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Pilot testing pyrolysis systems and reviews of solid waste use on boilers

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Abstract
This study has confirmed that thermal processes such as pyrolysis, gasification and combustion are technically viable for the processing of abattoir solid wastes, particularly paunch waste and DAF sludge. These materials can be successfully dried for processing in pyrolysis or gasification systems. Based on the results of the pilot plant pyrolysis and gasification trials these processes do produce a char suitable for reuse in agriculture and do generate GHG reductions. GHG credits of between 0.5 tonne and 1 tonne of CO_{2e}/ dry tonne of paunch waste or DAF sludge can be achieved. Process economics however indicate that a waste processing fee of between \$65 and \$90/ tonne of wet paunch waste/DAF sludge is required to generate a return on the capital investment for a 20 dry tonne per day facility. Co-combustion of dewatered paunch waste/DAF sludge in suitable boilers appears to be commercially attractive.

Executive summary

Two enabling technologies that MLA/AMPC has identified as having the potential to recover nutrients and energy from abattoir solid wastes are pyrolysis and combustion processes. Phase 1 of this MLA/AMPC project reviewed waste pyrolysis systems and recommended pilot testing of two systems to validate the projected process economics. Phase 2 of this project had the following specific objectives:

- with MLA staff design, arrange and supervise a suitable programme to dry and characterise the abattoir wastes to be used in the pyrolysis pilot plant test programme;
- with Pacific Pyrolysis develop a suitable test programme to demonstrate the use of pyrolysis to process both paunch waste and DAF sludge, supervise this test programme and report on the results;
- with Black is Green P/L (BiG) develop a suitable test programme to demonstrate the use of their BiGchar gasification system to process paunch waste, supervise this test programme and report on the results;
- conduct a desktop review of the practicality and economics of using dried paunch waste and DAF sludge in abattoir boiler.

The required quantities of paunch waste and DAF sludge from the Oakey Abattoir were successfully dried using solar drying techniques. For pyrolysis and gasification a feed TS in excess of 80% is desirable. The product dried at the Oakey abattoir had a TS in excess of 85%. The dried paunch waste and DAF sludge were characterised for the parameters of importance for pyrolysis and gasification.

The pilot testing of the Pacific Pyrolysis (PacPyro) process was conducted at their Somersby facility, in NSW on the 6th and 7th of December, 2010. Batch pyrolysis tests were conducted on the paunch/DAF blend on the 6th December and on the paunch waste on the 7th December. Approximately 20 L of each dried feedstock was processed in the PacPyro stirred batch pyrolysis kiln, by heating to 550 0C under an inert environment. The material (char) was held at temperature for 40 minutes before cooling commenced, again under an inert environment. The char yield for the paunch waste as 41% and for the paunch/DAF blend was 32%. The lower char yield for the blend is due to the lower ash content of the blend feed material. Mass and energy balances indicate that 57% of the paunch energy is transferred to the pyrolysis gas and 67% of the DAF blend energy is transferred to the pyrolysis gas. These are encouraging results since they indicate that much of the feedstock energy will be able to be recovered for reuse at the abattoir. Based on the results of these batch pyrolysis trials PacPyro have concluded that both paunch waste and the paunch/DAF blend would make suitable feedstocks for a commercial PacPyro pyrolysis plant. A stable biochar is produced which could find a market as a soil amendment product in agriculture. In addition a significant amount of usable energy is available in the gas stream. The economic modelling conducted by PacPyro has showed that even for large abattoirs processing about 1300 head per day, pyrolysis of the paunch waste and DAF sludge would not be commercially viable unless a waste service charge of at least $90/wet tonne was applied.

Pilot testing of the BiGchar process was conducted at the BiG Maleny facility on 1st February 2011. Testing was conducted using the 1 metre diameter BiG gasification unit, which has a nominal capacity of 200 kg/h. Due to the high energy content of the dried paunch waste and the limitations of the thermal oxidiser, the one hour steady-state trial was conducted at a feed rate of about 115 kg/h. The steady state operational run indicated that the char yield was 17%. This was lower than expected and was the result of operating the gasifier at a higher temperature than normal, due to constraints imposed by the thermal oxidiser. The quality of the flue gas from the thermal oxidiser was very good, with all measured parameters well below typical regulatory thresholds. Based on the measured char yield and estimated char NCV a mass and energy balance for the steady state run was prepared by BiG. Based on the BiG experience that 20% of the feed energy is lost from the process, the M&E balance revealed that 18% of the feedstock energy is retained in the char and 62% is transferred to the syngas. The char produced met the criteria for the current BiG char off-take agreements. Economic modelling conducted by BIG indicated that a waste service charge of $65 per wet tonne would have to be applied to a 20 dry tpd paunch waste gasification facility to make the investment commercially attractive.

Pyrolysis and gasification of these abattoir solid wastes would generate GHG credits of up to 1 tonne CO_{2e}/tonne of feedstock and net energy credits of up to 3.2 GJ/dry tonne of feedstock.

Based on the finding of this desktop study, co-combustion of thermally dried paunch waste/DAF sludge does not appear to be economically attractive. However, co-combustion of mechanically dewatered paunch waste in existing boilers does appear to offer a commercially attractive waste disposal option.

Based on the results of this study it is clear that thermal processing of abattoir solid wastes such as paunch waste and DAF sludge is technically feasible at a commercial scale. Processes such as pyrolysis and gasification offer the most significant environmental benefits, particularly significant reductions in GHG emissions compared to the current disposal practises of composting and landfilling of these wastes. It is estimated that for abattoirs producing 20 dry tpd of paunch waste and DAF sludge that GHG reductions of up to 5000 tpa of CO_{2e} can be achieved if these wastes are pyrolysed rather than landfilled and composted. Using the same accounting methodology, gasification will achieve similar results. These processes do however come at a cost, estimated at between $65 and $90 per wet tonne of feedstock. Co-combustion of dewatered abattoir solid wastes such as paunch waste in suitable combustors is likely to reduce waste disposal costs and provide some environmental benefits. Adoption of thermal processes for the management of abattoir solid wastes is thus likely to be gradually implemented within the industry, particularly as old boilers are decommissioned and new thermal systems commissioned. In five years time it is very likely that there will be many more thermal systems processing abattoir solid wastes than the single system currently operating in the industry, with concomitant environmental benefits.

Contents

1 Background

1.1 The Strategy

The Australian red meat industry, in response to the impacts of climate change, has embarked on programmes to improve abattoir waste management practices and minimise the consumption of fossil fuels. There is currently little effort put into reusing the nutrients and energy that are contained within the solid waste streams produced by the red meat processing sector. Two of the solid waste streams that are of interest are paunch waste and DAF sludge. Many plants are currently paying to dispose of the paunch waste while a few can dispose of it at zero net cost, but it is uncertain whether they will be able to do the same in the future. Disposal of DAF sludge always incurs a cost. The strategy is to minimise the costs for disposal of these solid wastes and at the same time implement systems that can recover and reuse the nutrients and energy contained in these wastes.

1.1.1 The way forward

Two enabling technologies that MLA/AMPC has identified as having the potential to recover nutrients and energy from abattoir solid wastes are pyrolysis and combustion processes. This project has been formulated to assess these processes in more detail and make recommendation regarding the way forward regarding these technologies

2 Project objectives

2.1 The broad objective

MLA and AMPC have approved a research project entitled “Waste to Energy: Alternative uses for paunch waste and DAF sludge”. The broad objectives of this project are to:

- identify suitable waste-to-energy pyrolysis systems that could be used to process paunch waste and DAF sludge to generate biochar and syngas to be used to minimise the carbon footprint of meat processing facilities; and
- assess the potential for reduction of boiler fossil fuel consumption through replacement of these fuels with processed paunch waste and DAF sludge and thus reduce the carbon footprint of meat processing facilities.

2.1.1 Specific objectives of this project

Phase 1 of this MLA/AMPC project (A.ENV.0101) reviewed waste pyrolysis systems and recommended pilot testing of two systems to validate the projected process economics. Phase 2 of this project has the following specific objectives:

- with MLA staff design, arrange and supervise a suitable programme to dry and characterise the abattoir wastes to be used in the pyrolysis pilot plant test programme;
- with Pacific Pyrolysis develop a suitable test programme to demonstrate the use of pyrolysis to process both paunch waste and DAF sludge, supervise this test programme and report on the results;
- with BiG develop a suitable test programme to demonstrate the use of their BiGchar gasification system to process paunch waste, supervise this test programme and report on the results;

- conduct a desktop review of the practicality and economics of using dried paunch waste and DAF sludge in abattoir boiler, and;
- compile a report summarising the results of this work.

3 Methodology

3.1 Solid waste drying and characterisation

The Nippon Meat Packers abattoir in Oakey, Queensland provided the paunch waste and DAF sludge for drying and undertook the drying on behalf of MLA. A protocol for drying and characterising the material was provided to the Oakey abattoir and Trevor Bridle visited the abattoir to inspect the wet waste streams and to outline the drying protocol. The wastes were air-dried on a concrete pad in the sun over a two week period. The objective was to dry the material to a TS of greater than 80%. ALS conducted the analyses on the dried materials. The waste drying and characterisation methodology is outlined in Appendix 1.

3.2 Pilot testing of the Pacific Pyrolysis process

Pacific Pyrolysis had provided MLA with a proposal to conduct pilot testing of their pyrolysis process in June 2010 and this formed the basis for the test programme for this study. Testing of both paunch waste and combined paunch waste/DAF sludge was conducted using the Pacific Pyrolysis 20 L batch pyrolyser. In addition, the scope of work for Pacific Pyrolysis was expanded to include development of budget pricing for 5 and 20 tpd pyrolysis facilities, processing both of the above-mentioned waste streams.

3.3 Pilot testing of the BiGchar process

BiG provided MLA with a proposal to conduct pilot testing of their BiGchar process and to develop budget pricing for commercial units to process 5 and 20 dry tpd of paunch waste. The pilot testing was to be conducted on the latest 1 metre diameter BiGchar gasification unit. In addition to their normal testing protocol, the MLA tests called for analysis of the combusted syngas from the unit. As a result of this requirement, BiG modified the pilot plant to include a flue-gas cleaning system. Due to the significant waste quantities required for this test work, only dried paunch waste was trialled.

3.4 Desktop review of solid waste use in boilers

This desktop study reviewed the types of boilers used by the meat processing industry in Australia to determine their suitability for using dried paunch waste and DAF sludge to replace some of the fossil fuels currently used. The solid waste data generated in 3.1 above was used as the basis for this review. Drying options, including the Keith Airless Dryer previously evaluated by MLA were evaluated to pre-dry the solid waste streams. The review also included an assessment of newer combustor systems, such as fluid-bed boilers, for use by the industry to maximise the utilisation of abattoir solid wastes to replace fossil fuels. The overall economics of solid waste use in boilers will be developed to confirm if full-scale demonstration trials are warranted.

4 Results and discussion

4.1 Solid waste drying and characterisation

The Nippon Meat Packers abattoir in Oakey, Queensland provided the paunch waste and DAF sludge for this programme and the drying was conducted at the abattoir. The paunch waste was obtained from the discharge of the rotary screen, which was contained in 1.5 m^3 skips prior to disposal. The DAF sludge was "shovelled" from the bottom of the vessel that contained the material discharged from the DAF. This was done to ensure the highest level of solids was obtained. Pictures of these wet materials are shown in Figure 4.1.

Figure 4.1: Wet paunch waste and DAF sludge

Wet paunch waste

Wet DAF sludge

Three skips of wet paunch waste (about 2 to 3 m^3) and 70 L of wet DAF sludge were collected and spread as a thin layer (100 to 150 mm thick) on a concrete pad (the disused truck wash bay) to dry in the sun. The drying process commenced on the 2nd of November 2010. The material was turned by hand twice a day to maximise the drying rate and samples of material were taken daily for TS analysis by the Oakey abattoir laboratory. Surprisingly the DAF sludge dried very quickly and within 5 days had reached a TS of 81.6% and consequently drying of this material was ceased. The paunch waste took much longer to dry and on the 8th of November the drying area was increased from 25 to 50 m^2 to enhance the drying rate. This increase in area had a dramatic impact on the drying rate as is evident from the graph shown in Figure 4.2. As can be seen the drying rate more than doubled on the 10th of November and the rate was linear till drying ceased on 15th November. Based on the best estimate of paunch waste mass at the start of the drying cycle (1350 kg wet weight) the drying rate from 10th to 15th November is calculated to be 2.1 kg water evaporated per m^2 per day. This is roughly half of the typical drying rates achieved by solar dryers. The final paunch waste TS achieved on the 15th November, when drying ceased, was 86.7%. Pictures of the dry DAF sludge and the paunch waste during drying are shown in Figure 4.3.

Figure 4.2: Paunch waste drying rate data

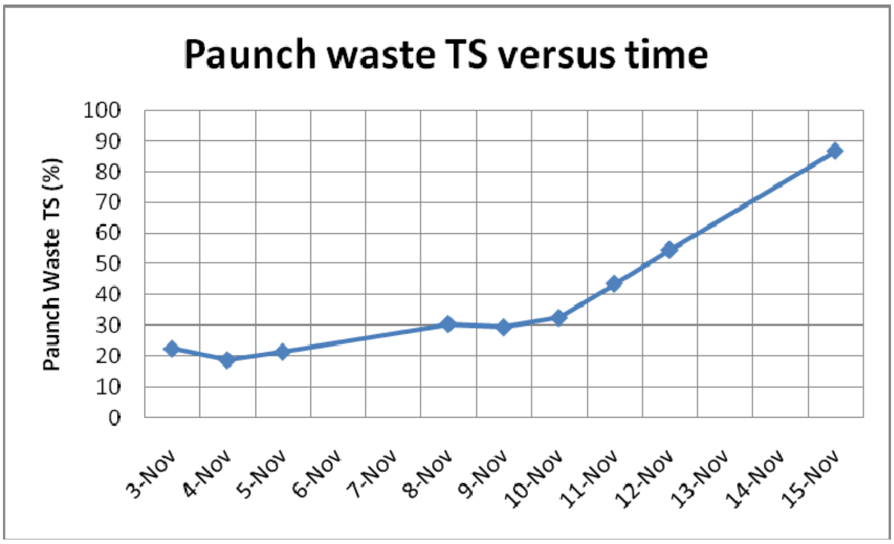

Figure 4.3: Dried DAF sludge and paunch waste

Dried DAF sludge

Paunch waste during drying

Based on the weight data recorded by Oakey Abattoir there was 270 kg of dried paunch waste, which was somewhat less than expected. Nonetheless this quantity was adequate for the pyrolysis trials.

Sub-samples of dried paunch waste (four samples) and DAF sludge (two samples) were analysed by ALS for the parameters of significance for the pyrolysis trials. The average results of these analyses are shown in Table 4.1.

Table 4.1: Dried abattoir solid waste characteristics

Parameter	Units	DAF sludge average	Paunch waste average
TS	%	81.5	86.7
VS	% of TS	90	92.98
Ash	% of TS	10	7.02
GCV	MJ/kg dry	38.09	18.74
Carbon	% of TS	72.5	47.52
Hydrogen	% of TS	10.96	5.75
Nitrogen	% of TS	0.38	1.17
Sulphur	% of TS	0.47	0.25
Oxygen	% of TS	5.55	39.02
Phosphorus	mg/kg dry	1223	1453
Potassium	mg/kg dry	65	220
Chromium	mg/kg dry	<0.01	0.05
Copper	mg/kg dry	0.125	0.63
Nickel	mg/kg dry	0.145	0.09
Zinc	mg/kg dry	2.54	4.42

Unfortunately ALS was not able to analyse the DAF sludge for ash, GCV and elemental (C, H, N. S, O) due to the fact that when heated the sample liquefied. However, Pacific Pyrolysis did analyse a paunch waste/DAF sludge blend and based on this analysis, the ash, GCV and elemental analysis of the DAF sludge has been inferred and the results in Table 4.1 are based on these inferred values. Nippon Meat has recently provided VS, ash and GCV data for the paunch waste from their Wingham abattoir and the results are very similar to the Oakey paunch waste data provided above. The Wingham paunch waste data for VS, ash and GCV was 91.4%, 8.6 % and 19.2 MJ/kg dry solids, respectively. The data in Table 4.1 indicates that both DAF sludge and paunch waste have relatively high calorific values and thus would be useful as feedstocks for pyrolysis, gasification or for use in boilers.

4.2 Pilot testing of the Pacific Pyrolysis process

The pilot testing of the PacPyro process was conducted at their Somersby facility, in NSW on the 6th and 7th of December, 2010. Batch pyrolysis tests were conducted on the paunch/DAF blend on the 6th December and on the paunch waste on the 7th December. Trevor Bridle was present for the char removal phase of the first run and the reactor loading and heating phase of the second run.

4.2.1 Technical results of the pilot test programme

The PacPyro technical results report from the batch pyrolysis test programme is attached as Appendix 2. The major findings of this report are summarised below.

PacPyro oven dried the solar-dried feed materials at 90 ^{0}C until constant weight was achieved. The as-fed oven dried paunch waste TS was 93% and the paunch/DAF blend was 95.2%. The bulk density (BD) of the dried material was very low, with the paunch waste BD being 130 kg/m3 and the paunch/DAF blend BD being 170 kg/m3.

Approximately 20 L of each dried feedstock was processed in the PacPyro stirred batch pyrolysis kiln, by heating to 550 0C under an inert environment. The material (char) was held at temperature for 40 minutes before cooling commenced, again under an inert environment. Pyrolysis gas generated during the run was released through a flue stack and combusted in a simple flare. Char yields were calculated by weighing the produced char and expressing yields as a percent of feedstock mass, on a dry weight basis. Pyrolysis gas yields were calculated by difference. The char yield for the paunch waste as 41% and for the paunch/DAF blend was 32%. The lower char yield for the blend is due to the lower ash content of the blend feed material. The BD of the char was higher than for the respective feed material with the paunch char BD being 220 kg/m3 and the blend char BD being 205 kg/m3. Photographs of the batch pyrolysis reactor, the feedstocks and chars can be found in the PacPyro report in Appendix 2.

PacPyro had the feedstocks and chars analysed for TS, VS, elemental analysis, GCV and had the ashed feed materials and chars analysed for major inorganic elements. These detailed results can be found in Appendix 2.

Based on the char energy and yield data mass and energy balances were conducted for both runs and these are shown in Figure 4.4 below.

Figure 4.4: M&E balances for the Pyrolysis runs

Basis: 1 kg(dry) feedstock

Feedstock	**Paunch**	**DAF blend**
Mass [kg(dry)]	1.00	1.00
Gross CV [MJ/kg(dry)]	17.68	23.08
Total Energy [MJ]	17.68	23.08

Batch Pyrolysis Kiln

Biochar	**Paunch**	**DAF blend**
Mass [kg(dry)]	0.41	0.32
Gross CV [MJ/kg(dry)]	18.22	23.79
Total Energy [MJ]	7.54	7.72
Feedstock energy retained in biochar [%]	43%	33%

Syngas	**Paunch**	**DAF blend**
Mass [kg(dry)]	0.59	0.68
Gross CV [MJ/kg(dry)]	17.30	22.74
Total Energy [MJ]	10.14	15.36
Feedstock energy converted to syngas [%]	57%	67%

These results indicate that 57% of the paunch energy is transferred to the pyrolysis gas and 67% of the DAF blend energy is transferred to the pyrolysis gas. These are encouraging results since they indicate that much of the feedstock energy will be able to be recovered for reuse at the abattoir.

The chars produced contained mainly fixed carbon and ash. They did however contain much needed nutrients such as nitrogen, potassium, phosphorus and sulphur. Essentially all the potassium and phosphorus in the feedstock is retained in the char and about 50% of the nitrogen and 15% of the sulphur are retained in the char. The ash in the char comprises mostly aluminium, iron, calcium and magnesium silicates.

Based on the results of these batch pyrolysis trials PacPyro have concluded that both paunch waste and the paunch/DAF blend would make suitable feedstocks for a commercial PacPyro pyrolysis plant. A stable biochar is produced which could find a market as a soil amendment product in agriculture, provided that adequate quality controls were in place and regulatory requirements were met. In addition a significant amount of usable energy is available in the gas stream. The PacPyro economic modelling of such commercial facilities is presented in the next section of this report.

4.2.2 Economical modelling of the PacPyro process

The PacPyro economic feasibility report, based on the process results from the batch pyrolysis test programme, is attached as Appendix 3. The major findings of this report are summarised below.

The PacPyro report presents the findings of an economic feasibility study of three slow pyrolysis plants, of sizes and feedstocks as outlined below:

- a 5 dry tonne per day (tpd) partial gasification plant processing dried paunch waste and DAF sludge,
- a 20 dry tpd continuous slow pyrolysis plant processing dried paunch waste and DAF sludge, and,
- a 48 dry tpd continuous slow pyrolysis plant processing 20 dry tpd of dried paunch waste and DAF sludge plus 28 dry tpd of green waste.

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A summary of the major inputs and outputs of these three plants, on which the economic feasibility is based, are shown in Table 4.2.

Table 4.2: Pyrolysis plant inputs and outputs

Plant Capacity (dry tpd)	5	20	48
DAF sludge processed (wet tpa)	1,250	5,000	5,000
Paunch waste processed (wet tpa)	3,750	15,000	15,000
Green waste processed (wet tpa)	0	0	20,000
Operating hours (h/annum)	1,250	6,000	8,000
Biochar output (wet tpa)	359	1,840	5,888
Thermal gas output (GJ/a)	3,375	13,500	0
Power output (MWh/a)	0	0	6,750
Carbon offsets (tonnes CO_2-e/a)	1,130	6,040	12,960

It should be noted that the carbon offsets include those from carbon sequestration in the char, avoided fossil fuel consumption (NGER credits) and also landfill avoidance credits. See the full report for details of these offset credits.

The key economic assumptions used in the economic modelling of the pyrolysis plants are shown in Table 4.3.

Table 4.3: Key Economic Assumptions

Parameter	Units	Value used
Waste service charge (abattoir wastes)	$/wet tonne	20
Biochar sale price	$/wet tonne	300
Green waste purchase price	$/wet tonne	0
Green waste TS	%	55
Export syngas price	$/GJ	10
Export electricity price	$/MWh	70
Electricity REC	$/MWh	40
Carbon offset credit	$/tonne CO_2-e	20
Electricity purchase price	$/MWh	70
Thermal gas purchase price	$/GJ	24
Operator cost	$/a	65,000

Based on the financial input assumptions shown in Table 4.3, the financial return on a 5 tpd slow pyrolysis plant processing a blend of DAF sludge and paunch waste does not appear to present a commercial opportunity while, although more viable than the smaller plant, a 20 tpd pyrolysis project was found to have a negative NPV_{20}. Revenue scenarios can be however be developed under which an attractive business case can be built. For example, if the waste service charge paid to the pyrolysis project is increased to $90/ wet tonne for the DAF sludge and paunch waste, then the facility could achieve a pre-tax IRR_{20} of 20% for the 20 tpd plants.

By increasing the plant capacity through the sourcing of an additional waste organic feedstock stream, greater economies of scale can be achieved. This economic modelling has shown that a 48 tpd plant presents a potentially commercial project opportunity. If the project can access additional waste organics at a zero net costs the project modelled returns a pre-tax IRR_{20} of 13.2%. If all the feedstocks attracted a waste service charge of $33/wet tonne, then project would yield an IRR_{20} of 20%.

In summary this modelling has shown that even for large abattoirs processing about 1300 head per day, pyrolysis of the paunch waste and DAF sludge would not be commercially viable unless a waste service charge of at least $90/wet tonne was applied.

4.3 Pilot testing of the BiGchar process

Pilot testing of the BiGchar process was conducted at the BiG Maleny facility on 1st February 2011. Testing was conducted using the 1 metre diameter BiG gasification unit, which has a nominal capacity of 200 kg/h. Due to the high energy content of the dried paunch waste and the limitations of the thermal oxidiser, the one hour steady-state trial was conducted at a feed rate of about 115 kg/h. Trevor Bridle was present to witness this steady state trial. The BiG report on this trial and the associated economics of commercial plants can be found in Appendix 4. A summary of the major findings is outlined below.

4.3.1 Technical results of the pilot test programme

The BiG trials were conducted on the dried paunch waste, with a TS of 83.7%. The gasifier was initially heated up by combustion of paper and wood waste placed on the bottom two hearths. Once up to temperature, the dried paunch waste was fed to hearth 1 at the top of the gasifier. The steady-state feed period was 76 minutes during which time 144 kg of material was continuously fed to the gasifier. The dry feed rate was 95.2 kg/h. Pictures of the feed conveyor and the gasifier during initial heat-up are shown in Figure 4.5. The gasifier photo shows the ash discharge chute at the bottom and the flue gas exhaust to the thermal oxidiser at the top.

Figure 4.5: Feed conveyor on left and gasifier on right

During the steady state run gasifier temperatures were maintained between 550 and 600 ^{0}C and the thermal oxidiser at about 800 ^{0}C. Off gas from the thermal oxidiser was routinely analysed using a hand-held on-line gas analyser (Testo 350 unit). This unit provided real-time measurement and analysis of flue gas temperature, CO, oxygen, NOx and SOx content. A picture of using this analyser in the thermal oxidiser chamber is shown in Figure 4.6. Char discharged from the bottom of the gasifier continuously into a steel container. This was routinely wetted with a water spray to prevent further combustion and the container was replaced with an empty one on an as required basis. A picture of the wetted char is shown in Figure 4.6. The wetted char was transferred to sealed 200 L drums to prevent any further combustion.

The feedstock contained stones up to 30mm diameter, as illustrated in Figure 4.7. These are not unexpected given that cattle frequently swallow inorganic matter of this nature. This did not present a problem for the pilot plant nor would it for a full scale BiGchar reactor. Stones of this size are however quite likely to cause jamming and damage in screw or auger devices so use of such conveyors is not recommended. Similarly this sort of contamination would not be acceptable in the char delivered to many end users, as it would affect their handling equipment (e.g. spreaders, blenders etc.). Hence a vibrating 6mm screen will be required at discharge from the char load-out bin.

The steady state operational run indicated that the char yield was 17%. This was lower than expected and was the result of operating the gasifier at a higher temperature than normal, due to constraints imposed by the thermal oxidiser.

Figure 4.6: Off-gas analysis on left and char sample on right

Figure 4.7: Stones removed from the char

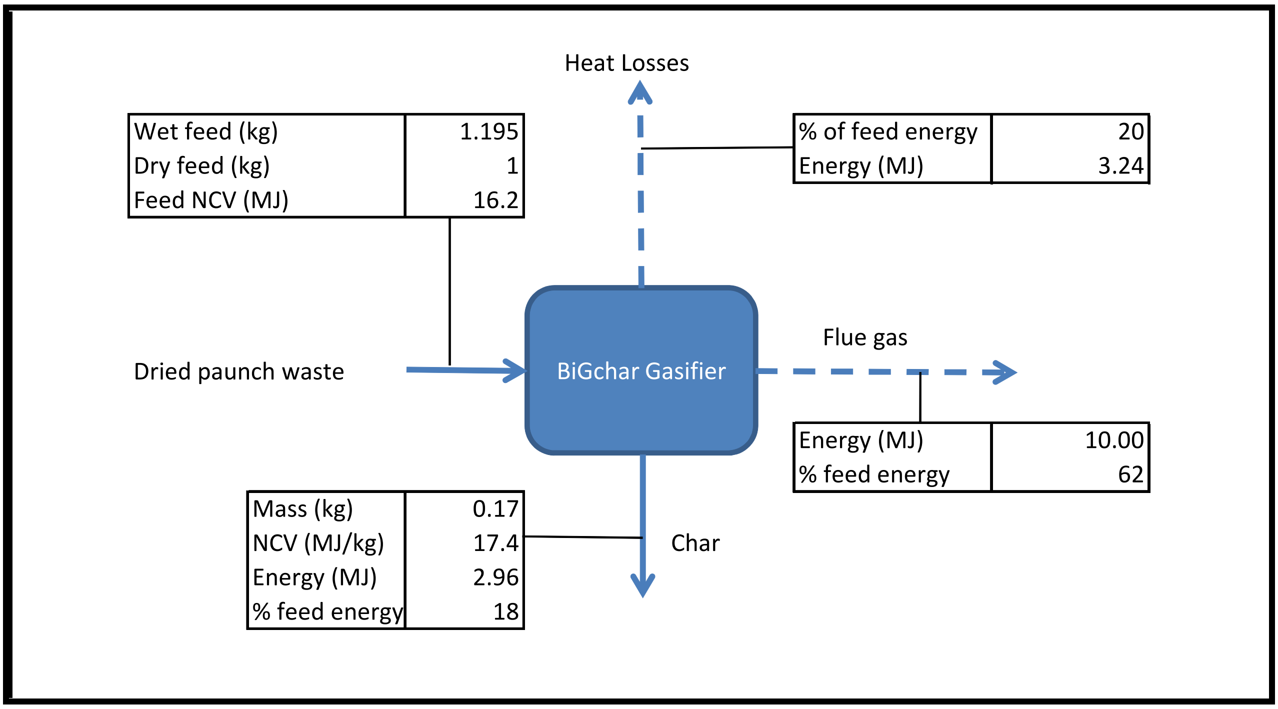
BiG had the feedstock and char analysed by HRL in Victoria and some of the results are shown in Table 4.4. The paunch analytical results are very similar to those generated by MLA (see Table 4.1 and those generated by PacPyro. The char VS and carbon content were lower than BiG had anticipated, again due to the higher temperatures caused by more combustion. BiG has estimated both the Gross and Net Calorific Value (NCV) of the paunch waste and char and these are also shown in Table 4.4.

Table 4.4 BiG paunch waste and char analyses

	TS (%)	VS (% of TS)	Ash (% of TS)	C (% of TS)	H (% of TS)	N (% of TS)	S (% of TS)	Estimated GCV (MJ/dry kg)	Estimated NCV (MJ/dry kg)
Paunch Waste	83.7	92.95	7.05	46.2	5.7	0.99	0.21	17.4	16.2
Char	58.3	58.1	41.9	52.9	0.5	0.8	0.1	17.5	17.4

The estimated GCV of the paunch waste is slightly lower than that measured by MLA (18.74 MJ/kg). Based on the measured char yield and estimated char NCV a mass and energy balance for the steady state run, assuming an input of 1 kg of dry paunch waste, was prepared by BiG and this is summarised in Figure 4.8.

Figure 4.8: M&E balance for steady state run



To prepare this M&E balance BiG has assumed, based on their experience, that 20 % of the feed energy is lost from the process, due to feedstock combustion and heat loss from the gasifier. On this basis 18% of the feedstock energy is recovered in the char, leaving 62% as recoverable heat in the syngas. This compares to 43% of the paunch waste energy recovered in the char and 57% recovered in the syngas in the PacPyro process (see Figure 4.4).

The measured median emission values for the flue gas, together with typical regulatory limits for waste combustors, are shown in Table 4.5.

Table 4.5: Emission monitoring data

Parameter	Units	Measured Median Value	Typical Regulatory Limit
CO	ppm_v at 8% O_2	109	1000
NOx	ppm_v at 8% O_2	214	300
SO_2	ppm_v at 8% O_2	<1	100
TSP	mg/Nm^3 at 8% O_2	<150 (est)	50-200
Exhaust temperature	^0C	740	

As can be seen the quality of the exhaust from the thermal oxidiser was very good with all measured parameters well below typical regulatory limit values. Unfortunately BiG could not source an on-line TSP analyser and their estimate of 150 mg/Nm^3 is based on experience with visual plume examination.

A sample of char was also sent to the Wollongbar Primary Industries Institute in NSW to assess its agronomical properties. Based on this analysis the char met all the current BiG criteria for reuse in agriculture, based on their existing char off-take agreements with other clients. The char chromium and zinc levels were high and could not be reconciled with the low paunch waste chromium and zinc levels. It is believed these char values are due to external contamination.

4.3.2 Economical modelling of the BiGchar process

In developing M&E balances for commercial 5 and 20 dry tpd paunch waste gasification plants BiG have assumed that char yields would be optimised to achieve a value of 25%, rather than the 17% achieved on the pilot plant. This is deemed reasonable and is consistent with BiG's experience on similar feed stocks processed in full-scale plants. In developing the M&E balances for the commercial plants BIG have used the following design parameters:

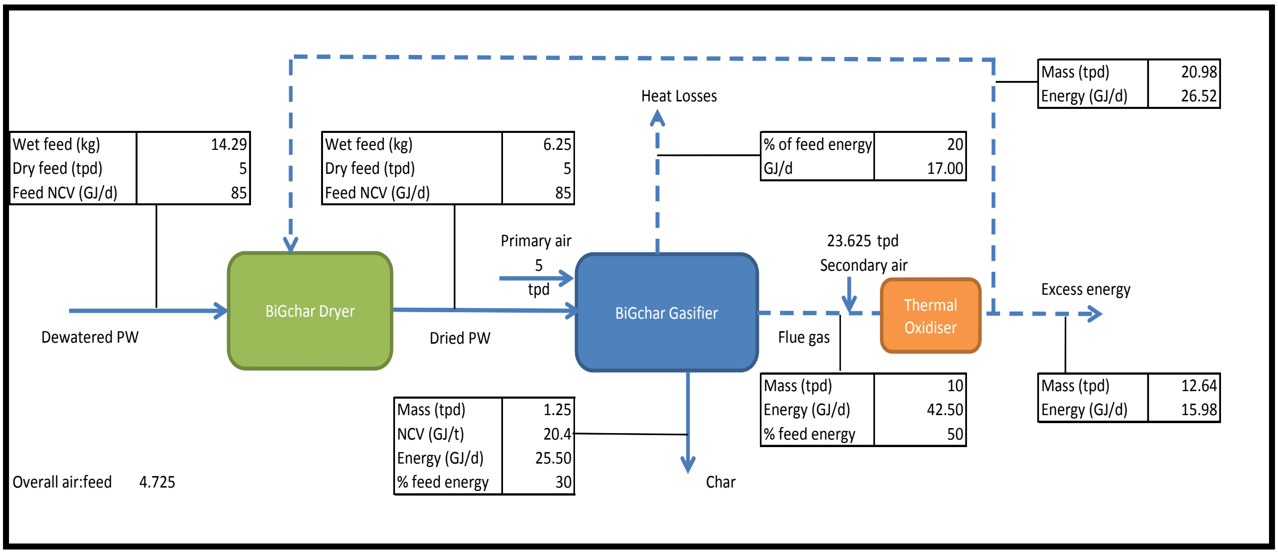
- Paunch waste is dewatered to a TS of 35% using a screw press.
- Dewatered paunch waste is dried to a TS of 80% using a BiG multiple-hearth dryer.
- The paunch waste NCV is 17 GJ/dry tonne.
- The dryer thermal energy requirements are 3.3 GJ/tonne of water evaporated. This heat duty provided by flue gas from the gasifier.
- Char yield is 25% on a dry weight basis.
- The char contains 30% of the feedstock net energy (on an NCV basis).
- Thermal losses across the gasifier are 20% of the feedstock energy.
- The syngas contains 50% of the feedstock energy.

Based on these input design values the outputs for commercial 5 and 20 dry tpd plants are shown below:

- 5 tpd plant
  - 1.25 tpd of char
  - 16 GJ/d of excess energy in the form of flue gas at about 800 ^0C
  - A GHG credit of 2 tpd CO_{2e}
- 20 tpd plant
  - 5 tpd char
  - 64 GJ/d of excess energy in the form of flue gas at about 800 ^0C
  - A GHG credit of 8.2 tpd CO_{2e}

A simple M&E balance for the proposed 5 dry tpd BiGchar plant is shown in Figure 4.9.

Figure 4.9: M&E balance for 5 tpd BiGchar plant



BiG have developed costs for the 5 and 20 tpd plants based on three project delivery methods. The first is the standard Engineer, Procure and Commission (EPC) approach where BiG would design, procure, install and commission the plant for the client, for an agreed fee. This is likely the most expensive approach for the client. The second approach is to form an unincorporated Joint Venture (JV) with BiG. This is BiG's preferred mode of delivery. Under this arrangement the host site is responsible for an agreed part of the project scope and BiG the remaining parts. Either party may operate the installation, with operating or maintenance costs divided to a pre-agreed ratio. The outputs of the process are owned in proportion to pre-agreed ratios with revenues flowing back to the host and BiG according to the respective revenue streams. The host site may supply the feedstock (pre-dewatered paunch waste) according to a pre-agreed transfer pricing schedule. The final project delivery option is a Build/Own/Operate (BOO) approach. In this mode BiG delivers or constructs the entire plant and operates it on the host site on a fee-for-service basis. This is the zero capital spend option for the paunch waste producer. BiG's service fee takes into account the necessary return on capital, operating and maintenance costs, offset by the revenue streams derived from the products of the process (eg. char and heat). After capital recovery has been achieved the fee may be replaced with a transfer pricing agreement. BiG have developed capital costs for the plants based on their internal costing procedures and are inclusive of all cost components to deliver an integrated, functional and commissioned facility. Char revenue has been based on prices currently paid to BiG on their existing take-off contracts (between $200 and $400/tonne). Excess energy has been valued at

$10/GJ. On this basis the costs for the three contract delivery options are summarised in Table 4.6.

Whilst it is difficult to compare the cost data for the PacPyro and BiG processes it does appear that the BiGchar gasification process costs are significantly lower than the PacPyro pyrolysis costs. For example, when processing 20 tpd of combined paunch waste and DAF sludge, with significantly higher energy content, PacPyro would require a service fee of $90/wet tonne compared to a service fee of $65/wet tonne for BiG when processing 20 tpd of only paunch waste.

The costs presented by BiG for the 20 tpd facility look attractive and it is thus recommended that as per the BiG report, MLA consider investing in an integrated 5 tpd demonstration facility, to be operated at an abattoir for a 6 month period. BiG has estimated the cost of such a demonstration programme at about $150,000.

Table 4.6: Costs for 5 and 20 tpd BiGchar plants

Scenario (dry t basis)	5 tpd	20 tpd
Daily operating hours	10 hours/day incl. up to 4 hours unattended.	20 hours/day incl. up to 12 hours unattended.
Dryer	BiGchar 1500 6 chamber containerised.	BiGchar 2200 6 chamber
Thermal processing unit	BiGchar 1500 4 chamber	BiGchar 2200
Nominal plant footprint	12x16m incl. 6Lx2.3Wx3H container, plus char product lay-down and load out area	12x22m plus char product lay-down and load out area
Total EPC project cost	$612,000	$908,400
Joint venture project cost	$255,000	$378,500
BiG Build Own Operate (Zero capital spend by host site. Processing on Fee for service basis)	$200 per wet tonne	$65 per wet tonne

4.4 Desktop review of solid waste use in boilers

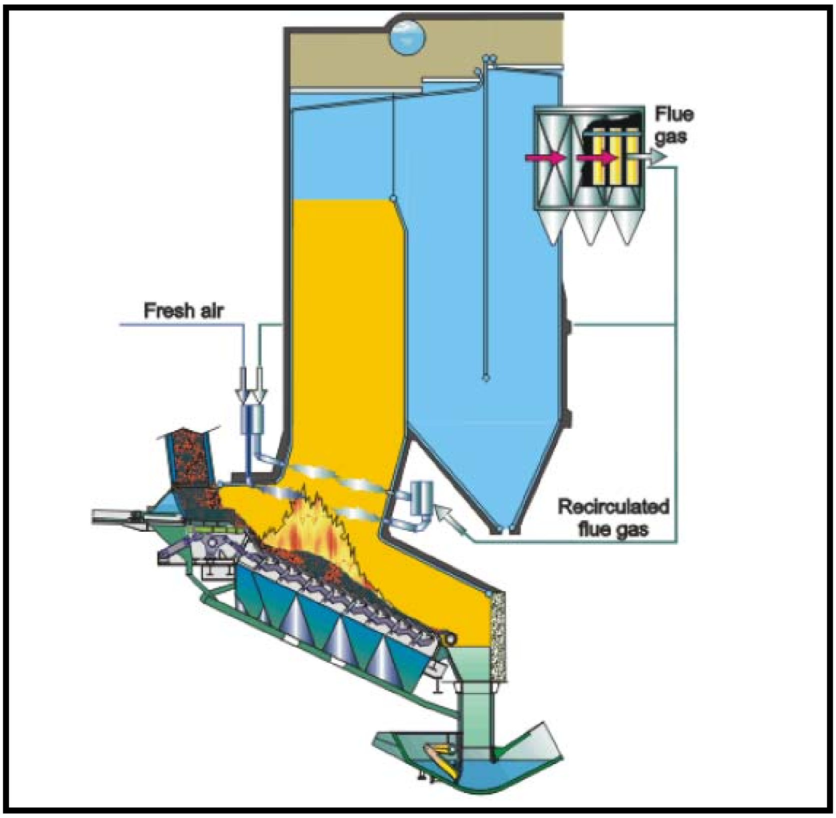
4.4.1 Current boiler operations

Most abattoirs currently use standard water-tube boilers, fired by coal, fuel oil or occasionally natural gas or diesel. If the boilers are fired with coal they have moving grates to transport the coal down the length of the boiler for complete combustion with the ash falling into a water bath at the end of the boiler. This is shown schematically in Figure 4.10. Only moving-grate boilers, which are designed for solid-fuel firing, would potentially be suitable for firing with dried abattoir solid waste. Liquid and gas-fired boilers are NOT suitable for firing with solid waste.

It has been reported that a few abattoirs do fire their boilers with waste materials such as wood waste, waste oils and even tallow[1]. At the time that this report was prepared there were two sloping moving-grate boilers operating on sawdust and wood waste in the Australian abattoir industry, one at the Nippon Meat abattoir in Wingham, NSW and the other at the JBS Swift abattoir in Longford, Tasmania. Grate movement in these boilers is controlled hydraulically. In addition the Longford boiler is reported to also co-combust dewatered paunch waste.

Most abattoirs in Australia have boilers with fuel input rates ranging from 20 to 80 GJ/h. This is equivalent to a coal firing rate of between 12 to 50 tonnes per day. It is also estimated that the energy content of the paunch waste and DAF sludge generated by abattoirs ranges from 5 to 20 GJ/h, or about a quarter of the energy needed for boiler operations. Thus from a theoretical viewpoint it makes sense to assess the potential of utilising these solid waste streams in the abattoir boilers.

Figure 4.10: Schematic of a moving-grate boiler



4.4.2 Solid waste quantities and characteristics

There is not a lot of data available on the quantity of paunch waste and DAF sludge generated by abattoirs. For paunch waste, MLA uses a figure of 3 to 5 % of the live carcase weight, which is equivalent to 14 to 23 kg wet weight per animal. Data has also been obtained from the Dinmore, Oakey and Mackay abattoirs in Queensland and the average data, expressed as weight per head, is shown in Table 4.7.

[1] Meat Research Corporation and Australian Meat Technology, “Steam Generation Systems”, 1997.

Table 4.7: Paunch waste and DAF sludge quantities

Parameter	Units	Average Value
Wet paunch waste	kg/animal	26.06
Dry paunch waste	kg/animal	5.75
Wet DAF sludge	kg/animal	3.68
Dry DAF sludge	kg/animal	2.08

The chemical and thermal properties of paunch waste and DAF sludge are shown in Section 4.1 of this report.

There does however not seem to be any information on the physical characteristics of paunch waste and DAF sludge in the literature. Some limited data has however been obtained on the dried paunch waste and DAF sludge collected for this project. From the photograph in Figure 4.3 it is very clear that the dried DAF sludge resembles a "soil contaminated lard". This material liquefies to oil when heated to above 50 ^{0}C and as discussed in Section 4.2 of this report, can be easily and homogeneously blended with dried paunch waste by heating and mixing. The dried paunch waste is a very fluffy material with a low bulk density. The bulk density as measured by Pacific Pyrolysis was 131 kg/m^3. This is a very low bulk density and will provide challenges when trying to feed this material into conventional moving grate boilers.

4.4.3 Possible boiler issues by co-firing abattoir solid wastes

There are a number of issues that can and are likely to occur when co-firing boilers with abattoir solid wastes and these are discussed below.

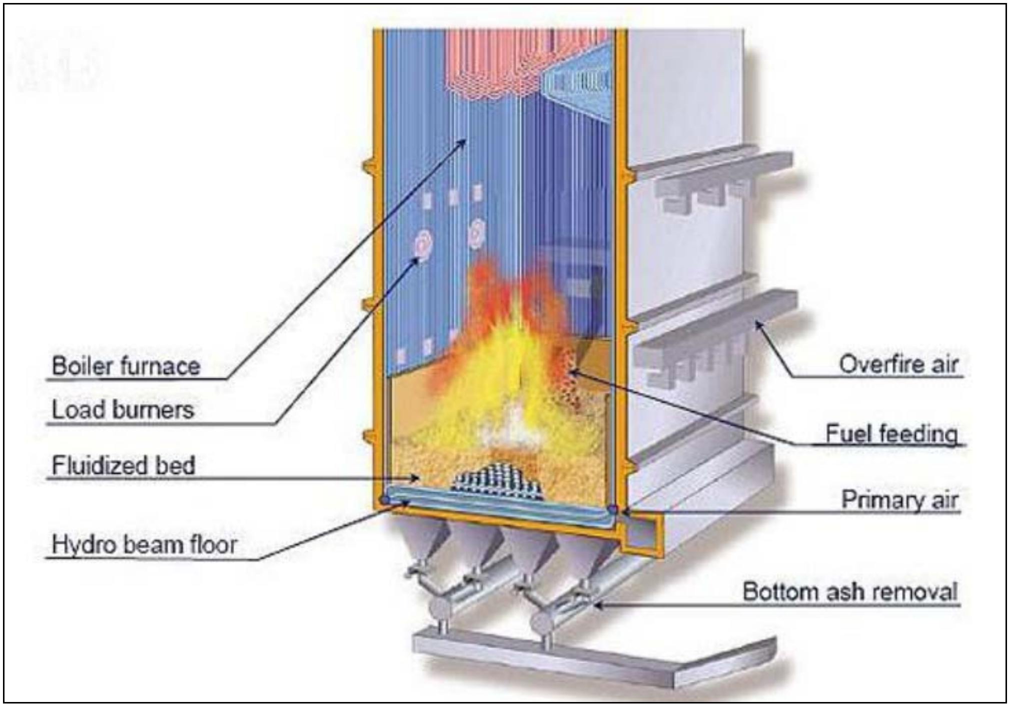
4.4.3.1 Waste particle size and bulk density

The first issue, particularly for moving grate boilers, is that dried paunch waste is light, fluffy, has a low bulk density and much of the material is less than 3 to 4mm in size. This could cause feed problems and more importantly could block and clog the small gaps (2 to 4 mm) in moving grate boilers. This would cause uneven burning on the grate and thus poor combustion efficiency. Use of fluid bed boilers (FBBs) or vibrating grate boilers will however overcome these potential problems. FBBs are used extensively to burn waste materials including manures, sludges, wood wastes and other organic residues. A typical schematic of a FBB is shown in Figure 4.11. Since combustion of the waste takes place within a bed of fluidised sand the particle size of the waste has little or no impact on combustion efficiency. The Australian company RCR Energy has recently installed a FBB to burn abattoir sludge at the Silver Fern abattoir in NZ[2]. This boiler produces 12.5 tph of steam. RCR Energy has also installed a FBB to process coffee bean residues, with a TS of 60%, at the Nestle facility in Gympie, Queensland.

Vibrating grate boilers have been developed by ERK of Germany and are offered in Australia by DGA Engineers and Consultants in Thailand. Vibrating grate boilers are used to combust a range of waste materials including animal manures and sludges. The vibrating grate overcomes the problems of grate fouling which occur in traditional moving grate boilers. A schematic of a vibrating grate boiler is shown in Figure 4.12

[2] RCR Energy, FROM &AT Brochure, November 2008

Figure 4.11: Schematic of a FBB



4.4.3.2 Ash fusion/melting

Compared to coal, waste materials including abattoir solid wastes have much higher levels of salts (cations and anions) that can significantly reduce the softening and melting point of the ash, which once molten can then re-solidify in the cooler parts of the boiler, typically the boiler tubes and superheater tubing. Cations such as sodium, potassium and phosphorus can significantly reduce the melting point of the ash[3]. Since abattoir solid wastes have substantial levels of phosphorus and potassium (see Table 4.1) it is expected that the ash from these wastes may have a lower ash fusion temperature than coal or wood waste. This does need to be evaluated prior to conducting any full-scale waste combustion trials. A typical example of the fouling of boiler tubes by molten ash is shown in Figure 4.13.

4.4.3.3 High particulate carry-over

Due to the low bulk density, fluffy nature and small particle size of dried paunch waste there may be increased carry-over of particulates, including unburnt fuel, when combusting this material in moving grate boilers and vibrating grate boilers. This would put an additional load on down-stream gas cleaning equipment and could require additional gas cleaning equipment in some cases. This would not be such an issue with FBB as the material is burned within the fluidised sand bed.

Figure 4.12: Schematic of a Vibrating Grate Boiler

[3] T R Bridle, et al, “Start-up of the Subiaco Sludge Conversion Plant”, Proceedings of the WEFTEC 99 Conference, New Orleans, USA, October 1999.

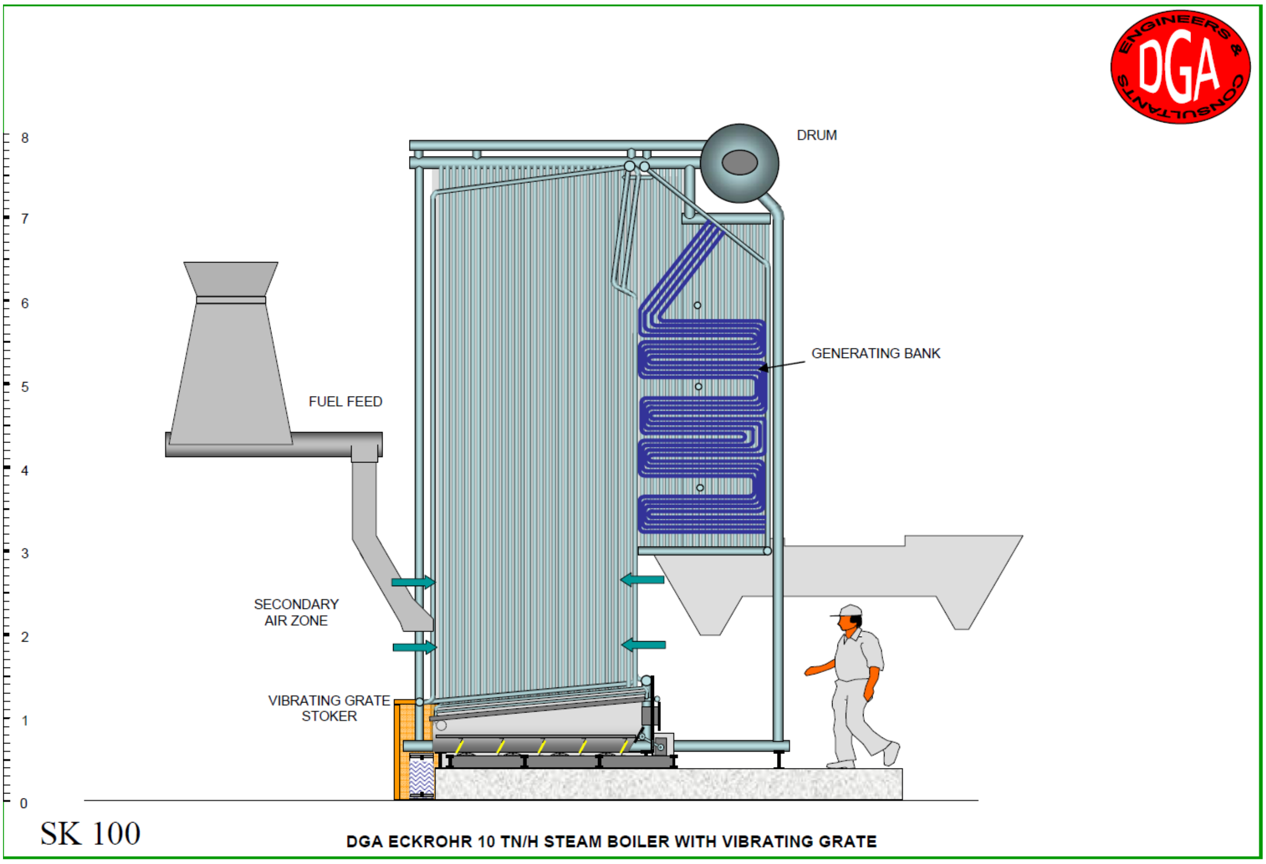


Figure 4.13: Example of Ash Fusion on Boiler Tubes

4.4.3.4 Increased corrosion

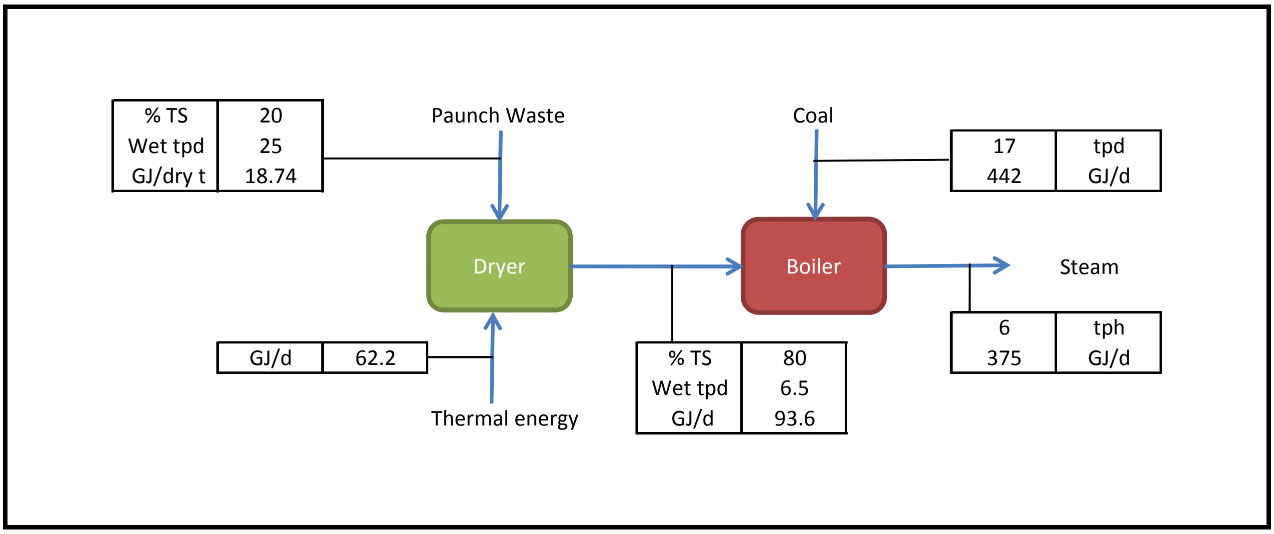
Abattoir solid wastes do have higher levels of chlorides than coal or wood waste and there is thus the potential for higher levels of acidic gas in the flue gas from a boiler burning these wastes. This needs to be assessed in more detail on a case-by-case basis prior to conducting full-scale combustion trials.

4.4.4 Preliminary economics of waste combustion in boilers

Two cases are developed for this desktop study, namely an abattoir of about 650 head per day and one of about 1300 head per day. It is assumed that such abattoirs would require boilers with thermal outputs of about 4 and 8 MW_{th}, respectively. This is equivalent to steam production rates of 6 and 12 tonnes per hour. To achieve these boiler outputs it is assumed that all the paunch waste from the abattoir, pre-dried to a TS of 80%, is co-combusted with coal. For the smaller abattoirs this amounts to 17 tpd of coal and 6.25 tpd of paunch waste, at a TS of 80%. For the larger abattoirs the fuel input is 34 tpd of coal and 12.5 tpd of paunch waste, at a TS of 80%. In addition two options are considered for case, namely use of the existing boiler (where this is technically suitable) or installation of a new vibrating gate boiler. Both options include installation of a paunch waste dryer.

A simple mass and energy balance for a paunch dryer linked to a boiler, for a 650 head per day abattoir is shown in Figure 4.14.

Figure 4.14: Mass and energy balance for a 650 head/day abattoir



As can be seen from the data in Figure 4.14, the net thermal benefit of combusting paunch waste, at a TS of 80%, in the boiler is 31.4 GJ/d (93.6 minus 62.2). Or presented in another format, the net thermal benefit of combusting dried paunch waste in boilers is 6.3 GJ/dry tonne of paunch waste.

Prices for the boilers were obtained from DGA Engineers and Consultants and for the dryer, from Keith Engineering, which are based on use of their airless (superheated steam) dryer, which was recently evaluated at the Dinmore abattoir on a MLA project. To develop total equipment costs Bridle Consulting has estimated the cost of other major equipment items such as waste feed systems and hoppers, air pre-heater and economiser, gas cleaning equipment and ash handling equipment. Standard engineering cost factors were then applied to the major equipment sub-total to develop total project costs. These capital cost estimates are shown in Table 4.8.

Table 4.8: Budget capital cost estimates for paunch waste co-combustion

COST COMPONENT	Cost factor (%)	650 head/d abattoir		1300 head/d abattoir	
		Existing boiler	New boiler	Existing boiler	New boiler
Major Equipment items					
Wet paunch storage and feed system		0.6	0.6	0.9	0.9
Keith Airless Dryer		1.85	1.85	3.7	3.7
Dry paunch storage and feed system		0.4	0.4	0.7	0.7
Air pre-heater and economiser			0.3		0.45
Vibrating grate boiler			0.85		1.1
Gas cleaning system			0.4		0.7
Ash handling system			0.2		0.3
Equipment sub-total		2.85	4.6	5.3	7.85
Factored costs					
Piping and valves	15	0.43	0.69	0.80	1.18
Elec and instrumentation	30	0.86	1.38	1.59	2.36
Mechanicals/civils	25	0.71	1.15	1.33	1.96
Installation	20	0.57	0.92	1.06	1.57
Design/Project management	20	0.57	0.92	1.06	1.57
Subtotal		5.99	9.66	11.13	16.49
Overhead and risk recovery	15	0.90	1.45	1.67	2.47
Contingency	30	1.80	2.90	3.34	4.95
Contractors profit	10	0.60	0.97	1.11	1.65
TOTAL CAPITAL COST ESTIMATE ($ millions)		**9.28**	**14.97**	**17.25**	**25.55**

The major additional expenses for operation of the paunch waste co-combustion system will be the fossil fuel used to dry the waste material and the maintenance costs for the dryer. On the assumption that the wet paunch waste TS is 20%, the thermal energy required to dry the material to 80% TS is 62 GJ/d for the small abattoir and 124 GJ/d for the larger abattoir. These operating expenses will however be off-set by reductions in coal use and potential reductions in paunch waste disposal costs. A summary of these costs is shown in Table 4.9. Also included in Table 4.9 are the whole of life costs for the facility, based on a NPV cost for 20 years, discounted at 7%.

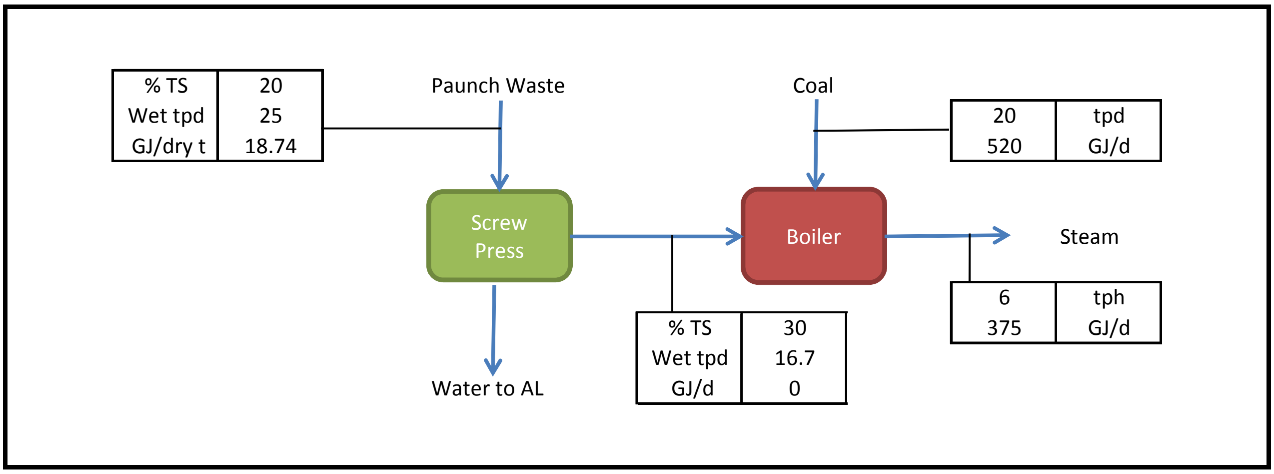
Table 4.9: Summary of operating and NPV costs for paunch waste co-combustion

COST COMPONENT	Unit Cost	650 head/d abattoir		1300 head/d abattoir	
		Existing boiler	New boiler	Existing boiler	New boiler
Major Operating Costs					
Thermal energy for drying	10	155,391	155,391	310,781	310,781
Dryer maintenance	2	119,700	119,700	222600	222600
Operating cost total		275,091	275,091	533,381	533,381
Major Revenue streams					
Coal credit	160	120,000	120,000	240,000	240,000
Paunch waste disposal credit	10	62,500	62,500	125,000	125,000
Revenue total		182,500	182,500	365,000	365,000
Net operating costs ($/annum)		**92,591**	**92,591**	**168,381**	**168,381**
20 year NPV cost at 7% discount factor ($ millions)		**10.26**	**15.95**	**19.03**	**27.33**

This preliminary review of the economics of paunch waste co-combustion in abattoir boilers indicates that even when existing boilers can be used, the economics do not appear to be attractive. This is primarily due to the high costs associated with paunch waste drying. Use of solar dryers could change these economics but a thorough review of the use of solar dryers, on a case-by-case basis, needs to be conducted to confirm if this significantly alters the economics of abattoir waste co-combustion in boilers. The economics are heavily dependent on the fact that paunch waste, at any abattoir, can generally only supply about 15% of the energy needs of the boiler. The use of other organic waste streams, such as wood waste, may offer significantly improved economics.

An alternate approach would be to use the boilers merely for waste disposal, with little if any energy recovery. Based on a paunch waste GCV of 18.74 GJ/dry tonne, the material only needs to be dewatered to a TS of about 30% to burn autogenously, that is, without the need for auxiliary fuel. Since most paunch waste has a TS of about 20%, a dewatering device such as a screw press would readily increase the paunch waste TS to the required 30% for autogenous combustion. A simple mass and energy balance for this option, for a 650 head per day abattoir is shown in Figure 4.15.

Figure 4.15: Autogenous paunch waste disposal in a boiler



This approach is very likely to be a cost effective method for abattoirs to dispose of their paunch waste and it is recommended that MLA explore this option in more detail.

5 Success in achieving objectives

This study has confirmed that thermal processes such as pyrolysis, gasification and combustion are technically viable for the processing of abattoir solid wastes, particularly paunch waste and DAF sludge. These materials can be successfully dried for processing in pyrolysis or gasification systems. Based on the results of the pilot plant pyrolysis and gasification trials these processes do produce a char suitable for reuse in agriculture and do generate GHG reductions. GHG credits of between 0.5 tonne and 1 tonne of CO_{2e}/ dry tonne of paunch waste or DAF sludge can be achieved. Process economics however indicate that a waste processing fee of between $65 and $90/ tonne of wet paunch waste/DAF sludge is required to generate a return on the capital investment. Co-combustion of dewatered paunch waste/DAF sludge in FBBs appears to be commercially attractive. All the objectives of this study have been successfully achieved.

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

Based on the results of this study it is clear that thermal processing of abattoir solid wastes such as paunch waste and DAF sludge is technically feasible at a commercial scale. Processes such as pyrolysis and gasification offer the most significant environmental benefits, particularly significant reductions in GHG emissions compared to the current disposal practises of composting and landfilling of these wastes. It is estimated that for abattoirs producing 20 dry tpd of paunch waste and DAF sludge that GHG reductions of up to 5000 tpa of CO_{2e} can be achieved if these wastes are pyrolysed rather than landfilled and composted. Using the same accounting methodology, gasification will achieve similar results. These processes do however come at a cost, estimated at between $65 and $90 per wet tonne of feedstock. Co-combustion of dewatered abattoir solid wastes such as paunch waste in combustors such as FBBs is likely to reduce waste disposal costs and provide some environmental benefits. Adoption of thermal processes for the management of abattoir solid wastes is thus likely to be gradually implemented within the industry, particularly as old boilers are decommissioned and new thermal systems commissioned. In five years time it is very likely that there will be many more thermal systems processing abattoir solid wastes than the single system currently operating in the industry, with concomitant environmental benefits.

7 Conclusions and recommendations

7.1 Conclusions

Based on the outcomes of this study the following conclusions can be drawn.

1. Paunch waste and DAF sludge can be successfully dried to a TS of above 85% using solar drying techniques. Based on this positive outcome it is clear that conventional engineered dryers will be capable of drying these materials.
2. The technical viability of processing paunch waste and DAF sludge via pyrolysis and gasification has been successfully demonstrated via the pilot plant trials conducted by PacPyro and BiG.
3. Both pyrolysis and gasification will produce char products suitable for reuse in agriculture.
4. Pyrolysis or gasification of paunch waste and DAF sludge generates net excess energy in the form of syngas. This is once the process energy needs, including those for feedstock drying, are taken into account. Net energy outputs range from 2.7 to 3.2 GJ/ tonne of dry feedstock.
5. Pyrolysis and gasification of paunch waste and DAF sludge will generate GHG credits of up to 1 tonne CO_{2e}/dry tonne of feedstock processed.
6. To make pyrolysis or gasification economically attractive, waste processing fees of between $65 and $90 per wet tonne of feedstock will have to be applied, for plants of 20 dry tpd capacity.
7. Co-combustion of mechanically dewatered paunch waste in combustors such as FBBs appears to offer a cost effective method for disposal of this abattoir solid waste.

7.2 Recommendations

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

1. To fully demonstrate the cost effectiveness of gasification, it is recommended that MLA consider investing in an integrated 5 tpd demonstration gasification facility, to be operated at an abattoir for a 6 month period. BiG has estimated the cost of such a demonstration programme at about $150,000.
2. To further evaluate the cost effectiveness of pyrolysis it is recommended that MLA consider funding a more detailed project feasibility study, for a specific abattoir site, to better refine the cost uncertainties identified in the PacPyro report.
3. It is recommended that MLA embark on a full-scale techno-economic assessment of paunch waste and DAF sludge co-combustion, using existing FBB combustion facilities in the industry.

8 Appendices

8.1 Appendix 1: Waste Drying and Characterisation Protocol

8.2 Appendix 2: Pacific Pyrolysis pilot plant testing report

8.3 Appendix 3: Pacific Pyrolysis economic feasibility report

8.4 Appendix 4: BiG pilot plant testing report