Biogas (30% eff.)		kW	50	99	199	497
			MW/annum	436	871	1,742	4,356
	Electricity saving (if connected to grid)	0.10	$/kW	$ 43,557	$ 87,113	$ 174,227	$ 435,567
	Diesel (generator 0.259L/kWh)	0.8	$/L	$ 90,249	$ 180,499	$ 360,998	$ 902,494
	Heat Recovery						
	Thermal energy (GJ/annum)	45%	recovery	2,352	4,704	9,408	23,521
	LPG (savings)	14	$/GJ	$ 26,343	$ 52,686	$ 105,372	$ 263,431
	NG (savings)	10	$/GJ	$ 18,816	$ 37,633	$ 75,266	$ 188,165

No.	Government Abatements/Incentives	Rate	Unit	5,000	10,000	20,000	50,000	Paybacks
	Methane (tonnes/yr)			98	196	392	981	
	CO2 equiv (t) - venting	21	CO2/t CH4	2060	4121	8241	20604	
	CO2 equiv (t) - energy not used from grid	1.05	t.CO2/MW	436	871	1742	4356	
	CO2 equiv (t) - energy used on site	2.75	kg CO2/CH4	270	540	1079	2698	
	CO2 equiv (t) - TOTAL			2226	4452	8904	22261	
	NGACs ($/yr) (NSW Grid only)	13	$/t CO2	$ 28,939	$ 57,879	$ 115,758	$ 289,394	
	RECs ($/yr)	30	$/MWh	$ 13,067	$ 26,134	$ 52,268	$ 130,670	
No.	**e.g. Total Savings Including Government Abatements (Options 3 & 4)**							Paybacks
3	Elec+RECS			$ 56,624	$ 113,247	$ 226,495	$ 566,237	4.4
4	Elec+Recovery+RECS			$ 82,967	$ 165,933	$ 331,867	$ 829,667	3.3
3	Elec+RECS+NGACs			$ 85,563	$ 171,126	$ 342,252	$ 855,631	2.9
4	Elec+Recovery+RECS+NGACs			$ 111,906	$ 223,812	$ 447,625	$ 1,119,062	2.5
3	Diesel+RECs			$ 103,316	$ 206,633	$ 413,266	$ 1,033,164	2.4
4	Diesel+Recover+RECs			$ 129,659	$ 259,319	$ 518,638	$ 1,296,595	2.1
3	Diesel+RECs+NGACs			$ 132,256	$ 264,512	$ 529,023	$ 1,322,559	1.9
4	Diesel+Recover+RECs+NGACs			$ 158,599	$ 317,198	$ 634,396	$ 1,585,989	1.7

Dairy Cost Estimate Options

No.	Dairy "Free-Stalls" (Ave liveweight 635kg)	Rate	Unit	500	1,000	2,000	5,000	Paybacks
	Loading - Manure							
	Total solids	3.85	kg/d	1,925	3,850	7,700	19,250	
	Volatile Solids	3.2	kg/d	1,600	3,200	6,400	16,000	
	Methane produced (m3/d)	0.32	m3CH4/VS kg added	512	1,024	2,048	5,120	
	Capital Cost Options							
No.	Anaerobic Pond							
1	Cover existing Lagoon (inc flare)	Biogas to boiler		$ 136,585	$ 273,171	$ 546,341	$ 1,365,854	
2	New lagoon and cover (inc flare)	Biogas to boiler		$ 214,634	$ 429,268	$ 858,537	$ 2,146,341	
	Anaerobic Pond + Power Generation							
3	Cover existing Lagoon (inc flare) + Cogeneration unit	Generate electricity		$ 348,098	$ 696,195	$ 1,392,390	$ 3,480,976	
4	Cover existing Lagoon (inc flare) + Cogeneration + Heat recovery	Generate electricity + heating		$ 382,439	$ 764,878	$ 1,529,756	$ 3,824,390	
	Engineered Digester + Power Generation							
5	Dual-stage engineered AD system + Cogeneration	Generate electricity + heating		$ 2,100,267	$ 4,200,533	$ 8,401,067	$ 21,002,667	
	Savings							
	Biogas (methane) Energy (GJ/annum)	35.8	MJ/m3	6,690	13,381	26,761	66,903	
	LPG (savings)	14	$/GJ	$ 74,931	$ 149,863	$ 299,726	$ 749,314	
	NG (savings)	10	$/GJ	$ 53,522	$ 107,045	$ 214,090	$ 535,224	
	Electricity Generated from Biogas (30% eff.)		kW	64	127	255	636	
			MW/annum	558	1,115	2,230	5,575	
	Electricity saving (if connected to grid)	0.10	$/kW	$ 55,753	$ 111,505	$ 223,010	$ 557,525	
	Diesel (generator 0.259L/kWh)	0.8	$/L	$ 115,519	$ 231,038	$ 462,077	$ 1,155,192	
	Heat Recovery							
	Thermal energy (GJ/annum)	45%	recovery	3,011	6,021	12,043	30,106	
	LPG (savings)	14	$/GJ	$ 33,719	$ 67,438	$ 134,877	$ 337,191	
	NG (savings)	10	$/GJ	$ 24,085	$ 48,170	$ 96,340	$ 240,851	
	Government Abatements/Incentives							
	Methane (tonnes/yr)			126	251	502	1256	
	CO2 equiv (t) - venting	21	CO2/t CH4	2637	5275	10549	26373	
	CO2 equiv (t) - energy not used from grid	1.05	t.CO2/MW	558	1115	2230	5575	
	CO2 equiv (t) - energy used on site	2.75	kg CO2/CH4	345	691	1381	3454	
	CO2 equiv (t) - TOTAL			2849	5699	11398	28494	
	NGACs ($/yr) (NSW Grid only)	13	$/t CO2	$ 37,042	$ 74,085	$ 148,170	$ 370,425	
	RECs ($/yr)	30	$/MWh	$ 16,726	$ 33,452	$ 66,903	$ 167,258	
No.	**e.g. Total Savings Including Government Abatements (Options 3 & 4)**							Paybacks
3	Elec+RECS			$ 72,478	$ 144,957	$ 289,913	$ 724,783	4.8
4	Elec+Recovery+RECS			$ 106,197	$ 212,395	$ 424,790	$ 1,061,974	3.6
3	Elec+RECS+NGACs			$ 109,521	$ 219,042	$ 438,083	$ 1,095,208	3.2
4	Elec+Recovery+RECS+NGACs			$ 143,240	$ 286,480	$ 572,960	$ 1,432,399	2.7
3	Diesel+RECs			$ 132,245	$ 264,490	$ 528,980	$ 1,322,450	2.6
4	Diesel+Recover+RECs			$ 165,964	$ 331,928	$ 663,857	$ 1,659,641	2.3
3	Diesel+RECs+NGACs			$ 169,287	$ 338,575	$ 677,150	$ 1,692,875	2.1
4	Diesel+Recover+RECs+NGACs			$ 203,007	$ 406,013	$ 812,026	$ 2,030,066	1.9

Beef Cost Estimate Options

No.	Beef Feedlot (Ave liveweight 525kg)	Rate	Unit	500	1,000	2,000	5,000
	Loading - Manure						
	Total solids	3.1	kg/d	1,550	3,100	6,200	15,500
	Volatile Solids	2.54	kg/d	1,270	2,540	5,080	12,700
	Methane produced (m3/d)	0.32	m3CH4/VS kg added	406	813	1,626	4,064
	Capital Cost Options						
No.	Anaerobic Pond						
1	Cover existing Lagoon (inc flare)	Biogas to boiler		$ 108,415	$ 216,829	$ 433,659	$ 1,084,146
2	New lagoon and cover (inc flare)	Biogas to boiler		$ 170,366	$ 340,732	$ 681,463	$ 1,703,659
	Anaerobic Pond + Power Generation						
3	Cover existing Lagoon (inc flare) + Cogeneration unit	Generate electricity		$ 276,302	$ 552,605	$ 1,105,210	$ 2,763,024
4	Cover existing Lagoon (inc flare) + Cogeneration + Heat recovery	Generate electricity + heating		$ 303,561	$ 607,122	$ 1,214,244	$ 3,035,610
	Engineered Digester + Power Generation						
5	Dual-stage engineered AD system + Cogeneration	Generate electricity + heating		$ 1,667,087	$ 3,334,173	$ 6,668,347	$ 16,670,867
	Savings						
	Biogas (methane) Energy (GJ/annum)	35.8	MJ/m3	5,310	10,621	21,242	53,104
	LPG (savings)	14	$/GJ	$ 59,477	$ 118,954	$ 237,907	$ 594,768
	NG (savings)	10	$/GJ	$ 42,483	$ 84,967	$ 169,934	$ 424,834
	Electricity Generated from Biogas (30% eff.)		kW	51	101	202	505
			MW/annum	443	885	1,770	4,425
	Electricity saving (if connected to grid)	0.10	$/kW	$ 44,254	$ 88,507	$ 177,014	$ 442,536
	Diesel (generator 0.259L/kWh)	0.8	$/L	$ 91,693	$ 183,387	$ 366,774	$ 916,934
	Heat Recovery						
	Thermal energy (GJ/annum)	45%	recovery	2,390	4,779	9,559	23,897
	LPG (savings)	14	$/GJ	$ 26,765	$ 53,529	$ 107,058	$ 267,646
	NG (savings)	10	$/GJ	$ 19,118	$ 38,235	$ 76,470	$ 191,175

No.	Government Abatements/Incentives	Rate	Unit	500	1,000	2,000	5,000	Paybacks
	Methane (tonnes/yr)			100	199	399	997	
	CO2 equiv (t) - venting	21	CO2/t CH4	2093	4187	8373	20933	
	CO2 equiv (t) - energy not used from grid	1.05	t.CO2/MW	443	885	1770	4425	
	CO2 equiv (t) - energy used on site	2.75	kg CO2/CH4	274	548	1096	2741	
	CO2 equiv (t) - TOTAL			2262	4523	9047	22617	
	NGACs ($/yr) (NSW Grid only)	13	$/t CO2	$ 29,402	$ 58,805	$ 117,610	$ 294,025	
	RECs ($/yr)	30	$/MWh	$ 13,276	$ 26,552	$ 53,104	$ 132,761	
No.	**e.g. Total Savings Including Government Abatements (Options 3 & 4)**							Paybacks
3	Elec+RECS			$ 57,530	$ 115,059	$ 230,119	$ 575,296	4.8
4	Elec+Recovery+RECS			$ 84,294	$ 168,588	$ 337,177	$ 842,942	3.6
3	Elec+RECS+NGACs			$ 86,932	$ 173,864	$ 347,728	$ 869,321	3.2
4	Elec+Recovery+RECS+NGACs			$ 113,697	$ 227,393	$ 454,787	$ 1,136,967	2.7
3	Diesel+RECs			$ 104,969	$ 209,939	$ 419,878	$ 1,049,695	2.6
4	Diesel+Recover+RECs			$ 131,734	$ 263,468	$ 526,936	$ 1,317,340	2.3
3	Diesel+RECs+NGACs			$ 134,372	$ 268,744	$ 537,488	$ 1,343,719	2.1
4	Diesel+Recover+RECs+NGACs			$ 161,137	$ 322,273	$ 644,546	$ 1,611,365	1.9