final report

FEEDLOTS

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Energy from feedlot wastes

Feasibility study of options

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Abstract

The disposal of solid and liquid wastes generated during the feeding process is one of the key environmental concerns facing feedlot operators. This project undertook an initial desk-top assessment of the feasibility of the various technologies available to feedlot operators to recover the energy in their liquid and solid wastes. Based on the outcomes of this study it does not appear that energy recovery from liquid wastes is economically attractive.

However, energy recovery from harvested manure does look economically attractive. Adoption of combustion or gasification technologies could significantly reduce manure disposal costs, generate significant amounts of green energy and electricity and in the case of gasification, sequester significant amounts of carbon in the char. It is recommended that the technical and economic benefits of combustion and gasification of manure be validated via pilot plant trials.

Executive summary

The disposal of solid and liquid wastes generated during the feeding process is one of the key environmental concerns facing feedlot operators. These wastes have residual amounts of energy and key nutrients, such as nitrogen and phosphorus. The overall objective of this project is to undertake an initial desk-top assessment of the feasibility of the various technologies available to feedlots to recover the energy in the liquid and solid wastes they produce. The major individual objectives of the project are listed below.

1. Collect and collate available information on the characteristics of feedlot solid and liquid wastes and develop input design values for the study;

2. Undertake a desktop feasibility study to compare the technologies available to feedlots to recover energy from these solid and liquid wastes, with a particular focus on the following technologies:
    a. Covering existing anaerobic lagoons and using the methane gas generated in a gas fired boiler;
    b. Installing a purpose built anaerobic digester to generate methane for use in a gas fired boiler;
    c. Processing the solid wastes in a pyrolysis or gasification unit and using the resulting syngas, char and/or bio-oil in some combination (i.e. syngas used in a gas fired boiler, char directly fed into a traditional coal-fired boiler, bio-oil used in the feedlot's vehicles in some combination);
    d. Directly combusting the solid wastes in a traditional boiler.

3. Provide recommendations to feedlot operators regarding the most cost effective and feasible technology/s available to them to recover energy from their solid and liquid wastes. The contract called for feedlots of 10,000, 25,000 and 60,000 SCUs to be addressed.

All the objectives of this desk-top techno-economic review of energy recovery options for feedlot effluent and solid wastes have been successfully achieved. There was sufficient effluent wastewater and solid waste characteristics data available in the MLA data-bases to allow the development of input design parameters to conduct the techno-economic study. Process designs for the energy recovery options were successfully developed and with cost data from appropriate equipment vendors, acceptable cost-benefit analyses of these energy recovery options were completed.

The following conclusions are drawn based on the findings of this study:

1. Based on the current best estimate of effluent quality and quantity from feedlot holding ponds, treatment of this effluent via either covered anaerobic lagoons (CAL) or engineered anaerobic digesters is not economically attractive. The best economics, based on use of a CAL at a 60,000 SCU feedlot, generated a positive cash flow of $1.256 million over a 20-year time-frame, which is equivalent to a simple pay-back time on the investment of 6 years. None of the other options offer any payback on the investments, based on a 20-year NPV basis.

2. The current best estimate of harvested manure characteristics indicates that this material is dry enough and has sufficient energy content to make processing in combustors or gasifier's technically feasible. No additional thermal drying of the feedstock is required.

3. Harvested manure is high in potassium and chlorides, known flux agents which depress the melting point of materials. Combustion of the manure may thus present some problems with respect to ash melting in the furnace. This issue can be minimised by use of fluid bed combustors, where temperature is well controlled, with minimisation of “hot spots” within the combustor. Ash melting is unlikely to be an issue in gasifier’s where temperatures are typically 250 ^{0}C lower than in combustors.

4. Combustion of harvested manure, with steam and electricity generation, provides an attractive manure management option for the industry. All the steam for feed flaking can be provided by the boiler and significant electricity production can be realised. Revenues from avoided fossil fuel use, electricity sales and avoided carbon taxes make manure combustion an attractive economic proposition. Based on the cost estimates generated in this study a 60,000 SCU feedlot could generate a positive cash flow of about $53 million over a 20 year time-frame, based on NPV calculations using a discount rate of 7%.

5. Even the smallest feedlot modelled (10,000 SCU) generates a positive cash flow of $2.8 million over a 20 year time-frame.

6. Gasification is a more mature technology than pyrolysis and thus gasification was used as the second manure thermal process evaluated in this study.

7. Gasification of harvested manure, with char, steam and electricity generation provides a very attractive manure management option for the industry. Revenues from char sales, avoided fossil fuel use, electricity sales and avoided carbon taxes make manure gasification a very attractive economic proposition. Based on the cost estimates generated in this study a 60,000 SCU feedlot could generate a positive cash flow of about $98 million over a 20 year time-frame, based on NPV calculations using a discount rate of 7%. Even the smallest feedlot modelled (10,000 SCU) generates a positive cash flow of $10 million over a 20 year time-frame.

Adoption of combustion or gasification technologies to process harvested manure could, in the next five years, effect significant reductions in waste disposal costs, generate significant amounts of green energy and electricity and in the case of gasification, sequester significant amounts of carbon in the char. To confirm the technical and economic viability of combustion and gasification for manure processing it is recommended that pilot-plant trialling of these technologies be undertaken as soon as is practical.

Glossary

BiG	Black is Green Pty Ltd
BOD	Biochemical oxygen demand
CAL	Covered anaerobic lagoon
CBA	Cost benefit analysis
CD	Contact digester
COD	Chemical oxygen demand
DAF	Dissolved air flotation
FBB	Fluid bed boiler
FBC	Fluid bed combustor
GCV	Gross calorific value
GHG	Greenhouse gas
GJ	Gigajoule
HRT	Hydraulic retention time
K	Potassium
kW	Kilowatt
LNG	Liquefied natural gas
M&E	Mass and energy
MJ	Megajoule
MLSS	Mixed liquor suspended solids
MW	Megawatt
MWh	Megawatt hour
N	Nitrogen
NCV	Net calorific value
NG	Natural gas
NOx	Oxides of nitrogen
NPV	Net present value
OLR	Organic loading rate
O&M	Operating and maintenance
P	Phosphorus
PFD	Process flow diagram
PW	Paunch waste
REC	Renewable energy credit
RIRDC	Rural Industries Research & Development Corporation
SCU	Standard cattle unit
SOx	Oxides of sulphur
SRT	Solids retention time
TDS	Total dissolved solids
TKN	Total kjeldahl nitrogen
TN	Total nitrogen
TP	Total phosphorus
tpd	Tonnes per day
TS	Total solids
TSS	Total suspended solids
VS	Volatile solids
VSS	Volatile suspended solids
UASB	Up-flow anaerobic sludge bed

Contents

1 Background

The disposal of solid and liquid wastes generated during the feeding process is one of the key environmental concerns facing feedlot operators. These wastes have residual amounts of energy and key nutrients, such as nitrogen and phosphorus. Improper management of these wastes can lead to eutrophication of waterways and contribute significantly to the emission of Greenhouse Gases (GHGs). It is likely that feedlots will in the future be required to report their GHG emissions and minimisation of these will become more important in the future. Also, the energy costs incurred by feedlot operators have been steadily increasing and with the prospect of a carbon tax scheme further increasing the retail cost of energy, it is likely that this trend will continue. There has been a significant body of work completed both in Australia and internationally investigating the characteristics of the solid and liquid wastes produced by feedlots. However, much of this information has not been collated and assimilated. This project will collate and analyse this information and use it to model the theoretical efficacy of a number of potential energy recovery technologies that the industry can consider.

2 Project objectives

The overall objective of this project is to undertake an initial desk-top assessment of the feasibility of the various technologies available to feedlots to recover the energy in the liquid and solid wastes they produce. The major individual objectives of the project are listed below.

1. Collect and collate available information on the characteristics of feedlot solid and liquid wastes and develop input design values for the study;

2. Undertake a desktop feasibility study to compare the technologies available to feedlots to recover energy from these solid and liquid wastes, with a particular focus on the following technologies:
    a. Covering existing anaerobic lagoons and using the methane gas generated in a gas fired boiler;
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    d. Directly combusting the solid wastes in a traditional boiler.

3. Provide recommendations to feedlot operators regarding the most cost effective and feasible technology/s available to them to recover energy from their solid and liquid wastes. The contract called for feedlots of 10,000, 25,000 and 60,000 SCUs to be addressed.

3 Methodology

The major steps to be followed in conducting this feasibility study include:

1. Conduct an initial global literature review of the characteristics of feedlot solid and liquid wastes and determine if the level of data already available is sufficient to model the performance of these waste products as feedstock for the technologies of interest. Recommend suitable waste characteristics for this study.

2. If the current data is insufficient, collect sufficient samples from a feedlot operation to ensure that proper modelling can be undertaken.

3. Develop generic process and cost spreadsheets to model the effectiveness of energy production via the following technologies, using feedlot waste products as feedstock:
    a. Covering existing anaerobic lagoons;
    b. Installing a purpose-built anaerobic digester;
    c. Processing the waste materials in a pyrolysis or gasification unit and using some combination of the products (syngas, char and bio-oil) for energy recovery;
    d. Directly combusting the solid waste products in a traditional boiler.

4. Based on the information generated from this study develop recommendations for the feedlot industry regarding the feasibility and effectiveness of the various energy recovery options investigated.

4 Results and discussion

4.1 Waste characteristics literature review

4.1.1 Liquid wastes

There is an abundance of data in the literature on the characteristics of liquid wastes produced by animal feedlots, with most of the data being reported from North America, Europe and Australia. Climatic conditions play a major role on effluent volumes requiring treatment and feeding regimes do impact on effluent quality parameters. As a consequence liquid waste characteristics from feedlot operations vary significantly. A recent MLA funded study[1] conducted by FSA Consulting has however generated a very sound data-base on liquid effluents generated by Australian beef feedlot operations. This study concentrated on feedlots located in each of the five main lot feeding regions of Australia, namely central Queensland, southern Queensland / northern New South Wales, central New South Wales, Riverina and south-western Western Australia. FSA Consulting used the Australian-developed feedlot hydrological model, MEDLI, to predict the annual average volume of effluent requiring treatment from Australian feedlots. Water balances were developed to model the inputs and outputs to the feedlot pad and the effluent holding pond. The inputs and outputs to these are summarised in Figure 4.1. Their modelling was done for feedlots holding 5,000, 10,000 and 25,000 standard cattle units (SCUs) at six locations across Australia. The locations included central and southern Queensland, central and western NSW, central Victoria and south-western WA. This data can thus be regarded as representative of typical Australian conditions. This modelling showed that between 45 and 80% of the inflow to the holding ponds needs to be extracted for treatment, to prevent the holding

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[1] MLA, “Determination of Effluent Volumes and Reliability: Effluent Characterisation of Feedlot Water Requirements”, Milestone 2 Report, MLA Project B.FLT.0348, 22nd October, 2010.

pond from overflowing. The predicted average volume of effluent available for treatment for the three sized feedlots is shown in Table 4.1.

Figure 4.1: Parameters modelled to predict effluent volumes (from citation #1)

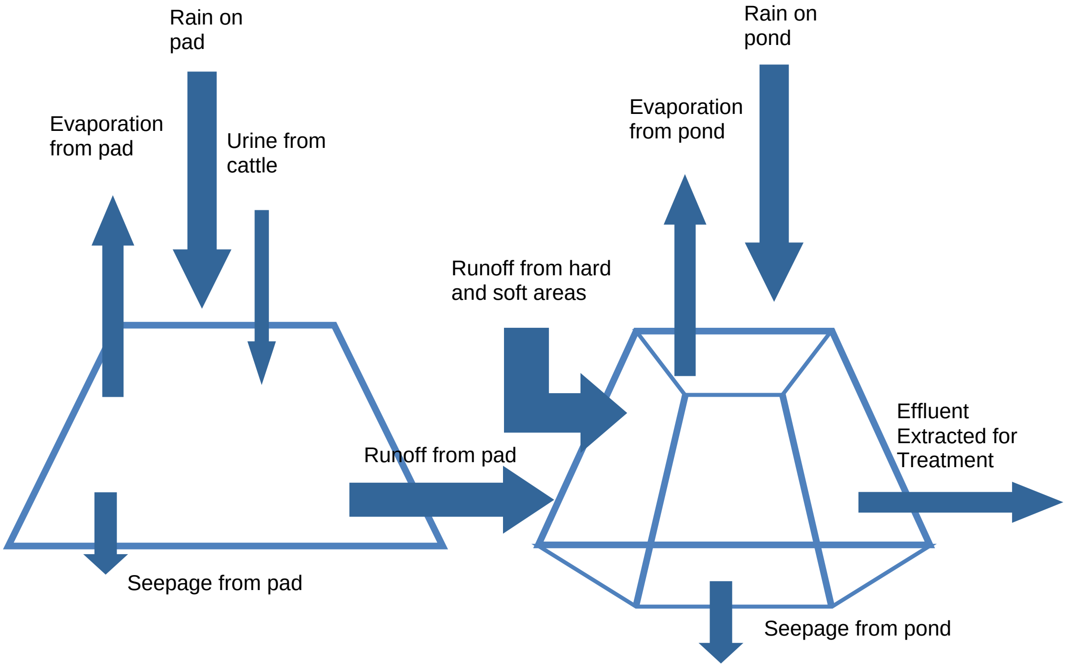

Table 4.1: Predicted feedlot effluent volume requiring treatment

Feedlot size (SCUs)	Effluent volume requiring treatment (kL/d)
5,000	62
10,000	115
25,000	300

This data has been plotted and an algorithm developed to predict the effluent volume which will require treatment from a 60,000 head feedlot. This plot is shown in Table 4.1. The data is linear, so prediction of the effluent volume for a 60,000 head feedlot can be made with a great deal of certainty.

As part of that MLA study FSA Consulting also conducted a global literature review on effluent quality data, which was amalgamated with their extensive in-house data-base on effluent quality from Australian feedlots. The information relevant to this study, obtained from the holding ponds of 18 feedlots in NSW and Queensland, is summarised in Table 4.2. All the data, with the exception of pH is reported in mg/L. It should also be noted that the COD data has been obtained from a Queensland DPI publication[2]. Furthermore it should be noted that the reported SS data

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[2] Queensland DPI, “Designing Better Feedlots”, Conference Publication Number QC 94002, 1994. Paper by Watts et. al.

did not appear to be consistent with the VS data and hence in Table 4.2 the TSS value reported is the difference between the average TS and TDS values.

Figure 4.2: Feedlot effluent volume graph

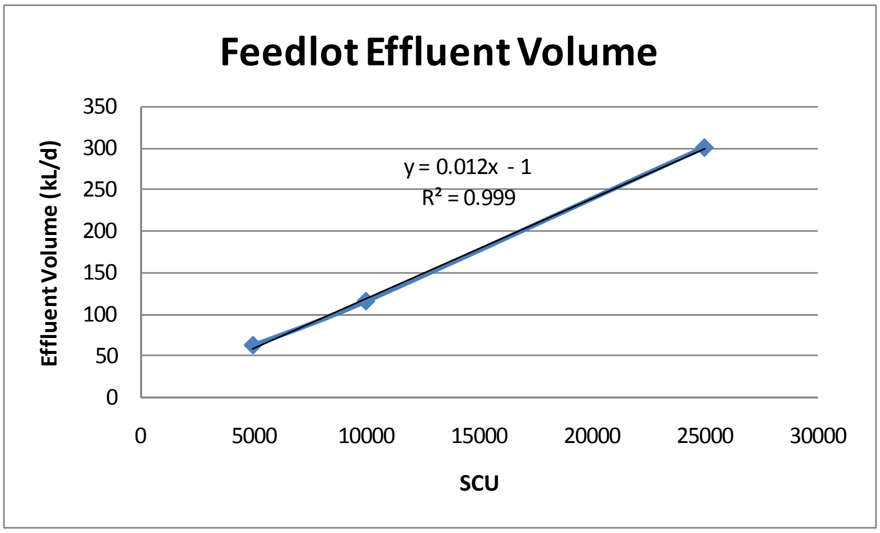

Table 4.2: Australian Feedlot Effluent Quality Data

Parameter	No. of samples	Minimum	Average	Maximum
COD		4,862	9,579	16,806
TN	21	9	156	471
TKN	57	6	197	656
Ammonia-N	49	0.1	86	383
Nitrate-N	21	0	21	35
TP	60	1	48	111
K	52	18	1,217	6,390
TS	4	7,242	13,345	19,030
TDS	35	812	5,457	18,644
TSS			7,888*	
VSS	4	2,732	4,631	5,620
Alkalinity	37	168	2,080	8,920
Sulphate	32	4	77	378
Mg	53	2	120	805
Zn	2	0.05	0.07	0.08
pH	58	6.9	8.0	9.6

* Note: The TSS value is calculated as the difference between the TS and TDS value.

Also, in the source material nitrate data is expressed as nitrate whereas in Table 4.2 this has been converted to nitrate-nitrogen. Finally it is noted that the average and maximum TN values reported in Table 4.2 are not consistent with the average and maximum TKN and nitrate-N values reported. The TN values should be equal to the sum of the TKN and nitrate-N values.

4.1.2 Solid Wastes

Manure, or the solid waste generated by feedlot operations also varies greatly in quantity and quality, depending on a number of factors including feeding regimes, whether or not feed flaking is practised and climatic conditions. The quality of the manure is also dependent on how old it is and the physical nature of the feedlot surface. The amount of feedlot surface material (normally gravel in Australia) that is included in harvested manure is also highly dependent on harvesting techniques. Typically manure is harvested from the feedlot surface every ten to twelve weeks and stockpiled on site prior to disposal or reuse.

A significant amount of data on manure characteristics from beef feedlots is available from literature published in North America and Australia. The Biological Systems Engineering department at the University of Nebraska in the US has generated very useful information on manure characteristics. Their most recently published data[3] reports results from six feedlots in Nebraska, housing from 5,000 to 20,000 head of cattle. This study reports that as-generated manure has a TS of between 10 and 20% and a VS of 80%, whereas harvested manure has a TS of 74% and a VS of only 34%. The low VS of the harvested manure is attributed to VS destruction and the significant amount of soil that is incorporated during the harvesting process. Typical harvested manure analysis, from the summer period, is shown in Table 4.3.

Table 4.3: Typical Harvested Manure Characteristics (Nebraska)

Parameter	Units	Average Value
TS	%	76.1
VS	% of TS	30.4
Ash	% of TS	69.6
TN	% of TS	1.35
TP	% of TS	0.64
K	% of TS	1.52
Sulphur	% of TS	0.46
Mass	kg TS/hd/d	5.3
Mass	kg VS/hd/d	1.5

The Texas Agricultural Experimental Station in Amarillo, Texas recently reported harvested manure characteristics generated from both fly-ash paved and un-paved feedlots in Texas[4]. A summary of this data is shown in Table 4.4, which are the average values obtained from 12 paved and 6 un-paved feedlots.

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[3] University of Nebraska, Biological Systems Engineering Papers and Publications, “Characteristics of Manure Harvested from Beef Cattle Feedlots”, by Kissinger et al, 2007.

[4] American Society of Agriculture & Biological Engineers, “Combustion-Fuel Properties of Manure or Compost from Paved vs. Un-paved Cattle Feedlots”, paper No. 064143 by Sweeten et al, presented at the 2006 ASABE Annual International Meeting, Portland, Oregon, July, 2006.

Table 4.4: Harvested Manure Characteristics from Paved and Unpaved Feedlots in Texas

Parameter	Units	Un-paved Feedlot	Fly-ash paved Feedlot
TS	%	80.19	79.73
VS	% of TS	41.2	79.8
Ash	% of TS	58.8	20.2
TN	% of TS	1.94	3.11
P (as P_2O_5)	% of TS	1.61	2.59
Carbon	% of TS	21.69	43.09
Sulphur	% of TS	0.42	0.67
GCV	GJ/dry tonne	7.86	16.8

This data very clearly shows that manure harvested from paved feedlots contains much higher levels of organic material, which is due to the lower levels of soil incorporated into the harvested manure.

RIRDC has recently published a comprehensive report which provides very useful information on Australian beef feedlot manure characteristics[5]. The average, minimum and maximum characteristics of harvested manure from Australian beef feedlots are shown in Table 4.5.

Table 4.5: Characteristics of Harvested Manure from Australian Feedlots

Parameter	Units	Minimum Value	Average Value	Maximum Value
TS	%	53.7	72.97	92
VS	% of TS	55	67.6	75.9
Ash	% of TS	24.1	32.4	45
TN	% of TS	1	2.18	3
TP	% of TS	0.4	0.8	1.3
K	% of TS	1.5	2.32	4
Na	% of TS	0.3	0.61	1.3
Cl	% of TS	0.7	1.35	2.3

Comparing the data in Tables 4.4 and 4.5, shows that the average characteristics of Australian harvested manure is very similar to that reported as generated from paved feedlots in America. This is most likely due to the fact that most new Australian feedlots have compacted pen surfaces often covered with crushed gravel. In addition, when manure is harvested the aim is to not disturb the compacted surface and leave a thin layer of manure on the surface. Thus most harvested manure in Australia now has virtually no foreign material included and hence the higher organic contents. One exception may be feedlots in southern Australia where the pads do breakdown during the prolonged wet winter periods.

The RIRDC report also indicates that the quantity of harvested manure from Australian beef feedlots averages 900 kg TS/hd/a or 2.5 kg TS/hd/d. This is about half the value reported from US feedlots (see Table 4.3).

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[5] RIRDC, “Quantification of Feedlot Manure Output for Beef-Bal Model Upgrade”, Project PRJ-004377, September 2010.

4.2 Design waste characteristics

4.2.1 Liquid wastes

The design liquid effluent volumes and characteristics used for this study are based almost exclusively on the average values reported by MLA in footnote 1. A summary of the relevant design effluent characteristics, as they apply to this study, are summarised in Table 4.6.

Table 4.6: Design effluent characteristics

Parameter	Units	Design Value
COD	mg/L	9,579
BOD	mg/L	5,747
TS	mg/L	13,345
TDS	mg/L	5,457
TSS	mg/L	7,888
VSS	mg/L	4,631
TN	mg/L	218
TKN	mg/L	197
Ammonia-N	mg/L	86
Nitrate-N	mg/L	21
TP	mg/L	48
Potassium	mg/L	1,217
Magnesium	mg/L	120
SO_4-S	mg/L	26
Alkalinity	mg/L	2,080
pH		8
10,000 SCU flow	kL/d	115
25,000 SCU flow	kL/d	300
60,000 SCU flow	kL/d	719

It should be noted that the BOD value reported in Table 4.6 is based on the standard wastewater assumption that the BOD/COD ratio is 0.6. This data is deemed adequate for the design of aqueous waste treatment systems and thus there was no need to obtain additional effluent quality data.

It must be re-emphasised that the effluent characteristics used for the design of anaerobic systems in this study, as shown in Table 4.6, are the average characteristics of the **effluent from existing feedlot holding ponds**. This is not “as-generated” liquid waste and thus will have lower contaminant concentrations than “fresh” effluent. The data in Table 4.6 cannot in any way be construed to represent the properties of what is often called “liquid manure”. The effluent from holding ponds has much lower COD, BOD and TSS values than “liquid manure”.

4.2.2 Solid wastes

The design solid waste characteristics used for this study are based almost entirely on the average characteristics for harvested manure from Australian feedlots, as reported in Table 4.5. The sulphur and carbon data, as reported in Table 4.4, for the paved feedlots in Texas, USA has been applied to the Australian data, pro-rated based on relative VS contents. A summary of the relevant design harvested manure characteristics, as they apply to this study, are summarised in Table 4.7.

Table 4.7: Design harvested manure characteristics

Parameter	Units	Design Value
TS	%	73
VS	% of TS	67.6
Ash	% of TS	32.4
Carbon	% of TS	41
TN	% of TS	2.18
TP	% of TS	0.8
Total Sulphur	% of TS	0.57
Potassium (K)	% of TS	2.32
Sodium (Na)	% of TS	0.61
Chlorides (Cl)	% of TS	1.35
GCV	GJ/dry tonne	16.1
NCV	GJ/dry tonne	15.1
Dry mass	kg/hd/d	2.5

The Gross and Net Calorific Values (GCV and NCV) are based on well-proven industry correlations of waste VS content and calorific values. The data in Table 4.7 is deemed adequate for the design of solid waste thermal treatment systems and thus there was no need to obtain additional solid waste quality data. It should also be noted that the harvested manure is dry enough for direct processing in combustors or gasifier's.

4.3 Process design of the treatment/energy recovery options

This project was required to develop process designs and costs for two effluent treatment and energy recovery technologies, namely Covered Anaerobic Lagoons and dedicated anaerobic digesters and two solid waste treatment and energy recovery technologies, namely pyrolysis or gasification and combustion. The process designs for these treatment and energy recovery options is summarised below.

It must be emphasised that for the effluent treatment schemes the option of covering the existing holding ponds, to create a CAL, was not considered since the sizing/dimensions of these holding ponds is not known and hence their suitability to be upgraded to form enhanced CALs is unknown. Consequently the CAL option involves the construction of a new properly sized lagoon.

4.3.1 Covered Anaerobic Lagoons (CALs)

There is not a lot of data in the literature on the basis of design for CALs treating effluent from cattle feedlot holding ponds. What little data is available is generally based on the treatment of "liquid manure" with much higher suspended solids and BOD values than that for holding pond effluents. In addition there is a fair amount of data in Australia on the use of CALs for the treatment of abattoir wastewater. A recent literature review on the use of CALs for treatment of effluent from animal husbandry has been completed by MLA[6]. A pilot plant demonstration on the use of CALs to treat abattoir wastewater was also conducted by MLA[7]. RIRDC also recently conducted a study to assess methane capture alternatives for the intensive livestock industry in

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[6] MLA, "Using Covered Anaerobic Ponds to Treat Abattoir Wastewater, Reducing Greenhouse Gases and Generating Bioenergy", Project A.ENV.0107 Milestone 1 Report, December 2010.

[7] MLA, "Treatment of Abattoir Wastewater using a Covered Anaerobic Lagoon", Project RPDA.315, January 1998.

Australia[8]. Based on data in these reports and typical design criteria for the treatment of high strength industrial wastewaters using anaerobic processes, the process design parameters used for the CAL option are shown in Table 4.8.

Table 4.8: CAL process design parameters

Parameter	Units	Process Design Value
Minimum CAL Temp.	^0C	20
Organic Loading Rate	kg COD/m^3/d	0.6
COD Removal	%	70
BOD Removal	%	80
TSS Removal	%	60
Biogas Production	m^3/kg BOD rem.	0.8
Biogas Energy	MJ/m^3	22
Sludge Yield	kg/kg BOD rem.	0.08
CAL depth	m	5
CAL Wall slope	Degrees	30
CAL Length/width ratio		2:1

It should be noted that it is assumed that the CALs are of the "enhanced" design type. That is they are fitted with baffles and sludge recirculation, to improve treatment performance. As shown in Table 4.8 it has been assumed that the minimum temperature in the CAL is 20 ^0C, which is deemed to be a reasonable assumption for most Australian feedlots. In addition the design of the CAL is based on the assumption that it is 5 m deep, that the length/width ratio is 2:1 and the wall slope is 30 degrees. Finally, the choice of an OLR of 0.6 kg COD/m^3/d is believed to be conservative for wastewater of the characteristics shown in Table 4.6. Since most of the biodegradable material is likely soluble or very small particles, biogas generation rates are designed on BOD removal and not VS destruction, as is normal for sludge and manure digesters.

Based on the design OLR of 0.6 kg COD/m3/d and the wastewater characteristics shown in Table 4.6, the HRT of the CAL is calculated to be 16 days, which is deemed to be conservative. Based on the design criteria in Table 4.8 the CAL dimensions and volumes, for the three design cases, are shown in Table 4.9.

Table 4.9 CAL Dimensions

CAL Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Length	m	39	57.6	84.4
Width	m	20.8	28.2	39
Surface Area	m^2	810	1,626	3,289
Volume	m^3	1,836	4,790	11,479

The area requirements for appropriately designed CALs are significant, varying from 810 m^2 for a 10,000 SCU feedlot and increasing to 3,289 m^2 for a 60,000 SCU feedlot. In the costings it is assumed that these land requirements are available at the feedlots.

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[8] RIRDC, "Assessment of Methane Capture and Use from the Intensive Livestock Industry", Final Report, September 2007.

The process outputs from CALs treating wastewater from feedlot holding ponds, based on the wastewater characteristics and process design parameters as outlined in Tables 4.6 and 4.8 is summarised in Table 4.10.

Table 4.10: CAL process outputs

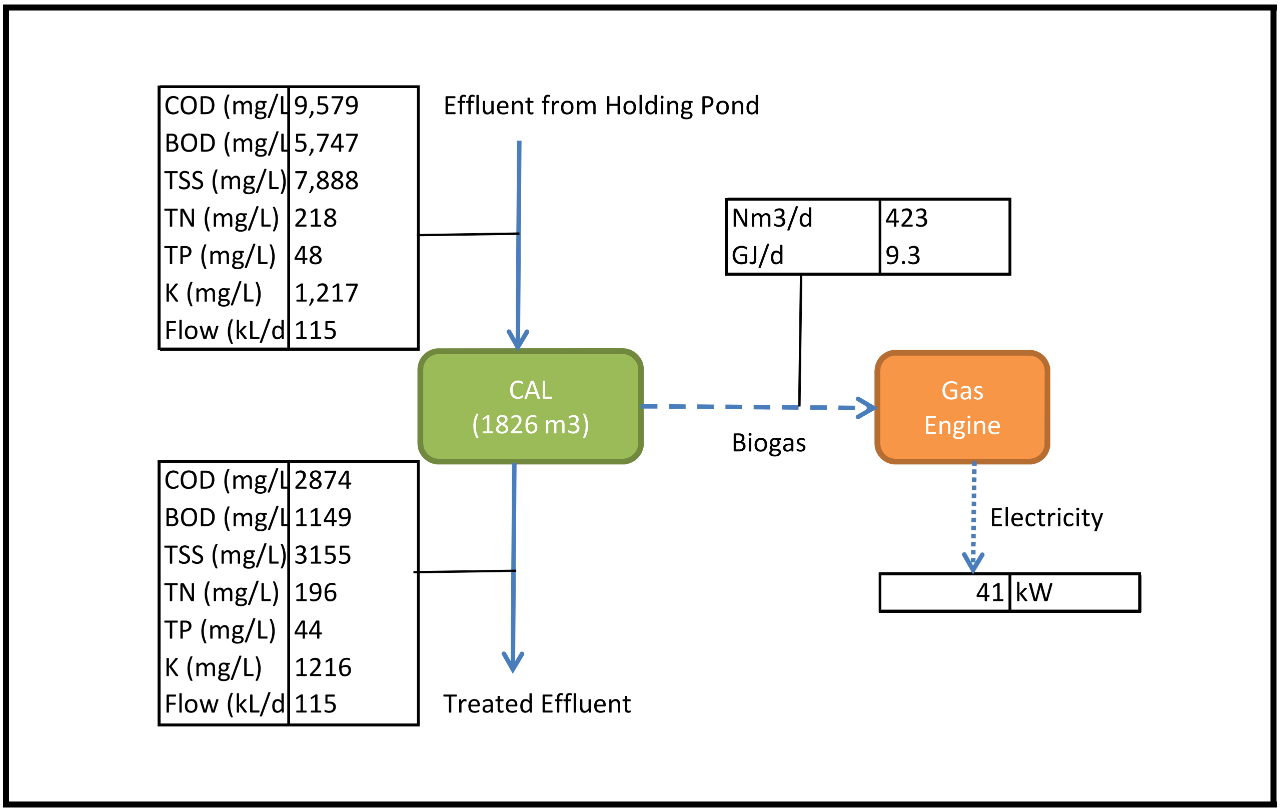
CAL Output Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
COD	mg/L	2,847	2,847	2,847
BOD	mg/L	1,149	1,149	1,149
TSS	mg/L	3,155	3,155	3,155
TN	mg/L	196	196	196
TP	mg/L	44	44	44
K	mg/L	1,216	1,216	1,216
Biogas Quantity	m^3/d	435	1,104	2,645
Biogas Energy	GJ/d	9.3	24.3	58.2
Electricity Potential	kW	41	107	256

It must be noted that CAL effluent TN, TP and K values were calculated based on the assumption that the sludge generated has N, P and K concentrations of 6, 1 and 0.2% respectively. The predicted effluent quality from CALs treating feedlot holding pond effluent is still not very good and due to the high nutrient loads, would not likely be acceptable for irrigation of pastures etc. The levels of potassium in the treated effluent are regarded as being very high. It should be noted that due to the high levels of ammonia, phosphate and magnesium in the wastewater (see Table 4.6) that struvite (magnesium ammonium phosphate) precipitation is likely to occur in the CAL, resulting in reduced levels of these parameters in the treated effluent. Struvite precipitation is a common occurrence in anaerobic digestion systems and can cause severe problems in engineered digestion systems by precipitating in pipelines, causing blockages. This could occur in enhanced CAL systems, particularly in the sludge recirculation piping.

As identified in Table 4.10 it is estimated that between 9.3 and 58.2 GJ/d of energy is recoverable from the biogas for the three design cases. If this biogas were combusted in gas engines between 41 and 256 kW of electricity could be generated by the three design cases. Although the electricity potential is low, recent advances in gas engines, particularly those supplied from China, make power generation a possible scenario. This will be explored in the economic assessment of energy recovery section of this report.

A simple CAL process flow diagram (PFD) for a 10,000 SCU feedlot is shown in Figure 4.3.

Figure 4.3: CAL PFD for a 10,000 SCU feedlot



4.3.2 Contact Digester

The contract called for an engineered anaerobic digestion process to be included in the assessment of technologies that could be considered for energy recovery from feedlot effluents. There are a number of engineered anaerobic processes that could be considered and some of these are listed below:

- Complete-mix mesophilic anaerobic digesters as used for sludge digestion,
- Contact anaerobic digesters with sludge recycle,
- Plug-flow mesophilic anaerobic digesters,
- UASBs,
- Hybrid anaerobic reactors,
- Fixed-film anaerobic reactors.

A recent RIRDC study reviewed anaerobic reactor systems suitable for the Australian intensive livestock industry[8]. This review by GHD Pty Ltd recommended that the following technologies were suitable:

- Complete-mix mesophilic anaerobic digesters as used for sludge digestion,
- Contact anaerobic digesters with sludge recycle,
- Plug-flow mesophilic anaerobic digesters.

Due to the relatively low TSS and VSS levels, compared to COD in the effluent from the holding ponds, it is recommended that contact anaerobic digesters be considered as the alternate liquid waste treatment scheme. Plug-flow reactors are more suited to high TSS “manure” streams.

The process design parameters used for the Contact Digester option are shown in Table 4.11.

Table 4.11: Contact digester process design parameters

Parameter	Units	Process Design Value
Digester Temperature	^{0}C	37
HRT	days	10
Equivalent OLR	kg COD/m^3/d	1
SRT	days	60
COD Removal	%	80
BOD Removal	%	90
VS Destruction	%	50
Biogas Production	m^3/kg BOD rem.	0.8
Biogas Energy	MJ/m^3	22
Sludge Yield	kg/kg BOD rem.	0.08

The contact digester is operated at mesophilic conditions (37 ^{0}C) to enhance treatment performance. This temperature is achieved using a heat exchanger to heat the holding pond effluent, using waste heat from the gas engine. There is more than sufficient energy in the engine exhaust for heating the incoming wastewater. The digester is operated at a HRT of 10 days, which is equivalent to an OLR of 1 kg COD/m^3/d. In addition the effluent from the digester is thickened in a thickener with sludge recycle to maintain the digester at a TSS of about 25,000 mg/L. A simplified mass and energy balance for a 10,000 SCU contact digester system is shown in Figure 4.4.

This Mass and Energy (M&E) balance shows that 25 m^3/d of sludge is returned from the thickener to the digester and excess sludge is wasted daily. Based on operating the digester at a MLSS of 25,000 mg/L, and with the design wasting rate, the SRT of the system is 60 days.

For design and costing purposes it is assumed that the contact digesters have an active depth of 8 metres. Based on this, the sizing of the digesters is shown in Table 4.12. Due to a higher reactor depth and the significant reduction in HRT, the footprint and volumes of the contact digesters is significantly lower than the CAL options.

The process outputs from the Contact Digesters treating holding pond effluent from 10,000, 25,000 and 60,000 SCU feedlots is shown in Table 4.13. The effluent quality is much better than that generated using CALs, particularly with respect to COD, BOD and TSS. However, effluent nutrient values (N, P, K) are essentially the same as those generated by CAL systems. As per the comments in the CAL design section of this report, precipitation of struvite is very likely which could lead to problems with pipe blockages in the system, particularly the sludge recirculation lines.

These contact digester designs are based on continual withdrawal of excess sludge from the systems, on a daily basis. It is estimated that between 13.5 and 85 kL/d of excess sludge is generated, that will require disposal.

The data in Table 4.13 estimates that between 10.5 and 65.5 GJ/d of energy is recoverable from the biogas for the three design cases. If this biogas were combusted in gas engines between 46 and 288 kW of electricity could be generated by the three design cases. Although the electricity potential is low, recent advances in gas engines, particularly those supplied from China, make power generation a possible scenario. This will be explored in the economic assessment of energy recovery section of this report.

Figure 4.4: Mass and Energy balance for 10,000 SCU contact digester system

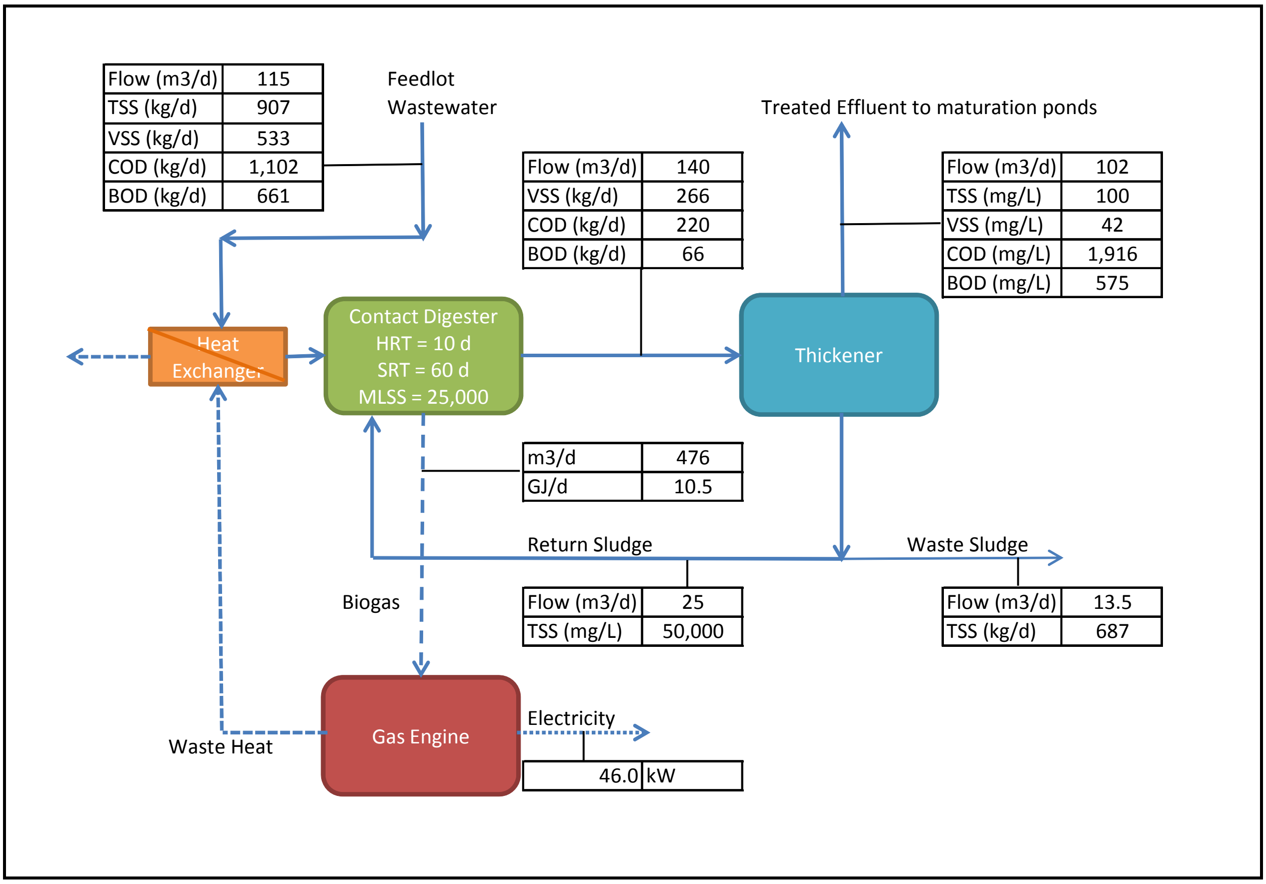


Table 4.12: Contact digester sizing details

Contact digester Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Active depth	m	8	8	8
Total volume	m^3	1,150	3,000	7,190
Digester diameter	m	13.5	15.5	17
No. digesters		1	2	4

Table 4.13: Contact digester process outputs

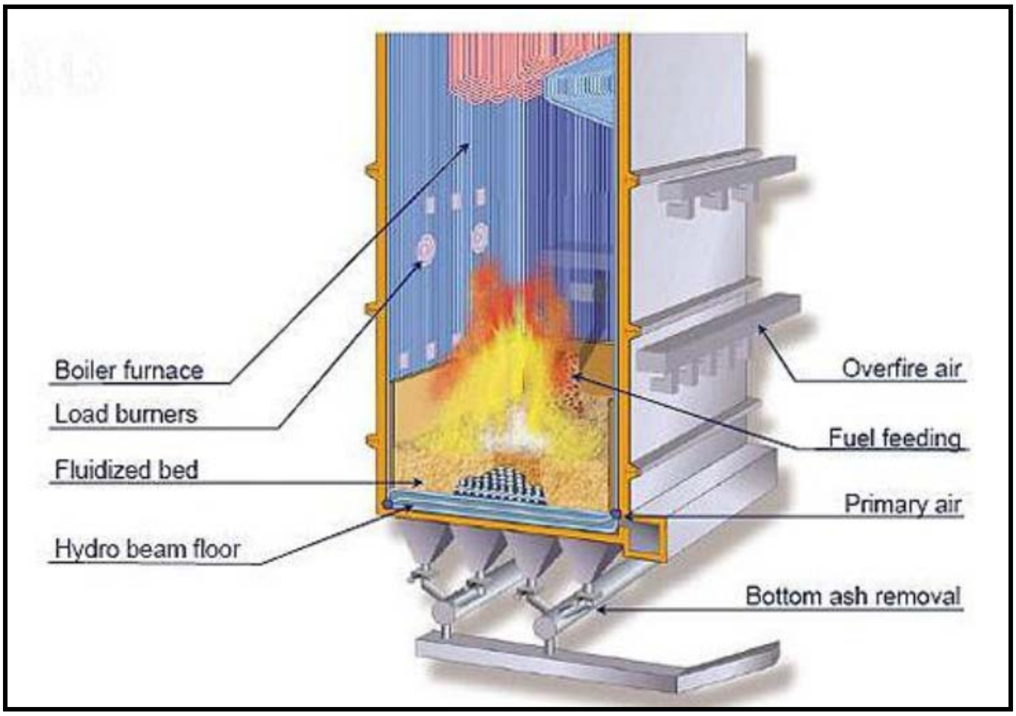
Contact Digester Output Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Treated effluent vol.	kL/d	102	264	634
COD	mg/L	1,916	1,916	1,916
BOD	mg/L	575	575	575
TSS	mg/L	100	100	100
TN	mg/L	193	193	193
TP	mg/L	44	44	44
K	mg/L	1,216	1,216	1,216
Waste sludge vol.	kL/d	13.5	36	85
Biogas Quantity	m^3/d	476	1,241	2,975
Biogas Energy	GJ/d	10.5	27.3	65.5
Electricity Potential	kW	46	120	288

4.3.3 Manure combustion

While there is not a lot of data in the literature on the combustion of harvested manure it must be noted, that with the exception of higher potassium and chloride levels, the characteristics of harvested manure, as shown in Table 4.7, is very similar to that of sewage sludge, for which there is a wealth of combustion information in the open literature. It is therefore considered that combustion is a well proven technology for manure processing, with the exception that the high potassium and chloride levels MAY cause problems with ash fusion and melting in the combustor. Potassium and chlorides are well known flux agents, which depress the melting point of solids. The US data on combustion of manures (see reference in footnote 4) with properties similar to those shown in Table 4.7, indicates that ash generated from manure combustion does have moderate levels of potassium (K_2O of 12.7%). Thus ash fusion/melting may very well be a problem. This would be best overcome by use of fluid-bed combustors (FBCs) which operate at very uniform temperatures without “hot-spots” which could cause ash melting. Thus for this desktop study it is assumed that combustion of the manure takes place in fluid beds.

FBCs are used extensively to burn waste materials including manures, sludges, wood wastes and other organic residues. A typical schematic of a FBC is shown in Figure 4.5. Since combustion of the waste takes place within a bed of fluidised sand the consistency or heterogenicity of the waste has little or no impact on combustion efficiency. It is this attribute that makes FBCs ideal for the combustion of organic wastes such as manure In addition very stable bed temperatures are maintained with very high combustion efficiencies being achieved.

Figure 4.5: Schematic of a FBC



The process design parameters for the manure FBC are shown in Table 4.14.

Table 4.14 FBC process design parameters

Parameter	Units	Process Design Value
FBC Temperature	^{0}C	800
Gas Retention Time	seconds	2
Boiler efficiency	%	70
Bottom ash	%	70
Fly ash	%	30
Steam Turbine effy.	%	25

The FBC is designed to operate under the minimum operating conditions specified in the European Union Waste Incineration Directive (WID)[9]. That is a minimum bed temperature of 800 ^{0}C and a minimum Gas Retention Time of 2 seconds at a minimum temperature of 800 ^{0}C. These conditions are required to ensure the complete thermal destruction of solid wastes, including manures. Standard industry boiler and steam turbine efficiencies are used in these combustion process designs.

MLA indicated that the best use of the energy generated from the processing of wastewater or solid wastes would be to provide the steam for feed flaking operations at the feedlots. Since there was not enough energy available in the wastewater treatment systems to provide the steam for flaking operations, the solid waste thermal systems are designed to provide this

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[9] European Parliament, "Directive 2000/76 on the incineration of waste", 28th December, 2000.

energy. A recent MLA report[10] has indicated that the average energy required for feed flaking is 120 MJ/head of cattle/month. Based on this data, the daily energy required for feed flaking at 10,000, 25,000 and 60,000 head feedlots is shown in Table 4.15. This table also shows the inherent energy in the steam required for flaking.

Table 4.15: Feed flaking energy requirements

Feedlot size (SCU)	Thermal energy for flaking (GJ/d)	Inherent steam energy for flaking (GJ/d)
10,000	40	28
25,000	100	70
60,000	240	168

This data indicates that a 10,000 SCU feedlot uses 40 GJ/d of energy for feed flaking. Referring to Tables 4.10 and 4.13 it is evident that treating effluent from a 10,000 SCU feedlot in CALs or contact digesters only generates about 10 GJ/d of energy, or 25% of that required for feed flaking. Thus the energy for feed flaking is derived from the solid waste (manure) energy recovery processes. Based on the process design parameters shown in Table 4.14 and the feed flaking energy requirements shown in Table 4.15, a simplified Process Flow Diagram and Mass and Energy balance for a 60,000 SCU manure combustor is shown in Figure 4.6.

The fluid-bed boiler (FBB) combusts 150 dry tpd of manure and generates 1586 GJ/d in thermal energy as steam for use in the feed flakers and steam turbines for electricity production. Flue gas from the FBB is first cleaned in a cyclone to remove fly ash and then in scrubbers to remove contaminants such as SOx, NOx and possibly dioxins. This sized FBB is designed to provide all the steam required for feed flaking and also generate 4.1 MW of electricity.

The process design inputs and outputs from the FBCs treating harvested manure from 10,000, 25,000 and 60,000 SCU feedlots are shown in Table 4.16. As indicated, compared to the effluent treatment systems, there is a very significant energy recovery potential from the combustion of stockpiled manure at feedlots. Even for relatively small feedlots of 25,000 head it is possible to generate 680 kW of electricity and provide all the energy for feed flaking.

The FBCs do produce bottom and fly ash which will require disposal. The total quantity of ash generated varies from 8.1 tpd for the 10,000 SCU feedlot increasing to 48.6 tpd for the 60,000 SCU feedlot. Since the ash is benign and does contain valuable nutrients (P&K) it is assumed it is disposed on the feedlot property. Such combustion facilities will require regulatory approval and the required gaseous emission limits might be stringent.

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[10] MLA, “Quantifying the water and energy usage of individual activities within Australian feedlots”, Part B report, Project No. B.FLT.0350, July, 2009.

Figure 4.6: M&E balance for a 60,000 SCU manure combustor

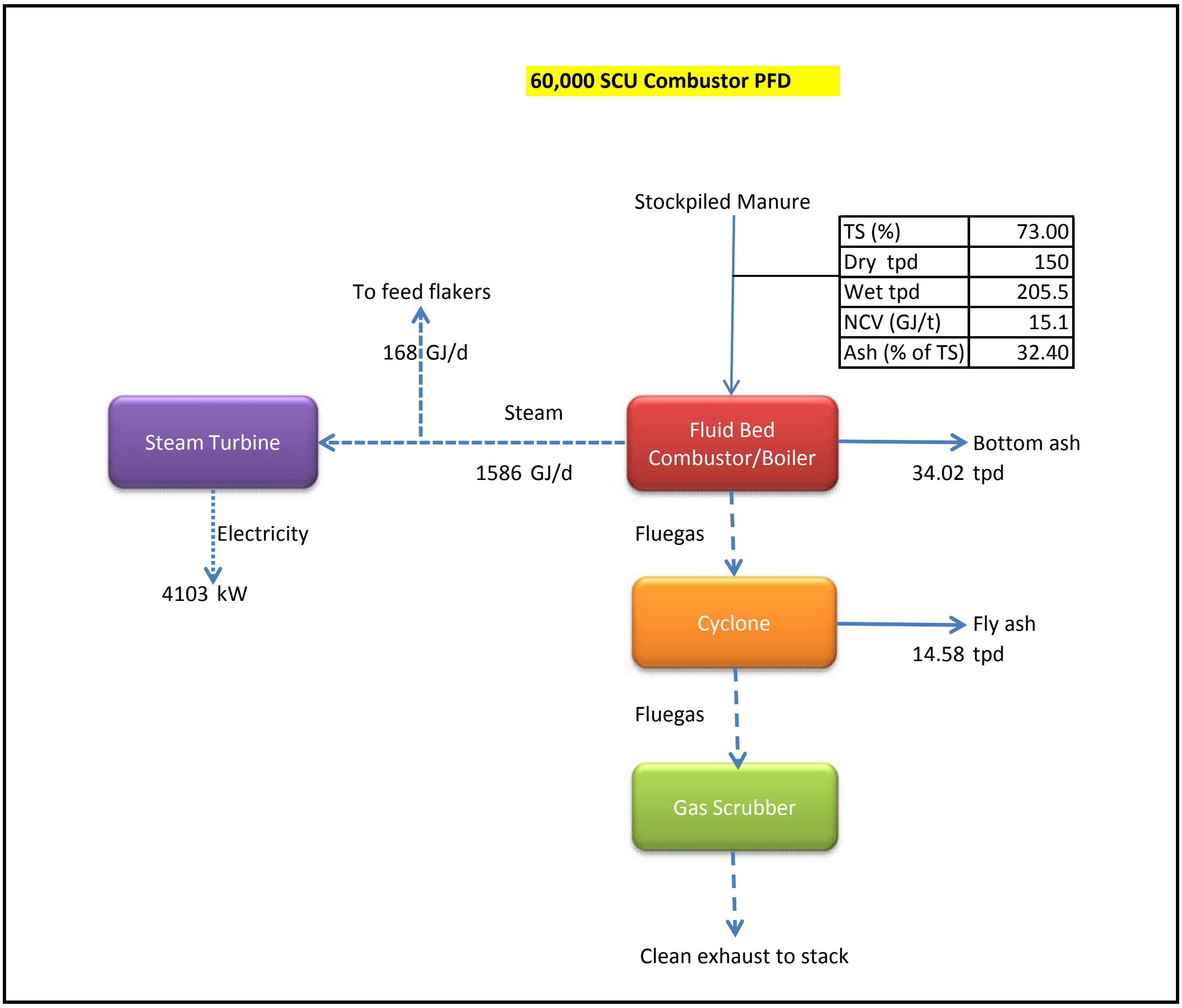

Table 4.16: Process inputs and outputs from manure combustion

Combustor Input/ Output Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Dry manure processed.	tpd	25	62.5	150
Thermal input	GJ/h	15.7	39.3	94.4
Steam to feed flakers	GJ/d	28	70	168
Bottom ash generated	tpd	5.67	14.18	34.02
Fly ash generated	tpd	2.43	6.08	14.58
Electricity generated	MW	0.68	1.71	4.1

4.3.4 Manure gasification

Since gasification is a much more mature technology than pyrolysis for the processing of solid waste materials, this technology is chosen to process the harvested manure from feedlots. MLA has recently completed a pilot-plant scale assessment of pyrolysis and gasification for the processing of dried Paunch Waste (PW) and Dissolved Air Flotation (DAF) sludge from abattoirs[11]. This study piloted the Black is Green Pty Ltd (BiG) gasification process, an Australian developed gasification of waste process. BiG is one of a number of Australian companies offering waste gasification technology and is one of the most mature companies, with commercial facilities currently under construction. Based on the very successful gasification trial on PW and DAF sludge, the BiGchar process has been selected for the gasification of the stockpiled manure.

The BiGchar gasification process is a conventional air-gasification technology, where a small proportion of the waste is combusted to provide the energy to raise the waste temperature to about 600 ^{0}C. The gasifier is a vertical tube with multiple hearths and rabble arms mounted on the central shaft which rotates to move the material from hearth to hearth. As the material moves downward from the top of the gasifier its temperature increases and pyrolysis and gasification occurs. The air required for limited combustion to raise the feedstock to about 600 ^{0}C is provided by a natural updraft ventilation system. The products of gasification are a syngas and a solid char material. The char discharges from the bottom of the vessel where there is essentially no oxygen. The char is sprayed with water as it exits the reactor to prevent combustion. The syngas exits from the large stack at the top of the reactor that creates the draft in the reactor. The ventilation rate is controlled by dampers on the side of the reactor. A picture of the BiGchar system is shown in Figure 4.7. Unlike conventional combustion, the conditions in the gasifier are reducing and at the lower operating temperature of about 600 ^{0}C there is unlikely to be any ash fusion of melting issues.

Figure 4.7: Photo of a BiGchar gasifier

The gasifier operating conditions and process design criteria are the best estimates of BiG, for manure of the characteristics shown in Table 4.7. These process design parameters are shown in Table 4.17.

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[11] MLA, “Pilot testing pyrolysis systems and review of solid waste use in boilers”, Project A.ENV.0111, April, 2011.

Table 4.17: Gasification process design parameters

Parameter	Units	Process Design Value
Gasifier Temperature	^{0}C	~600
Syngas energy	% of feed	55
Char energy	% of feed	25
Char yield	% of dry feed	45
Carbon to char	%	30
Nitrogen to char	%	40
Phosphorus to char	%	100
Potassium to char	%	100
Syngas to steam effy.	%	70
Steam Turbine effy.	%	15 to 25

Based on the process design parameters shown in Table 4.17 and the feed flaking energy requirements shown in Table 4.15, a simplified Process Flow Diagram and Mass and Energy balance for a 60,000 SCU manure gasifier is shown in Figure 4.8.

As indicated in Figure 4.8, 150 dry tpd of manure is gasified and generates 67.5 tpd of char for reuse and 1246 GJ/d of thermal energy in the syngas stream. The syngas is combusted in a boiler to generate steam for use in the feed flakers and steam turbines for electricity production. The char has significant quantities of nitrogen, phosphorus and potassium and thus should make an excellent soil amendment product, with high value. It must however be noted that the predicted carbon content of the char is 27%, which is below the 40% considered by the industry to be required to be classified as char. Thus there is some minor risk regarding the predicted sale price of $250/tonne for the char. This carbon deficiency is however offset by the very high nutrient contents of the char. A significant amount of carbon is sequestered in the char, which in light of the planned carbon tax of $23/t, might prove an additional financial benefit. This sized gasifier is designed to provide all the steam required for feed flaking and also generate 2.04 MW of electricity. This is significantly lower than the combustion option due to the energy captured in the char and the small portion of feedstock combusted to raise the material temperature to 600 ^{0}C. Flue gas from the combustor/boiler will require cleaning to remove particulates and other contaminants such as SOx and possibly NOx. These gasification facilities will require regulatory approval and the required gaseous emission limits might be stringent.

The process design inputs and outputs from the gasifier’s treating harvested manure from 10,000, 25,000 and 60,000 SCU feedlots are shown in Table 4.18. As indicated, compared to the effluent treatment systems, there is a very significant energy recovery potential from the gasification of stockpiled manure at feedlots, although not as much as for the combustion option. This is however offset by the generation and sale of char.

Figure 4.8: M&E balance for a 60,000 SCU manure gasifier

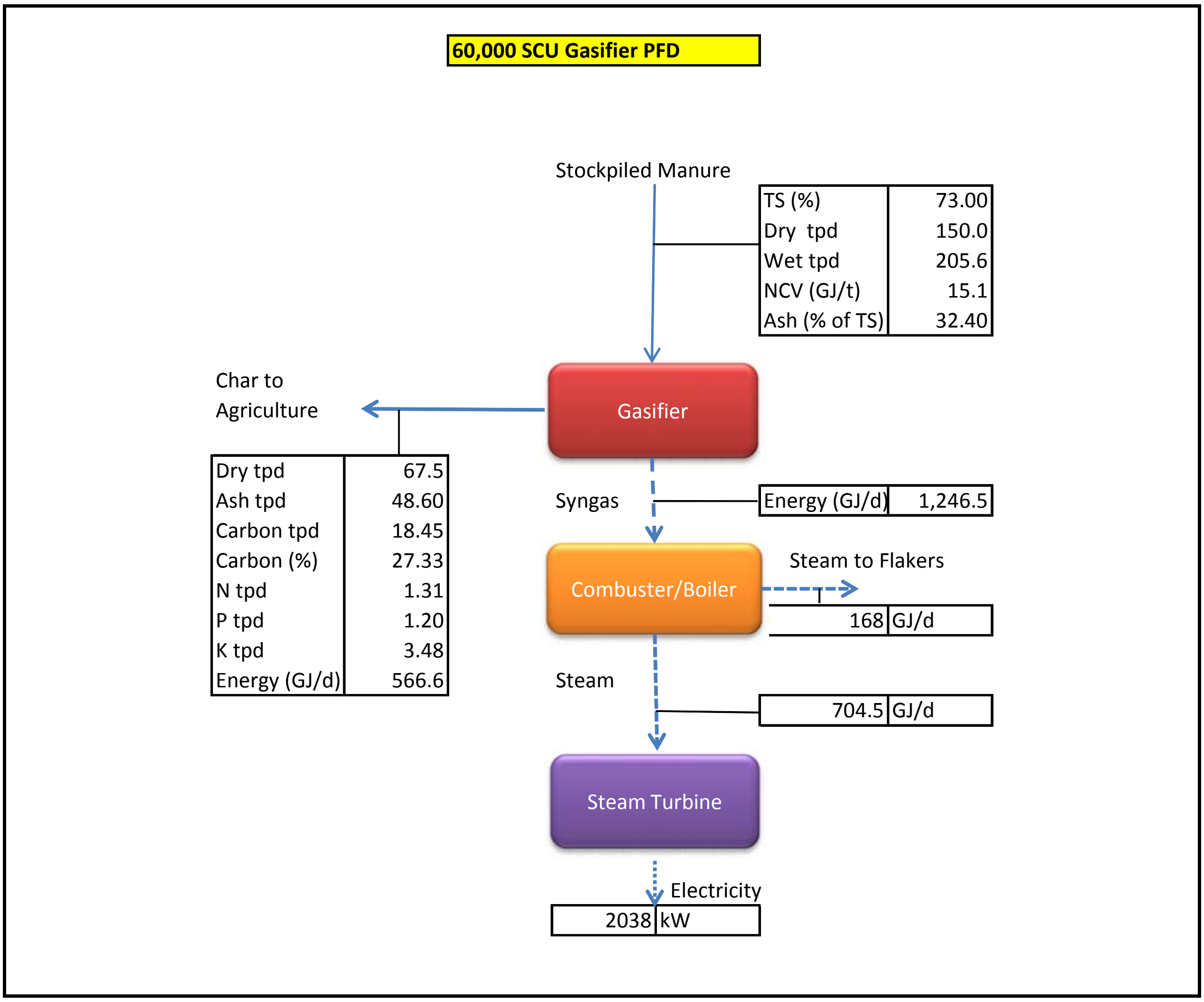

Table 4.18: Process inputs and outputs from manure gasification

Gasifier Input/ Output Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Dry manure processed.	tpd	25	62.5	150
Thermal input	GJ/h	15.7	39.3	94.4
Steam to feed flakers	GJ/d	28	70	168
Char generated	tpd	11.25	28.1	67.5
Carbon in char	tpd	3.08	7.69	18.45
Nitrogen in char	tpd	0.22	0.55	1.31
Phosphorus in char	tpd	0.2	0.5	1.2
Potassium in char	tpd	0.58	1.45	3.48
Electricity generated	MW	0.204	0.85	2.04

4.4 Cost Benefit Analysis of the options

4.4.1 Basis of the cost estimates

The capital costs for the major equipment items for energy recovery options have, where possible, been obtained from equipment vendors or from data in the literature. Where this has not been possible engineering cost estimates have been developed in-house by Bridle Consulting. Standard engineering cost factors have been used to generate cost data for other cost categories such as valves and piping, electrical, controls and instrumentation, civil works, mechanical installation etc. Standard cost factors for design, procurement and engineering project management fees, as well as a risk and profit allowance were also made to generate total project capital cost data for the options. Total project costs are based on the assumption that no charge is associated with the land required for the treatment/energy recovery options.

Facility operating costs were developed based on the estimation of costs for operational manpower, utility requirements (electricity etc) and maintenance costs.

Facility revenues from avoided thermal energy purchases, avoided carbon tax, electricity generation, Renewable Energy Credits (RECs) and char sales are based on data shown in Table 4.19.

Table 4.19: Revenue credit values

Revenue Parameter	Units	Value
Avoided Thermal Energy	$/GJ	17
Electricity sales	$/MWh	180
RECs	$/MWh	40
Avoided carbon tax	$/tonne carbon dioxide	23
Char sales	$/tonne	250

The avoided thermal energy price of $17/GJ is the average value for the use of coal ($5/GJ), diesel ($38.80/GJ), natural gas (NG) ($10/GJ) or liquid natural gas (LNG) ($15.50/GJ) to provide thermal energy at feedlots. It is recognised that avoided fuel costs will vary depending on the fuel used at the specific feedlot and thus the average value of $17/GJ used in this CBA will be significantly underestimated if diesel is used or overestimated if coal is used. The revenue and cost of electricity was assumed, by MLA, on average, to be $0.18/kWh or $180/MWh at Australian feedlots. A standard REC value of $40/MWh is used. The current proposed price on carbon of $23/tonne CO_2 is assumed. BiG have estimated that based on their current char off-take contracts, a char resale value of $250/tonne is reasonable.

4.4.2 CAL cost estimates

The CAL capital cost estimates have been based on MLA sourced data for lagoon construction costs and cover material costs. Costs for gas engine generator sets, flares and biogas scrubbing systems have been sourced from Quantum Power Limited[12]. These costs are based on the supply of 50, 120 and 300 kW gensets, with associated flares and gas scrubbing systems respectively for the three design cases. These cost estimates also include an allowance for electrical connection to the grid. A cost of $4/m^3 has been used for anaerobic lagoon construction and covers are based on the Fabtech quoted cost of $60/m^2. Detailed capital cost estimate data for the three CAL options are shown in Appendix 8.1.

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[12] Quantum Power Limited, www.quantumpower.com.au

Operating and maintenance costs were estimated on the assumption that 0.5 man-years of operational support is required to run the facility, that maintenance costs are 4% of installed capital costs and that the power draw for the facilities are 4, 8 and 16 kW respectively for the 10,000, 25,000 and 60,000 SCU CAL systems. Revenues for the facilities are based on the assumption that the generating sets will operate for 300 days per year. Operating and maintenance costs, as well as revenues for the three cases are also shown in Appendix 8.1. As shown in Appendix 8.1 and 8.2, no credit is shown for reductions in methane emissions from existing holding ponds since any methane generated in these ponds will continue, even if new CALs or contact digesters are installed.

A summary of this cost data is shown in Table 4.20.

Table 4.20: CAL cost data

Cost Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Capital cost estimate	$	685,352	1,074,356	1,920,205
Net O&M cost	$/a	-11,305	-98,390	-299,814
Simple pay-back time	years	61	11	6.4
NPV	$	538,889	32,008	-1,256,033

As shown in Table 4.20 the economics of installing CALs to treat the effluent from feedlot holding ponds does not look attractive, even for large feedlots with 60,000 head of cattle. This sized feedlot does generate an economic benefit over 20 years at a discount rate of 7% (the Net Present Value or NPV value), but in simple payback terms, the investment in a CAL does not look attractive, based purely on the predicted energy credits that would be realised.

4.4.3 Contact digester cost estimates

The contact digester capital cost estimates have been based on Bridle Consulting estimates for construction of the digesters and thickeners and literature cost data for the heat exchangers. Costs for gas engine generator sets, flares and biogas scrubbing systems have been sourced from Quantum Power Limited. These costs are based on the supply of 50, 120 and 300 KW gensets, with associated flares and gas scrubbing systems respectively for the three design cases. These cost estimates also include an allowance for electrical connection to the grid. A cost of $500/m^3 has been used for construction of the digesters and $300/m^3 for the thickeners. These cost factors were used to determine digester and thickener costs for the 10,000 SCU facility and then the two-thirds power law was used to calculate costs for the 25,000 and 60,000 SCU facilities. Detailed capital cost estimate data for the three contact digester options are shown in Appendix 8.2.

Operating and maintenance costs were estimated on the assumption that 0.5 man-years of operational support is required to run the facility, that maintenance costs are 4% of installed capital costs and that the power draw for the facilities are 6, 12 and 24 kW respectively for the 10,000, 25,000 and 60,000 SCU contact digester systems. Revenues for the facilities are based on the assumption that the generating sets will operate for 300 days per year. Operating and maintenance costs, as well as revenues for the three cases are also shown in Appendix 8.2.

A summary of this cost data is shown in Table 4.21.

Table 4.21: Contact Digester cost data

Cost Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Capital cost estimate	$	2,100,653	3,706,729	6,573,730
Net O&M cost	$/a	21,425	-44,451	-216,285
Simple pay-back time	years	Infinite	83	30
NPV	$	2,327,632	3,235,819	4,282,401

As can be seen from the data in Table 4.21, the capital costs for the contact digester options have been estimated to be about three times higher than the CAL options. This makes the economics of installing contact digesters to treat the effluent from feedlot holding ponds even less attractive than for the CAL options. Even for the 60,000 SCU facility, which does generate a reasonable annual return, the NPV, over a 20 year time frame, is not at all attractive. The facility would cost its operators $4.28 million over a 20-year life.

4.4.4 Combustor cost estimates

Capital cost estimates for the harvested manure Fluid Bed Boilers were obtained from Steam Systems P/L[13]. Costs for the steam turbine systems, which include an allowance for electrical connection to the grid were obtained from Quantum Power Limited. Bridle Consulting estimated the capital cost for the gas cleaning systems. Detailed capital cost estimates for the three combustor options are shown in Appendix 8.3.

Operating and maintenance costs were estimated on the assumption that 3 man-years of operational support is required to run the facilities, that maintenance costs are 4% of installed capital costs and that the power draw for the facilities are 40, 80 and 160 kW respectively for the 10,000, 25,000 and 60,000 SCU manure combustion systems. Electricity and REC revenues for the facilities are based on the assumption that the steam turbine generating sets will operate for 330 days per year. Thermal energy credits and avoided carbon tax credits are based on the combustors processing all of the manure generated per year. No allowance has been made for ash disposal as it has been assumed this is done on the existing feedlot site and costs will be lower than those associated with harvested manure disposal. Operating and maintenance costs, as well as revenues for the three cases are also shown in Appendix 8.3.

A summary of this cost data is shown in Table 4.22.

Table 4.22: Manure combustion cost data

Cost Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Capital cost estimate	$	7,931,371	15,047,409	27,860,245
Net O&M cost	$/a	-1,014,474	-2,962,618	-7,628,351
Simple pay-back time	years	8	5	3.7
NPV	$	-2,815,986	-16,338,611	-52,954,613

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[13] www.steamsystems.com.au

The capital costs for the manure combustion options have been estimated to be significantly higher than those for the effluent treatment systems. However, due to the significant energy credits generated, the economics of installing harvested manure combustion systems look quite attractive. Based on these cost estimates the simple payback periods range from 8 to 3.7 years and for all design cases the systems generate positive cash flows over the 20 year NPV calculation period. It is estimated that a 60,000 SCU harvested manure combustion facility would generate a positive cash flow of nearly $53 million over a 20-year period.

4.4.5 Gasifier cost estimates

Capital cost estimates for the 10,000 and 25,000 SCU harvested manure gasifier's were obtained from BiG P/L[14]. The 10,000 SCU gasification plant comprises two by BiGchar 2000 gasifier's and the 25,000 SCU plant comprises 3 by BiGchar 2200 gasifier's. Since BiG does not provide units large enough to service the 60,000 SCU facility, costs for this gasification facility was generated using the two-thirds power law to scale-up the costs from the 25,000 SCU gasifier. Costs for the steam turbine systems were obtained from Quantum Power Limited which includes an allowance for electrical connection to the grid. Bridle Consulting estimated the capital cost for the gas cleaning systems. Detailed capital cost estimates for the three gasifier options are shown in Appendix 8.4.

Operating and maintenance costs were estimated on the assumption that 3 man-years of operational support is required to run the facilities, that maintenance costs are 4% of installed capital costs and that the power draw for the facilities are 25, 50 and 100 kW respectively for the 10,000, 25,000 and 60,000 SCU manure gasification systems. Electricity and REC revenues for the facilities are based on the assumption that the steam turbine generating sets will operate for 330 days per year. Char credits, thermal energy credits and avoided carbon tax credits are based on the gasifier's processing all of the manure generated per year. No credit has been applied to any reductions in harvested manure disposal costs. Operating and maintenance costs, as well as revenues for the three cases are also shown in Appendix 8.4.

A summary of this cost data is shown in Table 4.23.

Table 4.23: Manure gasification cost data

Cost Parameter	Units	10,000 SCU Value	25,000 SCU Value	60,000 SCU Value
Capital cost estimate	$	4,017,869	7,733,172	14,531,945
Net O&M cost	$/a	-1,330,056	-4,268,282	-10,632,628
Simple pay-back time	years	3	1.8	1.4
NPV	$	-10,078,112	-37,485,065	-98,110,270

From Table 4.23, the capital costs for the manure gasification options have been estimated to be lower than those for the combustion systems. This is primarily due to the lower costs for the actual gasifier's compared to the FBBs and lower gas cleaning equipment costs. Due to the significant energy and char credits generated, the economics of installing harvested manure gasification systems look very attractive. Based on these cost estimates the simple payback periods range from 3 to 1.4 years and for all design cases the systems generate positive cash flows over the 20 year NPV calculation period. It is estimated that a 60,000 SCU harvested

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[14] www.bigchar.com.au

manure gasification facility would generate a positive cash flow of $98 million over a 20-year period.

5 Success in achieving objectives

All the objectives of this desk-top techno-economic review of energy recovery options for feedlot effluent and solid wastes have been successfully achieved. There was sufficient effluent wastewater and solid waste characteristics data available in the MLA data-bases to allow the development of input design parameters to conduct the techno-economic study. Process designs for the energy recovery options were successfully developed and with cost data from appropriate equipment vendors, acceptable cost-benefit analyses of these energy recovery options were completed.

6 Impact on meat and livestock industry – Now and in five years time

Based on the outcomes of this desk-top techno-economic assessment of energy recovery options from feedlot liquid and solid wastes it does not appear that energy recovery from liquid wastes is economically attractive. However, energy recovery from harvested manure does look economically attractive. Adoption of combustion or gasification technologies to process harvested manure could, in the next five years, effect significant reductions in waste disposal costs, generate significant amounts of green energy and electricity and in the case of gasification, sequester significant amounts of carbon in the char. Based on the estimates developed by this study, a 60,000 SCU feedlot could generate economic credits of between $53 and $98 million over a 20-year timeframe, by processing their harvested manure via combustion or gasification.

7 Conclusions and recommendations

7.1 Conclusions

The following conclusions are drawn based on the findings of this study:

1. Based on the current best estimate of effluent quality and quantity from feedlot holding ponds, treatment of this effluent via either covered anaerobic lagoons (CAL) or engineered anaerobic digesters is not economically attractive. The best economics, based on use of a CAL at a 60,000 SCU feedlot, generated a positive cash flow of $1.256 million over a 20-year time-frame, which is equivalent to a simple pay-back time on the investment of 6 years. None of the other options offer any payback on the investments, based on a 20-year NPV basis.

2. The current best estimate of harvested manure characteristics indicates that this material is dry enough and has sufficient energy content to make processing in combustors or gasifier’s technically feasible. No additional thermal drying of the feedstock is required.

3. Harvested manure is high in potassium and chlorides, known flux agents which depress the melting point of materials. Combustion of the manure may thus present some problems with respect to ash melting in the furnace. This issue can be minimised by use of fluid bed combustors, where temperature is well controlled, with minimisation of “hot

spots" within the combustor. Ash melting is unlikely to be an issue in gasifier's where temperatures are typically 250 ^{0}C lower than in combustors.

4. Combustion of harvested manure, with steam and electricity generation, provides an attractive manure management option for the industry. All the steam for feed flaking can be provided by the boiler and significant electricity production can be realised. Revenues from avoided fossil fuel use, electricity sales and avoided carbon taxes make manure combustion an attractive economic proposition. Based on the cost estimates generated in this study a 60,000 SCU feedlot could generate a positive cash flow of about $53 million over a 20 year time-frame, based on NPV calculations using a discount rate of 7%.

5. Even the smallest feedlot modelled (10,000 SCU) generates a positive cash flow of $2.8 million over a 20 year time-frame.

6. Gasification is a more mature technology than pyrolysis and thus gasification was used as the second manure thermal process evaluated in this study.

7. Gasification of harvested manure, with char, steam and electricity generation provides a very attractive manure management option for the industry. Revenues from char sales, avoided fossil fuel use, electricity sales and avoided carbon taxes make manure gasification a very attractive economic proposition. Based on the cost estimates generated in this study a 60,000 SCU feedlot could generate a positive cash flow of about $98 million over a 20 year time-frame, based on NPV calculations using a discount rate of 7%. Even the smallest feedlot modelled (10,000 SCU) generates a positive cash flow of $10.6 million over a 20 year time-frame.

7.2 Recommendations

Based on the findings of this study the following recommendations are made:

1. Based on the predicted economic viability of combustion as a suitable harvested manure management technology it is recommended that pilot-scale trials be conducted to confirm the technical and economic viability of combustion. Technical issues such as ash melting and the energy efficiency of manure combustion needs to be confirmed by sound pilot-scale trials. Suitable pilot-scale FBCs are currently available in Australia to conduct such studies, either at the supplier's site or at a selected feedlot. The costs and cost-benefits predicted by this study also need to be validated by a more detailed and thorough assessment of manure combustion once pilot-scale testing has confirmed the technical suitability of the technology.

2. Based on the predicted economic viability of gasification as a suitable harvested manure management technology it is recommended that pilot-scale trials be conducted to confirm the technical and economic viability of gasification. Technical and economic issues such as char quality considerations and marketability, as well as the energy efficiency of manure gasification, needs to be confirmed by sound pilot-scale trials. Suitable pilot-scale gasifier's, such as those offered by BiG are currently available in Australia to conduct such studies, either at the supplier's site or at a selected feedlot. The costs and cost-benefits predicted by this study also need to be validated by a more detailed and thorough assessment of manure gasification once pilot-scale testing has confirmed the technical suitability of the technology and the marketability of the char.

8 Appendices

8.1 Appendix 1: CAL Cost Estimates

CAPITAL COST ESTIMATE

Cost Component	Cost Factor	10,000 SCU	25,000 SCU	60,000 SCU
Major equipment items				
Anaerobic lagoon		7,344	19,158	45,915
AL Cover		48,573	97,573	197,358
Gas engine package		197,000	296,000	494,405
Subtotal		252,916	412,731	737,678
Piping, pumps and valves (%)	20	50,583	82,546	147,536
Electrics (%)	15	37,937	61,910	110,652
Instruments and control (%)	15	37,937	61,910	110,652
Civils (%)	10	25,292	41,273	73,768
Mech installation (%)	10	25,292	41,273	73,768
Equipment Subtotal		429,958	701,643	1,254,052
Engineering design (%)	8	34,397	56,131	100,324
Project management (%)	8	34,397	56,131	100,324
Subtotal		498,751	813,906	1,454,701
Overheads/risk (%)	7	34,913	56,973	101,829
Profit margin (%)	10	49,875	81,391	145,470
Contingency (%)	15	74,813	122,086	218,205
TOTAL		**658,352**	**1,074,356**	**1,920,205**

OPERATING COST ESTIMATE ($/annum)

Cost Component	No.	Unit cost	10,000 SCU	25,000 SCU	60,000 SCU
Operating staff	0.5	60,000	30,000	30,000	30,000
Electricity			6,307	12,614	25,229
Maintenance	4	% of equip	17,198	28,066	50,162
Total			53,506	70,680	105,391
Electricity credit	300	d/a	53,027	138,330	331,532
REC credit	300	d/a	11,784	30,740	73,674
Net O&M Cost			-11,305	-98,390	-299,814

NPV	$538,589	$32,008	-$1,256,033

8.2 Appendix 2: Contact Digester Cost Estimates

CAPITAL COST ESTIMATE ($)

Cost Component	Cost Factor	10,000 SCU	25,000 SCU	60,000 SCU
Major equipment items				
Contact Digester		575,000	1,060,000	1,901,000
Thickener		15,000	28,000	50,000
Heat exchanger		20,000	40,000	80,000
Gas engine package		197,000	296,000	494,405
Subtotal		807,000	1,424,000	2,525,405
Piping, pumps and valves (%)	20	161,400	284,800	505,081
Electrics (%)	15	121,050	213,600	378,811
Instruments and control (%)	15	121,050	213,600	378,811
Civils (%)	10	80,700	142,400	252,540
Mech installation (%)	10	80,700	142,400	252,540
Equipment Subtotal		1,371,900	2,420,800	4,293,188
Engineering design (%)	8	109,752	193,664	343,455
Project management (%)	8	109,752	193,664	343,455
Subtotal		1,591,404	2,808,128	4,980,098
Overheads/risk (%)	7	111,398	196,569	348,607
Profit margin (%)	10	159,140	280,813	498,010
Contingency (%)	15	238,711	421,219	747,015
TOTAL		**2,100,653**	**3,706,729**	**6,573,730**

OPERATING COST ESTIMATE ($/annum)

Cost Component	No.	Unit cost	10,000 SCU	25,000 SCU	60,000 SCU
Operating staff	0.5	60,000	30,000	30,000	30,000
Electricity			9,461	18,922	37,843
Maintenance	4	% of equip	54,876	96,832	171,728
Total			94,337	145,754	239,571
Electricity credit	300	d/a	59,655	155,622	372,973
REC credit	300	d/a	13,257	34,583	82,883
Net O&M Cost			21,425	-44,451	-216,285

NPV	$2,327,632	$3,235,819	$4,282,401

8.3 Appendix 3: Combustor Cost Estimates

CAPITAL COST ESTIMATE ($)

Cost Component	Cost Factor	10,000 SCU	25,000 SCU	60,000 SCU
Major equipment items				
FBB package		2,000,000	3,680,000	6,600,000
Gas cleaning package		500,000	922,000	1,653,000
Steam Turbine package		737,400	1,540,000	3,118,900
Subtotal		3,237,400	6,142,000	11,371,900
Piping and valves (%)	10	323,740	614,200	1,137,190
Electrics (%)	15	485,610	921,300	1,705,785
Instruments and control (%)	15	485,610	921,300	1,705,785
Civils (%)	10	323,740	614,200	1,137,190
Mech installation (%)	10	323,740	614,200	1,137,190
Equipment Subtotal		5,179,840	9,827,200	18,195,040
Engineering design (%)	8	414,387	786,176	1,455,603
Project management (%)	8	414,387	786,176	1,455,603
Subtotal		6,008,614	11,399,552	21,106,246
Overheads/risk (%)	7	420,603	797,969	1,477,437
Profit margin (%)	10	600,861	1,139,955	2,110,625
Contingency (%)	15	901,292	1,709,933	3,165,937
TOTAL		**7,931,371**	**15,047,409**	**27,860,245**

OPERATING COST ESTIMATE ($/annum)

Cost Component	No.	Unit cost	10,000 SCU	25,000 SCU	60,000 SCU
Operating staff	3	60,000	180,000	180,000	180,000
Electricity			63,072	126,144	252,288
Maintenance	4	% of equip	207,194	393,088	727,802
Total			450,266	699,232	1,160,090
Electricity credit	330	d/a	974,809	2,437,022	5,848,853
REC credit	330	d/a	216,624	541,560	1,299,745
Thermal energy credit	365	d/a	253,399	633,497	1,520,392
Avoided C tax (fossil)	365	d/a	5,430	13,574	32,577
Net O&M Cost			-999,996	-2,926,421	-7,541,478

NPV	-$2,662,597	-$15,955,139	-$52,034,280

8.4 Appendix 4: Gasifier Cost Estimates

CAPITAL COST ESTIMATE ($)

Cost Component	Cost Factor	10,000 SCU	25,000 SCU	60,000 SCU
Major equipment items				
Gasifier &boiler package		1,000,000	1,800,000	3,300,000
Gas cleaning package		250,000	500,000	900,000
Steam Turbine package		390,000	856,500	1,731,600
Subtotal		1,640,000	3,156,500	5,931,600
Piping and valves (%)	10	164,000	315,650	593,160
Electrics (%)	15	246,000	473,475	889,740
Instruments and control (%)	15	246,000	473,475	889,740
Civils (%)	10	164,000	315,650	593,160
Mech installation (%)	10	164,000	315,650	593,160
Equipment Subtotal		2,624,000	5,050,400	9,490,560
Engineering design (%)	8	209,920	404,032	759,245
Project management (%)	8	209,920	404,032	759,245
Subtotal		3,043,840	5,858,464	11,009,050
Overheads/risk (%)	7	213,069	410,092	770,633
Profit margin (%)	10	304,384	585,846	1,100,905
Contingency (%)	15	456,576	878,770	1,651,357
TOTAL		**4,017,869**	**7,733,172**	**14,531,945**

OPERATING COST ESTIMATE ($/annum)

Cost Component	No.	Unit cost	10,000 SCU	25,000 SCU	60,000 SCU
Operating staff	3	60,000	180,000	180,000	180,000
Electricity			39,420	78,840	157,680
Maintenance	4	% of equip	104,960	202,016	379,622
Total			324,380	460,856	717,302
Electricity credit	330	d/a	290,513	1,210,470	2,905,129
REC credit	330	d/a	64,558	268,993	645,584
Thermal energy credit	365	d/a	253,399	633,497	1,520,392
Avoided C tax (fossil)	365	d/a	5,430	13,574	32,577
Char credit	365	d/a	1,026,563	2,566,406	6,159,375
Net O&M Cost			-1,316,082	-4,232,085	-10,545,755

NPV	-$9,924,723	-$37,101,593	-$97,189,936