FINAL REPORT

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PREPARED BY:	Max Barnes, Dr Gareth Forde **All Energy Pty Ltd**
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Rev	Purpose	By	Date	Checked	Date
A	Final Report	MCB	11/6/2020	GMF	12/6/2020
B	Final Report	MCB	5/8/2020	GMF	5/8/2020
C	Public Report	MCB	28/8/2020	DT, PG	

1.0 EXECUTIVE SUMMARY

Based upon industry surveys and preliminary economic modelling, two specific waste to energy technologies were considered in detail:

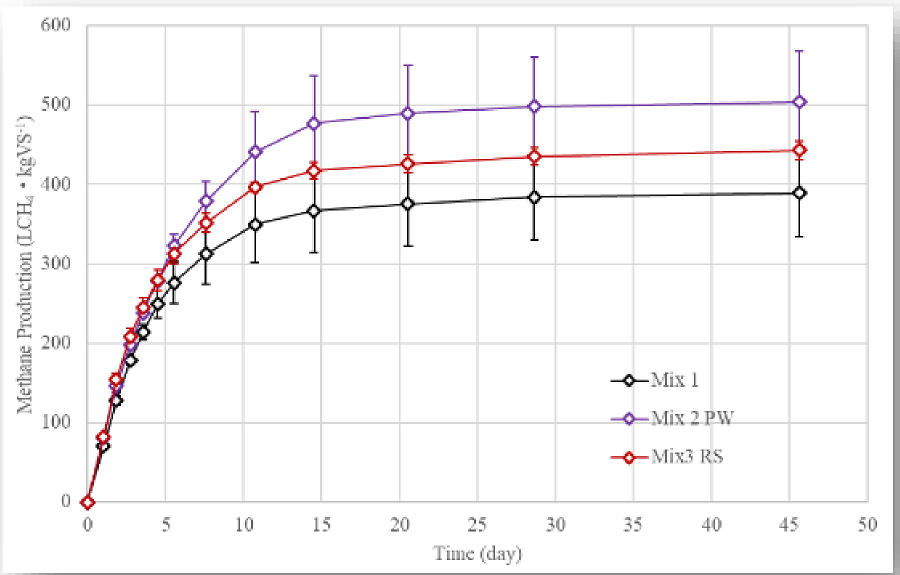
(1) Anaerobic digestion of red meat process (RMP), pig processing wastes, food organics and green organics from municipal wastes in continuous stirred tank reactors (CSTRs) to generate biogas used to fuel reciprocating cogeneration engine, and
(2) Aggregation of different biomass fuels from within RMP operations and adjacent to operations for combustion in boilers for creating steam.

1.1 Anaerobic Digestion of Aggregated Organic Waste to Biogas

This report provides an analysis and evaluation of the energy content of current available beef processing and piggery pork processing wastes, and the financial opportunity of digesting these wastes anaerobically to offset power usage and costs at NSW red meat processor.

All Energy visited both sites, collecting samples for lab analysis in partnership with the University of Queensland Advanced Water Management Centre led by Associate Professor Paul Jensen. Results of the energy content and individual streams and mix methane potential are shown below.

	Blood	***Guts***	***Saveall Overflow***	***Yard Manure***	***Paunch***	***Paunch Water***
TS (g/kg)	*232.43±0.3*	*380.77±2.11*	*3.81±0.02*	*4.54±0.13*	*339.16±21.63*	*7.15±0.1*
TS%	*23.24%*	*38.08%*	*0.38%*	*0.45%*	*33.92%*	*0.72%*
VS (g/kg)	*223.01±0.26*	*367.45±2.67*	*3.27±0.02*	*3.06±0.12*	*325.22±20.85*	*5.04±0.11*
VS/TS %	*95.95%*	*96.50%*	*85.83%*	*67.40%*	*95.89%*	*70.49%*
Ash (g/kg)	*9.42±0.08*	*13.31±1.82*	*0.54±0.04*	*1.49±0.03*	*13.94±0.87*	*2.11±0.03*
Total COD	*320.3±10.9*	*537.2±20.5*	*7.1±0.2*	*5.2±0.6*	*433.1*	*9.7±0.3*
TCOD/VS	*1.44*	*1.46*	*2.17*	*1.70*	*1.33*	*1.92*



Three submissions were received from the market, with All Energy filling the gaps with estimates of balance of plant, biogas generation, and thermal recovery. Total installed capital, operating costs, and revenue were estimated, with the discounted economics of each proposal compared below.

	Energy 360	Biogass	Gaia
CAPITAL			
SIMPLE PAYBACK	5.7	6.1	8.7
IRR	21.6%	20.4%	14.9%
NPV	$ 20,317,784	$ 19,890,693	$ 16,962,238
DPP	5.6	6.0	8.4

With the above economic feasibility, this appears to be an attractive option to offset electrical and thermal energy costs, reduce site Scope 1 and Scope 2 emissions, improve energy security, and provide a more sustainable approach to waste management.

Sensitivity Analysis	Delivery Cost		Power Cost		Piggery Waste Disposal Cost	
Change in Key Cost/Revenue Item	NPV	IRR	NPV	IRR	NPV	IRR
-50%			$ 8,881,200	12.6%	$ 15,324,334	16.8%
-40.0%			$ 11,083,099	14.3%	$ 16,237,606	17.5%
-30.0%			$ 13,284,998	15.9%	$ 17,150,878	18.3%
-20.0%			$ 15,486,896	17.5%	$ 18,064,150	19.0%
-10.0%			$ 17,688,795	19.0%	$ 18,977,421	19.7%
0.0%	$ 19,890,693	20.4%	$ 19,890,693	20.4%	$ 19,890,693	20.4%
10.0%	$ 19,375,698	20.0%				
20.0%	$ 18,860,703	19.6%				
30.0%	$ 18,345,708	19.2%				
40.0%	$ 17,830,712	18.8%				
50.0%	$ 17,315,717	18.4%				

The key sensitivity is to variation in power cost in a scenario where the site kVA demand spikes outside of the engine operation period, meaning only kWh and not kWh + kVA are offset. This may happen due to a DOL stop-start in a large motor or motor system (e.g. the refrigeration system) on a non production day where site demand spikes. It should be checked that site refrigeration plant and any other large motors are fitted with variable speed drives, voltage optimization, and site power factor correction to ensure that the plant continues to deliver savings as expected.

All Energy recommends to invest in this opportunity and progress to detailed design.

1.2 Aggregated Biomass Combustion

This report presents the results of a feasibility study for co-combusting a range of biomass fuels including higher calorific value fuels of cotton gin trash (CGT) and air dried hardwood chip with fuels generated within the red meat supply chain, specifically waste grain materials from feedlots and paunch from RMPs. The financial viability was compared against "business as usual" operations at two SEQ feedlots and one SEQ processor.

Red meat processors and processors operating inside a vertically integrated supply chain with operational control over a feedlot(s) can use these findings for a basic understanding of what conditions may make their site suitable for a waste to energy plant, and how aggregating wastes/collaborating with other sites may improve viability, and help offset waste management and thermal energy costs. At the conclusion of this project, RMPs will have a clearer understanding of multi-fuel boiler options.

	Feedlot 1	Feedlot 2	Processor	
Current Annual Thermal Spend	$ 489,859	$ 517,941	$806,390	$806,390
Current $/GJ [fuel purchase only]	$ 26.96	$ 27.64	$ 4.20	$4
Steam tpa	5,891	6,076	55,306	55,306
Technology	Multifuel biomass boiler; Understoked.			
Vendor	Visdamax			
MWt Rating	2.5	2.5	12	12
Delivery Model	Turn-key. Cap ex estimate below:			
Biomass tpa	790	883	11,509	10,665
Fuel	Cotton Gin Trash with 200t waste grain	Woodchip with 100t waste grain	Woodchip	Woodchip mixed with 7800t paunch
Biomass fuel $/GJ	$ 1.36	$ 3.48	$ 3.48	$ 3.48
Fuel Costs pa	17,371	48,204	628,286	285,998
Fuel Costs_15 years	$ 260,565	$ 723,054	$ 9,424,294	$ 4,289,974
$/t 7bar Steam ["fully inclusive"]	$ 17.00	$ 21.56	$ 15.43	$ 9.24
% Thermal Load Offset	100%	100%	100%	100%
$ pa Cost Savings	$ 472,488	$ 469,737	$ 178,104	$ 520,392
Simple Payback - Years	2.63	2.64	18.95	6.49

As shown above, offsetting the very expensive thermal energy from LPG at the two feedlots (blue and yellow columns) with biomass has very good economic viability. A key improvement for paunch utilisation is to reduce the moisture content. By reducing the moisture content from ~80% to ~50%, the energy in paunch increases from ~13,260 GJ pa to ~25,428 GJ pa LHV. Due to the low value of heat from the coal at the processor (green columns), the payback period for paunch dewatering at the processor is ~15 years (for a rotary fan press at ~$750k CapEx).

An option to improve the viability of the system is to dewater the paunch then backload cattle trucks with 50% moisture paunch to a feedlot, thereby supplying all of the boiler fuel required. Backloading cattle trucks with paunch results in a similar simple payback period, however provides an overall much high net present value due to the year on year reduction in paunch waste management costs; with the undiscounted NPV for a CGT fuelled boiler at $5.8 mil after 15 years and that for a paunch fuelled boiler at $9.0 mil after 15 years.

2.0 INTRODUCTION

2.1 Site Selection

An expression of interest survey was sent out to processors to collect data on the sites and assess the capacity to report data and infer the ease of collaboration in future milestones. The survey covered the following

- On average, how many tHSCW per week did your facility process over the past 12 month period?
- What is the approximate production of the following wastes in tonnes per week?
    - Paunch
    - DAF sludge
    - Waste activated sludge from aerobic ponds
    - Green stream screenings
    - Red stream screenings
    - Manure
    - Kitchen / cafeteria waste
    - Contaminated plastics
    - Contaminated cardboard
- Do you operate a rendering plant?
    - If so, what is the thermal load in MWt?
- What is the approximate plant average power load in MWe?
- What boiler fuel does your site burn?
- Approximately how much do you pay for power in $/kWh, including the volume and demand charges?
- Approximately how much do you pay for thermal fuel in $/GJ, including supply and transport charges?
- Please enter your street address to help determine surrounding industry and councils for suitable waste aggregation
- Please outline any additional sources of waste or other entities you have identified and communicated with in the past (e.g. councils, waste management companies, adjacent businesses etc)

Responses were compared with a weighted criteria matrix with the primary metrics of waste generation, as tpw of organic and non-organic wastes and inferred by LGA population, and estimated cost per annum of thermal and electrical energy. These were weighted with an importance factor of 2 and 1 respectively, with responses ranked from lowest to highest, multiplied by the weighting factor, and summed with the lowest score being desirable.

2.2 Aggregated Anaerobic Digestion at Red Meat Processor

The workshop was attended on the 12th of December by one technical staff member, two project managers from AMPC, and one from All Energy Pty Ltd.

The notes taken by All Energy during this workshop are summarized as follows:

- A background problem to the partner site's interest in participating in this project is the availability of power in the local area, presenting an infrastructure barrier to attracting business.

- As the process has access to adjacent industry and multiple producer suppliers, this will prove beneficial to an aggregated W2E plant by providing access to wastes in the supply chain of the processor
    - A previous pre-feasibility study had been completed for bio-hub nodes in NSW, with the local area being identified as a beneficial node
    - This was done in conjunction with a combined waste assessment, however the project eventually stagnated, due to an apparent lack of direction and responsibility of any one party, and questionable cost benefit analysis assumptions
- A goal of the site is reducing N&P loads in soils, currently achieved via cropping, with potential to reduce loads via combustion of wastes currently composted and spread to land
    - A new electro coagulation unit is being commissioned by the sites to reduce the fats, oils, and greases (FOG) content of wastewater from processing and tannery. This was not operational at the time of the workshop
    - There is interest in the N value of hair from the tannery (reported 14% mass fraction of hair as N)
        - Currently other tannery wastes are sent to QLD due to a mould inhibitor prohibiting blending this with the hair and de-watered paunch and composting for application on the co-located farm
    - A site tour showed a relatively simple wastewater treatment plant, consisting of a rotary screen, save-all, and belt press for paunch, with an uncovered anaerobic and aerobic dam located at the adjacent farm, but not seen during the site tour.
        - The unrealistically high sludge value reported in the survey was assumed to be referring to high moisture content dam sludges
- There is preference in staging such a project, an example of which may be starting with one digester tank, then scaling up modularly with additional tanks as more wastes are accepted. Due to the small generation of organic wastes and difficulties in handling dam sludges, it is likely that to reach the minimum scale for viability, third-party wastes will need to be aggregated in the first stage.

Overall, the partner site recognized the limitation of W2E using only their own meat processing wastes, and hence the value in aggregating suitable wastes. There was no expected opposition to taking third party wastes on site or opposition to a third party operating adjacent.

Reduction of the high N and P in soils from irrigation with mixed processing and tannery wastewater is a core goal of participating in this project; the commissioning of the electrocoagulation unit and how it will integrate and may affect the viability of a W2E plant is a key consideration for discussion.

The general reaction of anaerobic digestion is the microbial conversion of volatile organic carbon to methane (CH_4), with organic conversion rates of up to 90% observed in concentrated and well managed systems. Previous University of Queensland works on digesting red meat processing wastes have reported increases in N in digestate due to excessive proteins in feedstock as a potential challenge.

Management of N in the digestate is controlled by the feedstock, with the biological C to total N (C:N) ratio being a key value, with a favourable range reported as 25 – 32[1] for general co-digestion. Monitoring and controlling the C:N ratio is important to control and prevent the amount of both NH_3

[1] Nkemka et al (2015)

accumulation in the system, inhibiting methanogens (under 4000 mg N/L), and total N in the digestate. C:N ratio is often controlled by adjusting the fraction of green wastes in the feedstock.

If running mixed processing (expected to be higher N due to blood content) and tannery wastewater through the EC unit, it is expected that if EC sludge is sent to anaerobic digestion, NPK may accumulate in the digestate, however it is unknown if this will be retained in digestate solids and thus able to be dewatered and separated, or in supernatant, thus nullifying the purpose of EC in the first place. Depending on concentrations of NPK, this may be able to be mixed with the larger irrigation waste stream and still maintain a suitable specification. Regardless of this, the NPK will likely require purging from the system periodically. All Energy will consult with red meat processing waste anaerobic digestion experts from University of Queensland and University of Southern Queensland[2] for greater clarity on this.

One management option suggested by All Energy is that if the digestate supernatant is too high in NPK even after mixing with irrigation water, the digestate can be periodically dewatered with the supernatant re-processed through the EC, with this sludge then sent to composting.

Another unknown is the composition of the tannery wastewater and how it may affect digestion. Tannery wastewater has been reported as highly complex and characterized by high content of organic, inorganic, and nitrogenous compounds, very high chromium, sulfides, suspended solids (e.g. hair and trimmings), and dissolved solids. Sulfides are a strong inhibitor of AD, affecting almost all contributing species of bacteria, particularly hydrogenotrophic, acetogenic, and acetoclastic species; and should be kept under 3 mM of total S, or 2-3 mM H_2S. The N content of tannery water may present another issue; however it is unknown at this stage what inhibitory effect the high chromium content may have. It is recommended to take samples of the save-all effluent (i.e. EC influent) and tannery wastewater for testing to infer how this may impact an AD plant. If one stream proves to be significantly more problematic than the other, these may have to be segregated and run through the EC unit separately, in order to not poison the EC sludge.

2.3 Site Visit – Sampling of Key Streams

2.3.1 Water Treatment Block Flow Diagram

Previous works commissioned by the partner site produced the following block flow diagram of the existing wastewater treatment plant.

[2] Paul Jensen and Bernadette McCabe

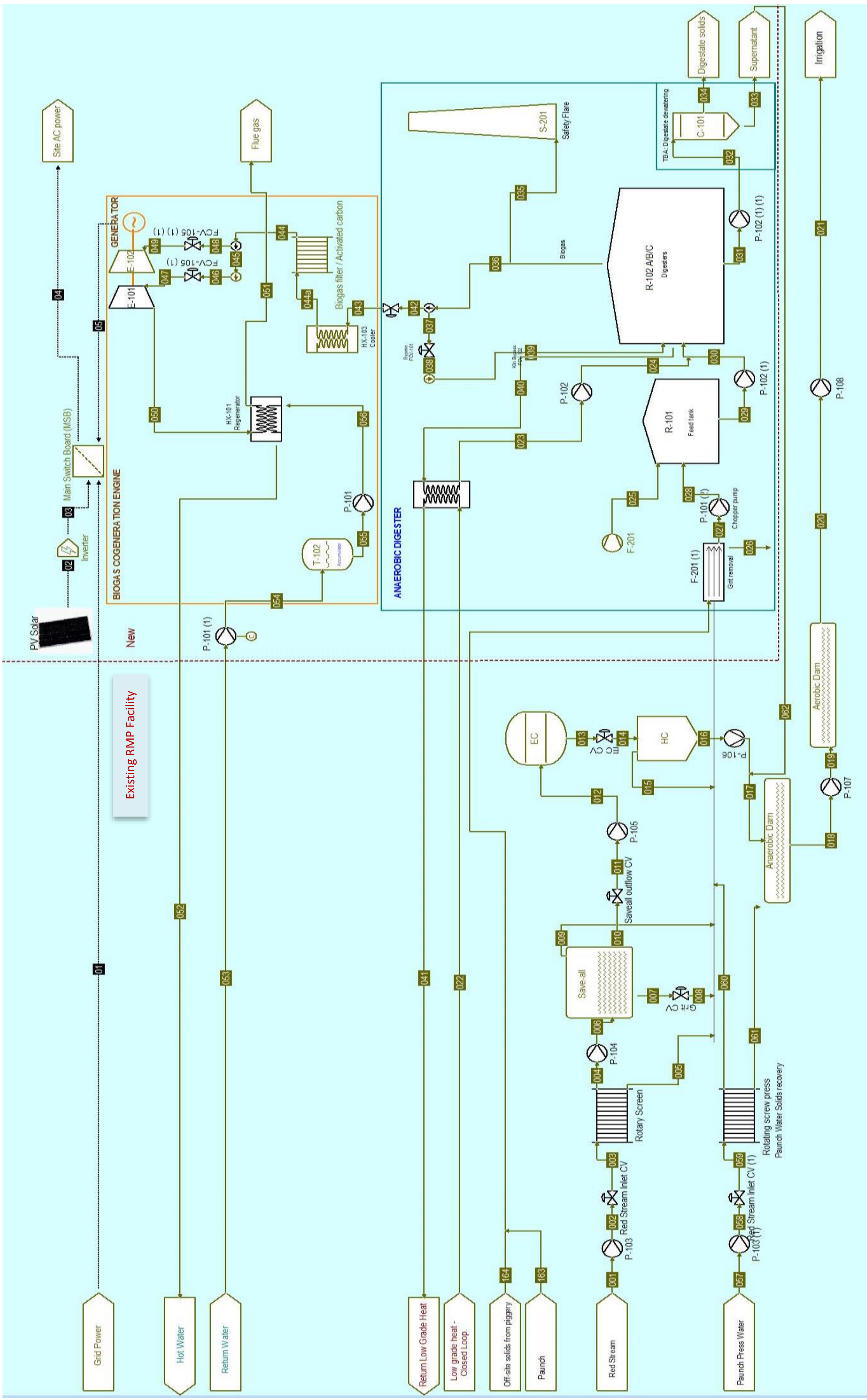


Figure 1: Flow diagram showing integration of an existing red meat processing (RMP) facility with an anaerobic digester and biogas cogeneration engine.

Saveall solids and rotary screenings are excluded from use as a W2E feedstock as these streams are currently sent to rendering, generating a direct saleable product revenue stream that is unlikely to be matched by W2E. A literature review of previous works[3][4][5][6][7][8] uncovered the following information on the current waste streams. Where cells are blank, information on the assay did not exist; where cells are highlighted in yellow, these numbers are assumed based on site knowledge and/or using available data.

Table 1: Existing known parameters of waste streams[9].

Stream	Paunch	Tannery hair	Tannery wastewater	Effluent mix pit	Pig blood
kL pw			4073	*18,900*	*20*
tpw	40	25	4073	18,900	20.6
m^3 pw	50		4073	18,900	
kL/hr			45	180 - 240	
ML / day				2.5 - 3	
TS%	29%	18%	0.48%	0.17%	0.15%
VS%					
Total N	1.31%	9.32%	476	172	1100
TKN			476	172	
NH_3		651.9	94		394
Total P	0.11%	0.05%	13	24	
Trivalent Cr		6.4	4 - 76 (34)		
BOD [or COD]			4570 11200	2760 5580	 13620
pH	7.2	11.6	Typically 9-12.5 with hair drop. Sunday morning as low as 5.2	6.5	7.17

[3] Johns Environmental 2020
[4] Southern Cross University Environmental Analysis Laboratory 20th October 2017, *Compost 'Totals' Analysis Report*
[5] Southern Cross University Environmental Analysis Laboratory 27th October 2017, *Compost 'Totals' Analysis Report*
[6] Eco Waste Pty Ltd 2016
[7] Environmental Earth Sciences 2019
[8] GHD Pty Ltd 2018,
[9] Yellow indicates inputs that are assumed based upon site knowledge and/or available data.

Stream	Paunch	Tannery hair	Tannery wastewater	Effluent mix pit	Pig blood
TSS			4840	1670	1483
K	0.10%	0.10%	46		
Cl			2110		
So4			3160		
Ca	0.32%	7.51%	530		
Mg	0.07%	0.07%	170		
Na	0.31%	3.69%	2020		
FOG			750	902	
S2-	0.11%	4.72%	570 (range from 60 to 1200)		
Ni			0.1		
Zn	103	100	0.44		
°C			22-25 low peak 31-32		
Alkalinity			1590		
TDS			9920	961	
C	45.50%	31.50%			
C:N	34.7	3.40			

In order of expected biochemical methane generating potential, the preference of wastes for W2E is as follows

Table 2: Energy content of waste streams, in order of expected BMP

Waste stream	Comment
1. Saveall float	Excluded – goes to rendering
2. Saveall overflow **– pre effluent mix pit**	Viable dilution stream, sampled by All Energy
3. Piggery guts	High value solid stream, sampled by All Energy
4. Dewatered paunch	High value solid stream, sampled by All Energy
5. Piggery blood	High value liquid stream, sampled by All Energy
6. Electro-coagulator inlet	Excluded – EC not yet commissioned

7. Manure	Difficult to sample solid manure – diluted yard wash water sampled by All Energy
8. Paunch screen and press water	Viable dilution stream – sampled by All Energy
9. Cattle wash water	As above "7. Manure"
10. Tannery hair screenings	Excluded – 4,3-CMP antifungal, Cr, and Na inhibitory effect on methanogenic bacteria

At the date of sampling by All Energy (3rd March 2020), the paunch press and auger were not operational; due to extended downtime, the samples of paunch and paunch water were posted up to Brisbane on the 17th of March 2020. Samples were kept refrigerated until BMP testing, which is not expected to significantly affect results due to Volatile Organic Carbon (VOC) degradation.

2.4 Supply Chain Facility Descriptions and Energy Consumption

2.4.1 Feedlot 1

This is a beef feedlot located in QLD. This facility takes in livestock from farms within the supply chain, primarily droughtmasters, and feeds on barley for an average of 100 days before transfer to the abattoir. This facility is 100% off grid, with power supplied via two 700 kVA diesel generators, steam flaking by a 3 MW (calculated to be over-spec) LPG boiler in a shift of 6 hours, and bore water. The capacity of the feedlot was recently expanded to 40,000 SCUs, with future plans to expand up to 50,000 SCUs. It is assumed the feedlot operates for 365 days per year.

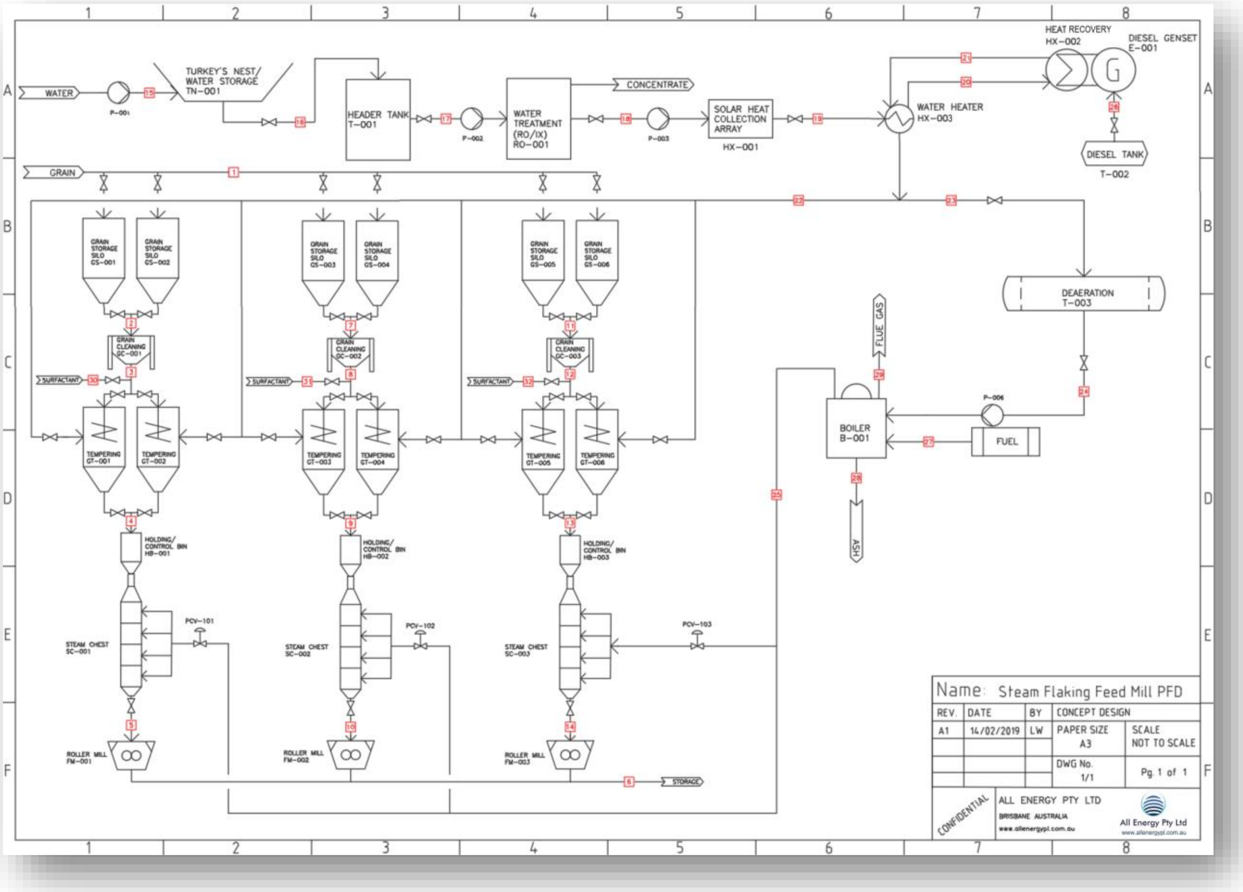


Figure 2: General feedlot steam flaking process flow diagram

Steam consumption and annual spend on LPG as reported by Feedlot 1 for FY18-19 is summarised below, along with calculated energy content and steam requirements.

Table 3: Feedlot 1 steam consumption and thermal spend

	Feedlot 1
Current $/t Steam [fuel only]	$ 83.15
Current $/GJ [fuel purchase only]	$ 26.96
GJ burned pa	18,169
Steam tpa	5,891
steam tpd	16
steam tph	2.69
Steam overall GJ/t	3.084
Estimated current boiler efficiency	75.0%

LPG purchased at $26.96 per GJ is comparatively very expensive for a thermal fuel, but typical for a site not on the gas grid and serviced only by trucking. This presents a strong motivation to offset this high cost item.

2.4.2 Feedlot 2

Feedlot 2 is located in QLD, with 23,000 SCUs on feed for an average of 60 days, before transfer to the abattoir. Power is supplied via the grid, with thermal energy for steam flaking from a 3 MW LPG boiler running for 6 hours per day, and bore water. It is assumed the feedlot operates for 365 days per year.

Steam consumption and annual spend on LPG as reported by Feedlot 2 is summarised below, along with calculated energy content and efficiency of the boiler.

Table 4: Feedlot 2 steam consumption and thermal spend

	Feedlot 2
Current $/t Steam [fuel only]	$ 85.24
Current $/GJ [fuel purchase only]	$ 27.64
GJ burned pa	18,740
Steam tpa	6,076
steam tpd	17
steam tph	2.77
Steam overall GJ/t	3.084
Estimated current boiler efficiency	70.0%

Compared to Feedlot 1, it can be seen that Feedlot 2 is consuming a disproportionate amount of steam at 2.77 tph for 23,000 SCUs vs 2.69 tph for 30,000 SCUs, or 0.09 kg/hr/SCU vs 0.121 kg/hr/SCU respectively. This along with the higher cost of LPG at $27.64/GJ contributes to a greater annual thermal cost of $517,941 and specific thermal cost of $22.52/annum/SCU capacity vs $16.33/annum/SCU capacity respectively. This presents an even stronger motivation to offset this high cost item.

2.4.3 Processing Plant

This abattoir located in QLD processes approximately 6000 hpw, supplying the local supermarkets and exporting. The site is on an 11 kV high voltage grid power feeder, potable water supplied via the water mains, and thermal energy for rendering supplied by a coal-fired boiler run for 16 hours per day. It is assumed that the boiler runs for 300 days per annum, with paunch produced at 156 tpw, 50 weeks pa.

Annual spend on coal as reported by the processor is summarised below, along with calculated energy content and efficiency of the boiler. Steam consumption figures are calculated with an assumed boiler efficiency of 80%.

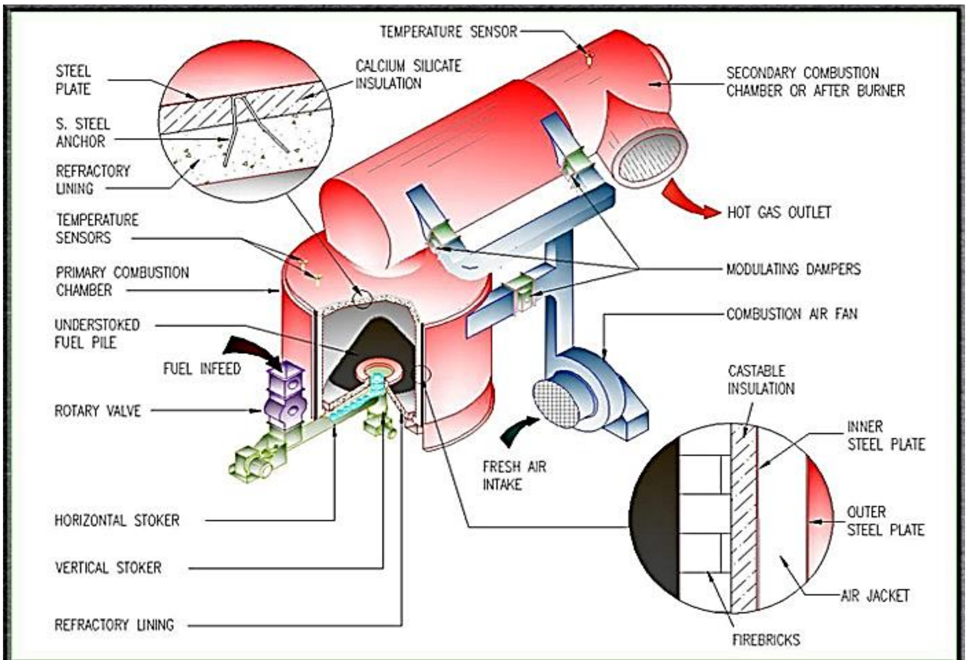
Table 5: Processor steam consumption and thermal spend

	Processor
Current $/t Steam [fuel only]	$ 14.58
Current $/GJ [fuel purchase only]	$ 4.20
GJ burned pa	191,988
Steam tpa	55,306
steam tpd	184.4
steam tph	11.5
Steam overall GJ/t	3.471
Estimated current boiler efficiency	80.0%

Based on the relatively cheap $/GJ for coal purchased at the processor, a multi-fuel boiler is expected to have modest economic feasibility, compared to the feedlots where offsetting high cost LPG is expected to present an attractive opportunity. Depending on the avoided disposal cost of paunch, assumed at $60/tonne, when blending with woodchip, this may be the redeeming revenue item.

2.5 Multi-Fuel Biomass Boiler

All Energy Pty Ltd has recently become aware of a multi-fuel biomass boiler with a price point not seen before in the market, with good potential to offset steam costs in the red meat industry due to the wide range of biomass and high moisture content that can be combusted. The Bio-T (Turbomax) boiler by Visdamax[10] has been developed in New Zealand for the sawmill industry and its high-moisture, low energy content, sticky, green sawdust and sawmill residues, utilising a high residence time combustion chamber heap burning an under-stoked conical fuel pile. A schematic of this plant is shown below.



TURBOMAX Boiler / Heater Model No.	BIO T-BURNER Model No.	OUTPUTS			FUEL CONSUMPTION	
		Steam (kg/hr)	Hot Water (MW)	Thermal Oil (MW)	Hardwood tonne / day at 50% mc	Radiata Pine tonne / day at 130% mc
					Moisture Content = dry weight basis	
Turbomax-2	1800	2,000	1.4	1.1	14.9	21.5
Turbomax-4	2700	4,000	2.8	2.2	29.7	43.6
Turbomax-6	3300	6,000	4.2	3.4	48.2	69.5
Turbomax-8	3600	8,000	5.3	4.5	59.4	85.5
Turbomax-10	4200	10,000	7.0	5.6	74.2	107.0

Figure 3: Visdamax Bio-T (Turbomax) heap burn biomass boiler

As shown above, combustion air is injected tangentially to the heap, forming a cyclonic flame front. The temperature inside the combustion chamber is maintained over this high residence time by high refractory firebricks providing good insulation, achieving complete combustion. The Bio-T (Turbomax) is claimed to be capable of burning biomass with moistures up to 130% (dry basis) or 56.5% (wet basis).

[10] http://www.visdamax.com.my/Products-HeatPlants.html#VisdamaxBioTTurbomaxBoiler

This boiler would then be suitable for combusting the paunch produced in red meat processing after blending with dryer and higher calorific value biomass or after multi-stage mechanical dewatering.

3.0 PROJECT OBJECTIVES

The objectives of the project are:

- Creation of tools to assess the economic viability of W2E that aggregate wastes from processors, feedlots and other streams.
- Creation of tools to assess the thermal energy and power generation potential from processing plant wastes and other waste streams.
- Provide clarity on the key parameters impacting the economic and technical viability of waste to energy (W2E) facilities for processors e.g. types of waste, scale, etc.
- Explore current interest and activity in W2E throughout Australian RMI processors.
- Map out options and collaborations for aggregated W2E facilities.
- Feasibility studies for two specific case studies considering how waste type, tonnages, composition and technology selection impacts CAPEX and economic viability of aggregated W2E projects.
- Communicate findings via reports, articles, snapshot, workshops and other suitable avenues.

The project will consider all output streams from RMPs, with a particular emphasis on materials that are landfilled, the RMP pays to have removed or are not undergoing any value-adding. Processors generate a wide range of wastes with different compositions, moisture contents, and lower heating values (LHV; GJ / t of net energy). A facility processing 900 head of cattle a day, five days a week was estimated to generate the following tonnages of waste (interpolation of available data from RMP waste audits):

- paunch 3798 tpa at 24.8% solids
- activated sludge from waste water treatment plant 7887 tpa at 11% solids
- other organics and mortes 1377 tpa at 25% solids
- DAF sludge 2839 tpa at 5% solids (DAF cell float, un-dewatered)
- non-recyclable plastics (e.g. multi-layer plastics, plastics unsuitable for recycling,
- contaminated plastic) 598 tpa
- non-recyclable paper (e.g. multi-layered or contaminated). 432 tpa
- workshop wood wastes 174 tpa
- recycled material not considered for this project (paper, carboard, metals, plastics)
- garden / green wastes (highly variable between plants)

Sources of data: AMPC Project 2016.1010 and AMPC/MLA Project P.PIP.0547.

Previous works have highlighted the variability in the moisture content of materials (due to different levels processing and sources) which impacts the energy content and materials handling options for the wastes. Whilst paunch is often "solid" after processing through a mechanical press, it will routinely have free moisture and require either further drying or blending with a higher energy fuel before utilization in a W2E facility.

4.0 METHODOLOGY

4.1 Sampling and Lab Testing

4.1.1 Eurofins mgt

Samples of saveall overflow, piggery guts (lung, spleen, and heart composite sample), and piggery blood (from stuck pig) were delivered to Eurofins mgt in Brisbane on the 4th of March 2020. It was advised that blood and guts were outside of Eurofins' capability; result of total solids and volatile solids tests for saveall overflow measured by Eurofins is:

Table 6: Saveall overflow Eurofins mgt assay result

	Total Solids	***Volatile Solids a.k.a. "Combustible Solids"***
Saveall Overflow	*940 mg/L (0.094%)*	*100 mg/L (10.6% VS/TS)*

The value of VS/TS reported by Eurofins was significantly lower than expected (> 75% expected), and TS% somewhat lower than expected at around 0.2%; one hypothesis for this is extended time with the sample bottle in an upright position, where solids had settled to the bottom, with a small sample poured off the top. During the solids percentage test where the sample was heated to 103 – 105 °C until all liquid was evaporated, it is hypothesised that this drove off the volatile solids, thus not reflected in the VS/TS reported.

4.1.2 University of Queensland Advanced Water Management Centre

The following samples were delivered to the UQ AWMC on the 4th of March 2020

- Piggery blood
- Piggery guts
- Saveall overflow
- Yard manure wash water

With the following samples delivered on the 17th of March 2020

- Paunch
- Paunch water

Table 7: UQ AWMC assay results

	Blood	***Guts***	***Saveall Overflow***	***Yard Manure***	***Paunch***	***Paunch Water***
TS (g/kg)	*232.43±0.3*	*380.77±2.11*	*3.81±0.02*	*4.54±0.13*	*339.16±21.63*	*7.15±0.1*
TS%	*23.24%*	*38.08%*	*0.38%*	*0.45%*	*33.92%*	*0.72%*
VS (g/kg)	*223.01±0.26*	*367.45±2.67*	*3.27±0.02*	*3.06±0.12*	*325.22±20.85*	*5.04±0.11*
VS/TS %	*95.95%*	*96.50%*	*85.83%*	*67.40%*	*95.89%*	*70.49%*
Ash (g/kg)	*9.42±0.08*	*13.31±1.82*	*0.54±0.04*	*1.49±0.03*	*13.94±0.87*	*2.11±0.03*
Total COD	*320.3±10.9*	*537.2±20.5*	*7.1±0.2*	*5.2±0.6*	*433.1*	*9.7±0.3*
TCOD/VS	*1.44*	*1.46*	*2.17*	*1.70*	*1.33*	*1.92*

The observed values above are more in-line with expected values, particularly the TS% of the saveall overflow, and VS/TS of each stream. The low TS% and COD of the saveall overflow indicate a high removal of FOGs from the saveall, suggesting that the saveall is running quite effectively. It is important to divert this stream before it reaches the effluent mix pit and is further diluted by yard wash water, ensuring that this stream will become unviable.

The above suggests that piggery blood, guts, and paunch are all high value streams, with all available feedstock consumed in a W2E plant. Yard manure / cattle wash water was confirmed to be highly dilute and low energy content, and not of value to this project, continuing being sent to the existing aerobic dams. It is of interest to All Energy to compare saveall overflow and paunch water as the dilution stream, as these substrates have comparable TS%, VS/TS%, and COD. Two mixes were formulated for BMP testing, details below:

Table 8: BMP test representative mix fractions, HRT, SLR, and tpw

Data	MIX #1	MIX #2	Notes
Tonnes per week (tpw)	789	616	
Solids tpw	75	58	
Mix TS%	9.5%	9.5%	
HRT [days]	22	28	Hydraulic Retention Time = Digester volume [m3] / Input flowrate [m3/day] Mix 2 preferable HRT to ensure more complete digestion
SLR [kg/m3/day]	4.3	3.3	Solids Loading Rate = Solids [kg/day] / Digester volume [m3] Mix 2 more manageable SLR
Blood [mass fraction %]	2.6%	3.3%	
Guts [mass fraction %]	10.1%	13.0%	
Paunch [mass fraction %]	5.1%	6.5%	
Saveall overflow [mass fraction %]	82.2%		Concentrated to 4% TS
Paunch water [mass fraction %]		77.2%	Concentrated to 2% TS

The total saveall overflow 13,600 tpw and paunch water is available at 200,700 tpw. It was decided to utilise 475 tpw dewatered paunch water at 2% solids (~18% of total available). The dewatering technology will need to be considered. An allowance of $182k has been made for a hydrocyclone technology to dewater the required fraction of the paunch water.

4.2 Biochemical Methane Potential (BMP) Test

A schematic of a BMP test supplied by UQ is shown below. The BMP test measures a sample's biodegradability and is used to determine the cumulative volume yield of CH4 that is produced from the short-term, dynamic (that is, not steady state) digestion of a sample at the lab scale[11]. BMP results are commonly used to evaluate digestion efficiency (when compared to the theoretical yield) and the extent of organic solids destruction and residual solids at the completion of the digestion process[12]. In the following stages of this project, BMP results were obtained for two representative mixes of samples of specific feedstocks and utilized for process modelling, rather than highly variable theoretical or assumed values.

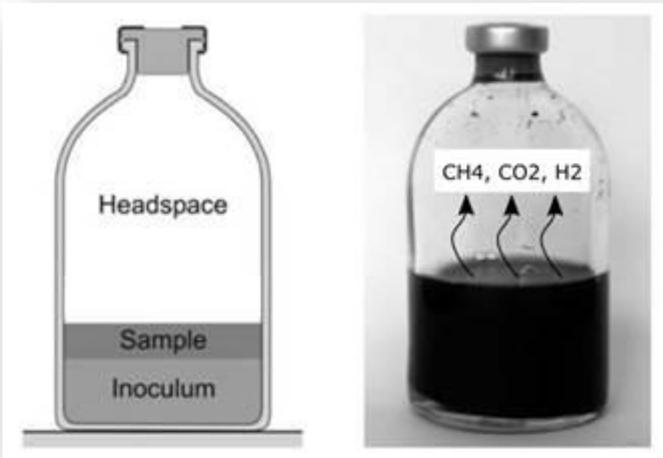


Figure 4: Simple schematic of BMP test

Samples as received by UQ AWMC, from left to right: saveall overflow, tannery wastewater, piggery guts, yard wash water, piggery blood, paunch press water, paunch solids are shown in figure 5. These samples were mixed at the fractions specified above, incubated, and digested as shown in figures 6, 7, 8, and 9.

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[11] Navaratnam 2012, *Anaerobic co-digestion for enhanced renewable energy and greenhouse gas emission reduction [PhD Thesis].* Marquette University, Milwaukee WI

[12] For a complete review of factors affecting the BMP assay method, refer to Filer, Ding, and Chang, 2019. *Biochemical Methane Potential (BMP) Assay Method for Anaerobic Digestion Research.* Water

Figure 5: Samples as received by UQ

Figure 6: Subsamples for testing

Figure 7: Samples in incubation

Figure 8: Incubated samples

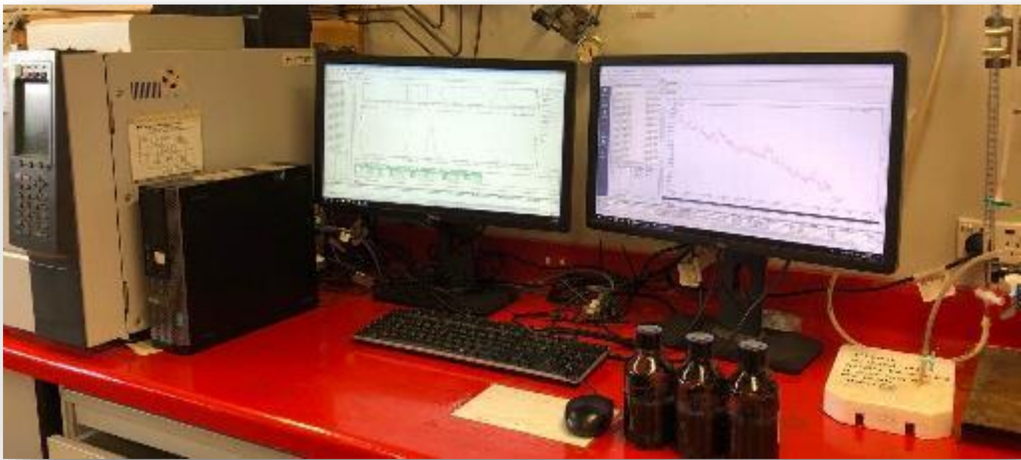

Figure 9: Gas sampling and measurement

4.3 BMP Results

Figure 10 shows the cumulative methane potential test results. Note that 'Mix 1' refers to the supplied solid wastes only (i.e. no dilution stream and thus solids at 26%), 'Mix 2 PW' is the mix option where paunch press water is the dilution stream, and 'Mix 3 RS' is the mix option with saveall overflow (red stream) is the dilution stream.

It can be observed that the optimal mix fraction is Mix 2, due to the slightly higher fraction of volatile solids and COD in paunch press water compared to saveall overflow, with a BMP asymptote at 506 L CH4/kg.VS (40 m3/t wet) and 432 L CH4/kg.VS (27m3/t wet) respectively. This corresponds to a COD destruction of 98% and 85% respectively.

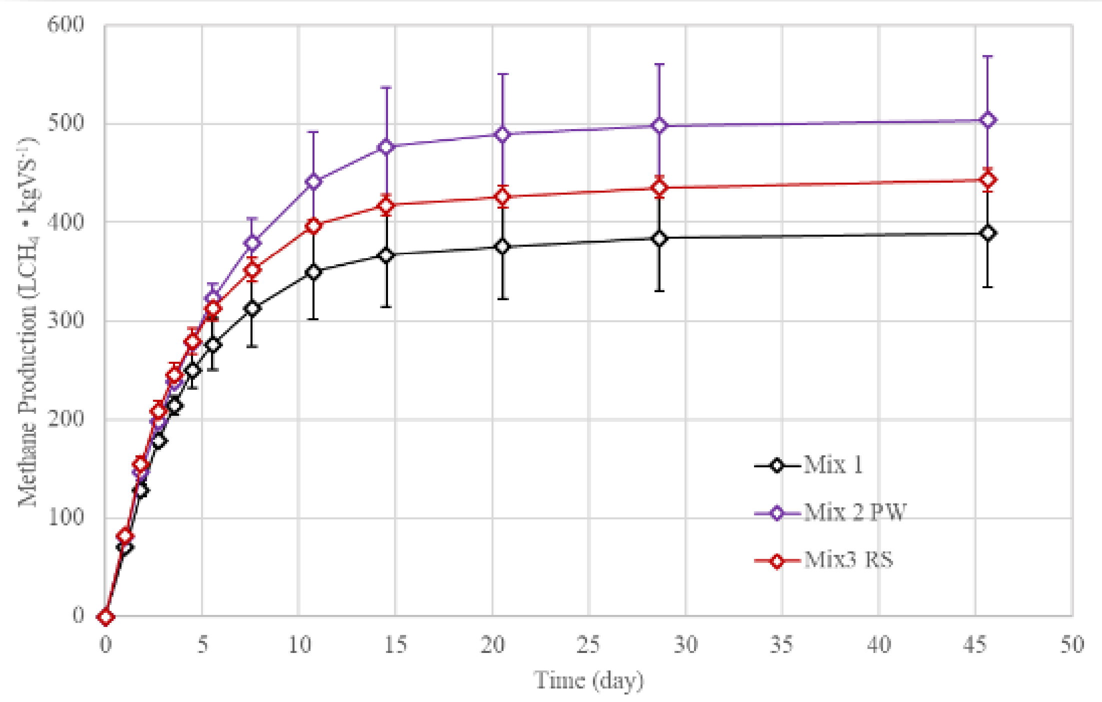

Figure 10: Methane production from tests digesting composite mixes at 37 DegC

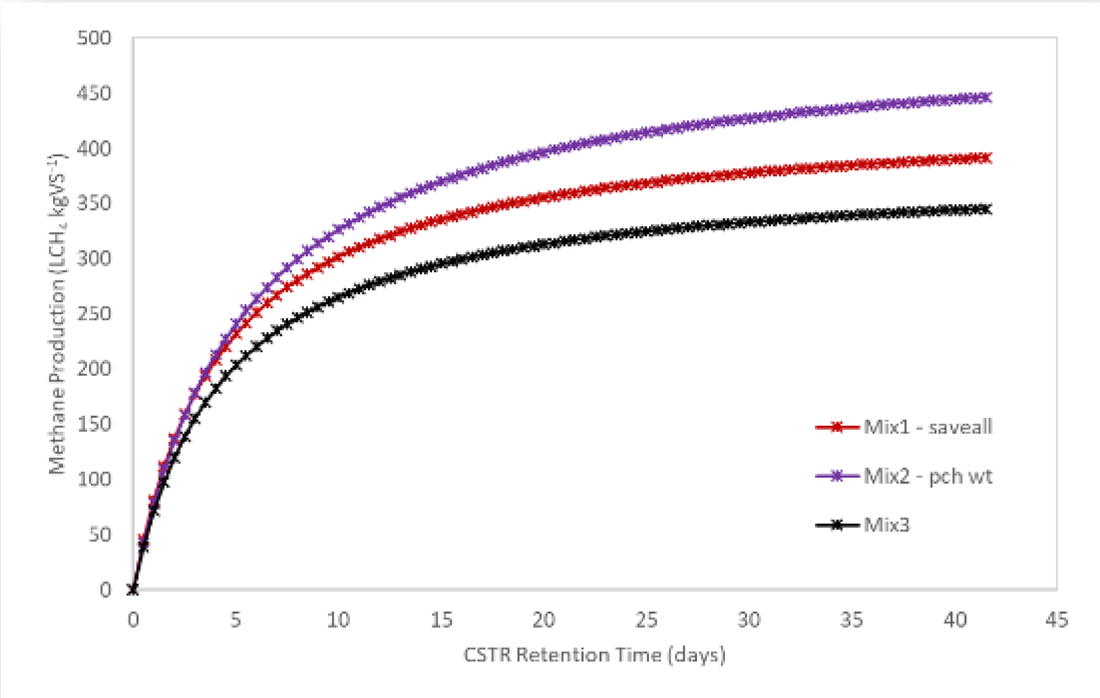

Figure 11: Model prediction of methane recovery for CSTR reactor

4.4 Anaerobic Digester Plant Technical Specification

The technical specification sent to vendors to quote a budget price against is shown below.

Technical Specification - Beef / Veal / Pork Processing Wastes Anaerobic Digestion			
Rev	**By**	**Details**	**Checked**
A	MCB	For budget pricing	GMF
1. General Description			
This Specification covers the minimum design, supply, manufacture, delivery to site, installation & commissioning requirements for a facility to create biogas			
Due to the low value of thermal energy, it is anticipated that all biogas will be converted into electricity			
This project is partly funded by Australian Meat Processor Corporation (AMPC) hence note that the final report is to made available on-line via the AMPC website.			
One purpose of the project is to improve the overall profitability of Australian meat processing facilities by an on-site AD plant aggregating wastes			
The plant must be capable of continuous, unattended, and automated operation for **30,000 - 40,000 tonnes of feedstock per annum**, with a view to expanding the plant in modules of 2500 m3 as more wastes are accepted			
"Turn key " pricing is required for an anerobic digester facility to process materials as outlined below.			
Budget pricing required by COB Thur 21 May 2020. Email submissions to: max@allenergypl.com.au			
2. Project Location			
Site Characteristics			
Site Location:	Brownfields site (available land adjacent to existing plant) in industrial zoning.		
Footprint area available:	As required.		
3. Primary Feedstocks			
Stream #1 - Piggery Blood	Production	20.6	tpw
	TS%	23.24%	
	VS/TS%	95.95%	
	Total N	1100	mg/L
	NH3	384	mg/L
	BOD		
	COD	13,620	mg/L
		320	g/kg
	pH	7.17	
Stream #2 - Piggery Guts - Whole	Production	80	tpw
	TS%	38.08%	
	VS/TS%	96.50%	
	BOD		
	COD	537.2	g/kg
Stream #3 - Paunch	Production	40	tpw
	TS%	34%	
	VS/TS%	95.89%	
	Total N	1.31%	
	pH	7.2	
	C	45.50%	
	C:N	34.7	
	BOD		
	COD	433.1	g/kg
Stream #4 - Saveall Overflow	Production	13,608	tpw
	TS%	0.38%	
	VS/TS%	85.83%	
	BOD	3833	mg/L
	COD	7750	mg/L
		7	
	Total N	239	mg/L
	pH	7	
	FOG	1253	mg/L
Stream #5 - Paunch Press Water	Production	475	tpw
	TS%	2%	
	VS/TS%	70.49%	
	COD	9.7	g/kg
4. Representative Mix			
Mass Fractions			
Piggery Blood		3.3%	
Piggery Guts		13.0%	
Paunch		6.5%	
Saveall Outflow		0%	
Paunch Press Water		77.2%	
Mix BMP_30 days		**430**	**m3 CH4 / kg VS**
For 1 x 2500 m3 digester			
HRT	**28**	**days**	
SLR	**3.3**	**kg/m3/day**	
Estimated biogas production	**23,000 - 27,000**	**m3 pw**	
Estimated engine rating	**1000 - 1,100**	**kWe**	
Estimated recoverable thermal energy	**1,100 - 1,200**	**kWt**	

Figure 12: Aggregated Waste Digester Technical Specification - Key Data

5. Scope of Work
The Scope of work comprises the provision of all labour, material, equipment and services necessary to carry out the design, detailed engineering, supply, manufacture, inspection, packing and preparation for shipment, delivery to the project site, site supervision, installation, testing, commissioning, and training of management and operators for the Equipment. The Equipment shall include all of the major and ancillary unit operations for correct operation of the plant, including:
- Feed stock receiving and handling - feedstock should be processed immediately i.e. no stockpiling.
- Any feed stock pre-treatment / mixing / dewatering / drying / dillution.
- Equipment for the biogas cleaning, compression, storage and cogeneration
- Equipment for loadout of the digestate (note that dewatering is not required as digestate will be used in the co-located cropping operations).
- Any dosing and/or mixing systems.
- Vapour / exhaust gas handling, exhaust and safety flare (including treatment)
- Any heat generation where required (Note: excess heat or hot water is not available)
- Associated utilities (all facility electricals, compressed air, cooling water, heat exchangers, etc)
- Programmable Electronic Control System to enable automated and unattended / remote operation.
- Instrumentation, Controls and Control Room located locally.
It is expected that the system will be capable of automatically turning down production by at least 50% and have the cabability to be expanded in the future. The capacity of the components of each subsystem shall be sized by the vendor taking into account the information provided. The vendor shall include in their proposal an allowance for safety and risk reviews (HAZOP and Constructability) for a total of two days.
6. Australian Standards
The designed plant must adhere to all applicable Australian Standards. Non-conformance must be rectified by the vendor at no cost to the client.
Relevant standards include
- Electrical installation in accordance with AS3000. Wiring not conforming will be rectified by the vendor at no cost to purchaser.
- Hazardous area rating to more stringent of State or National compliance (National is ANZ Ex or IEC Ex).
- High-pressure piping, in accordance with AS 4041 or B31.3
- Pressure Vessels, in accordance with AS 1210 or ASME VIII. MDRs in accordance with AS1210 must be supplied.
- Boiler standards: AS2593, AS1228, AS1548.
- Design of access ladders, platforms, walkways and handrails, in accordance with AS 1657.
- Machine guarding, in accordance with AS 4024.1.
- Three phase electric motors minimum energy performance (MEPS) AS/NZS 1359.5:2004
- Variable Speed Drives / UPS / Inverters EMC Compliance Requirements (c-tick)
- Instruments. Conform to either SAA or IEC standards for hazardous area applications where required.
- Storage: flammable & combustible liquids (AS1940), corrosives (AS3780), oxidizing agents (AS4326), cryogenics (AS1894).
- Type B gas installation and in keeping with AS5601 and AS 3814 (preference that natural gas and LPG not to be used).
- Gas-fired appliances (e.g. for start-up), in accordance with AS 3814, (preference that natural gas and LPG not to be used).
7. Site Specific Specifications
Compliance with NSW biogas requirements.
The following site specific requirements apply to the facility:
- Duty / Standby of critical pumps is required
- Plant must be designed for 24/7 operation for 334 days per year.
- All flanges are to be suitably ANSI rated with raised face. DIN will not be accepted.
- All piping must be an appropriate material of construction for the contained fluid.
- Field junction boxes are to be stainless steel.
- All structural steel members, pipe supports, cable trays & ladders to be galvanised. All cable trays / ladders to be covered.
- Plant operation and equipment maintainability must be considered during design to ensure suitable access is provided.
- Overall sound pressure levels must be less than 80 dBA at a distance of 1 metre.
- All piping where any surface is above 55°C will be insulated for heat conservation and personnel protection
- Cold insulation (below +15°C) must have an impervious vapour barrier and be covered by aluminium.
- Equipment selected must be serviced within Australia with readily available spares.
Digestate from the facility will be pumped for use in the adjacent cropping land
8. Itemised Price List
Please provide full pricing: supply, delivery, installation and commissioning. Budget pricing **itemised** with exclusions clearly noted
9. Utility Requirements
The Technology Provider shall nominate a list of utilities, operating costs, operating requirements & other materials required for the operation of the Equipment. The vendor shall nominate required consumption rates & quality requirements as well as:
- Personnel
- Heating
- Cooling Water
- Waste Management
- Pneumatics (e.g. for instrumentation and control)
- Water.
- Power Supply
- Chemicals
- Consumables (e.g. filter bags, filter cartridges)
10. Submission Documentation
In general, the Technology Provider shall present in the Proposal the following documentation:
- Layout and General Arrangement drawings
- Process flow diagrams
- Design Calculations
- Performance guarantees that can be provided for quality, reliability, and noise emissions.
- Personnel / staffing requirements
- Itemised pricing of equipment and services
- Terminal / Tie-in point (TIP) details - list terminal points and connection details for interconnecting pipe work (e.g. flow, size, pressure)
- Electrical equipment load list
- Equipment List
- Service requirements
- Major equipment specifications, datasheets [where available]
- Stack information [where available]
- Any other operational costs

Figure 13: Aggregated Waste Digester Technical Specification – Supplementary Requirements

Due to delays in collecting paunch samples, delays in lab testing due to public holidays and coronavirus lockdowns, and greater turnaround time from vendors while working at home, it was specified for vendors to quote only on the following plant

- One (1) 2500 m3 digester
- Feedstock receival
- Feedstock buffer tank
- Flare
- Necessary civil works
- Additional balance of plant
- Delivery to site, installation, and commissioning

Biogas cleaning and cogeneration engine was excluded from the RFQ in order to improve budget price turnaround times. All Energy Pty Ltd has extensive capital cost correlations for this piece of plant, so can interpolate for the scale with a high degree of accuracy.

4.5 Fuel Options and Available Biomasses Assay

The following table summarises some fuel options for southern Queensland.

Table 9: Fuel options specific for southern Queensland.

Fuel [all estimates exclude GST]	Units	Quote	LHV MJ/kg	LHV MJ/L	$/GJ - calculated; fuel supply only	Onsite tank storage per month	$/GJ incl. fuel supply and tank storage. 10 yrs.
LNG	$/t retail	$817.50	49.10	20.92	16.65	16,590	21.94
LPG (Propane) - Origin (retail)	per litre	$ 0.62	46.61	23.07	27.00	250	27.08
Diesel	per Litre	$ 1.16	42.61	35.58	32.52	NA	32.52
Heavy fuel oil (i.e. recycled lube oil)	per Litre wholesale + haulage	$ 0.50	37.28	34.67	14.47	NA	14.47
Biomass - ground greenwaste woodchip landscaping 40% moisture	per tonne delivered	$190.00	10.0		19.00	NA	19.00
Biomass - air dried hardwood sawmill residue ~30mm; assumed 16.4% moisture	**per tonne delivered**	**$54.59**	**15.7 to 17.5**		**3.48 to 3.12**	**NA**	**3.48 to 3.12**
Cotton gin wastes: Cotton gin wastes - high seed and lint content; ginning season approx. Apr-Aug; 15.5% moisture.	**per tonne delivered**	**$22.00**	**16.2**		**1.36**	**NA**	**1.36**
Refuse derived fuel	per tonne delivered	-$53.43	13.43		-3.98	NA	-3.98

The seasonal ginning of cotton for 3-5 months per year means that some CGT will need to be stockpiled. Due to the very low moisture content of this fuel and inherent fire risk, safety considerations such as proper stockpile design and wetness management will need to be considered and implemented. The CGT is "free issued" by the gin with the main expense being haulage from the gin to site.

An analysis by HRL Technology in accordance to AS 1038.5-1998 Coal and Coke – Analysis and Testing – Gross Calorific Value, reported the following properties of CGT[13]:

Table 10: Analysis results for Cotton Gin Trash (CGT), hardwood chip, cypress and paunch Proximate, Ultimate Analysis.

Moisture Content [%] – NSW	**8.0**
Ash [%] – NSW	10.0
Ash [%] – Netherlands (NL)[14]	17.6
LHV [MJ/kg] – NSW	15.5
Volatile [%] – NL	67.3
Fixed C [%] – NL	15.1
H [%] – NL	5.26
N [%] – NL	2.09
O [%] – NL	36.38
C [%]	39.59
LHV [MJ/kg] – NL CGT	15.27

[13]http://www.insidecotton.com/xmlui/bitstream/handle/1/4172/CGA1203%20Fuel%20Investigation%20CRDC.pdf?sequence=3&isAllowed=y
[14] https://www.ecn.nl/phyllis2/Biomass/View/1242

Job Number: 170521	70 day cotton seed	Hardwood Chip Project 2	Paunch
	170521-1	170521-4	170521-5
Ash Yield			
Ash Yield	4.4 % (db)	0.9 % (db)	7.7 % (db)
CHN			
Carbon	48.8 % (db)	50.7 % (db)	48.3 % (db)
Hydrogen	6.5 % (db)	6.2 % (db)	5.9 % (db)
Nitrogen	0.59 % (db)	0.08 % (db)	0.53 % (db)
Total Moisture			
Total Moisture	15.5 % (ar)	7.7 % (ar)	80.1 % (ar)
Volatile Matter			
Fixed Carbon	17.8 % (db)	17.2 % (db)	20.2 % (db)
Volatile Matter	77.8 % (db)	81.9 % (db)	72.1 % (db)
Calorific Value (CV)			
Gross Dry Calorific Value	20.9 MJ/kg (db)	20.4 MJ/kg (db)	18.9 MJ/kg (db)
Gross Wet Calorific Value	17.6 MJ/kg (ar)	18.8 MJ/kg (ar)	3.8 MJ/kg (ar)
Net Wet Calorific Value	16.2 MJ/kg (ar)	17.5 MJ/kg (ar)	1.7 MJ/kg (ar)
S, Cl, F, Br, I			
S	0.20 % (db)	0.01 % (db)	0.50 % (db)
Cl	0.01 % (db)	0.03 % (db)	0.11 % (db)
F	134 mg/kg (db)	48 mg/kg (db)	152 mg/kg (db)
Br	<10 mg/kg (db)	<10 mg/kg (db)	13 mg/kg (db)
I	10 mg/kg (db)	<10 mg/kg (db)	35 mg/kg (db)

SGS Ref No. MKY16-10926
Sple No. Wood Waste

ANALYSIS RESULTS Sample ID:		MKY16-10926.001 Cyprus Chip	MKY16-10926.002 Pine hardwood Chip	MKY16-10926.003 Hardwood Sawdust	MKY16-10926.004 Hardwood Chip
Total Moisture (as received)	(%)	12.5	8.8	22.5	9.1
Air Dry Basis unless otherwise stated					
Moisture (air dried)	(%)	4.6	4.9	0.7	1.2
Total Sulfur	(%)	0.12	0.15	0.12	0.05
Gross Calorific Value	(MJ/kg)	18.19	17.78	17.95	17.22
Gross Calorific Value	(kcal/kg)	4345	4247	4287	4114
Gross Calorific Value (db)	(kcal/kg)	4555	4466	4317	4164

Figure 14: Biomass assays

5.0 PROJECT OUTCOMES

5.1 Proposals Received from Market

Bespoke proposals were received from Biogass Renewables Pty Ltd and Gaia EnviroTech, with Energy 360 adapting a previous red meat processor quote of a similar scale. Exclusions were estimated by All Energy Pty Ltd through a combination of previous works and industry heuristics.

5.2 Biogas Cleaning and Cogeneration Engine

5.2.1 List of Assumptions

- Biogas produced at 23,000 – 27,000 m3 / week at 60 - 70 mass% CH4 purity (LHV 25 MJ/m3), with the remainder made up primarily by CO2 with trace of amounts of CO, H2S, and water vapour
- H2S content assumed 1000 – 5000 ppm
- Free moisture content removed via knockout pot

5.2.2 Biological Scrubber[15]

Biogas cleaning is typically required in order to prevent against premature wear in pipeline and engine plant, and to improve the heating value of the gas. The biological scrubber operates on the ability of micro-organisms to biochemically oxidize certain undesirable inorganic and organic compounds present in raw biogas. An example schematic of a biogas scrubber is shown in Figure 15.

[15] The majority of the content in section 4.7.2 is based on Forkmann, 2014. *Technological Concept for the Biological Gas Treatment at Biogas Plant VEGGER in for Reduction of the Amount of Hydrogen Sulfide in the Biogas of the Fermentation Stage,* TS Umweltanlagenbau GmbH

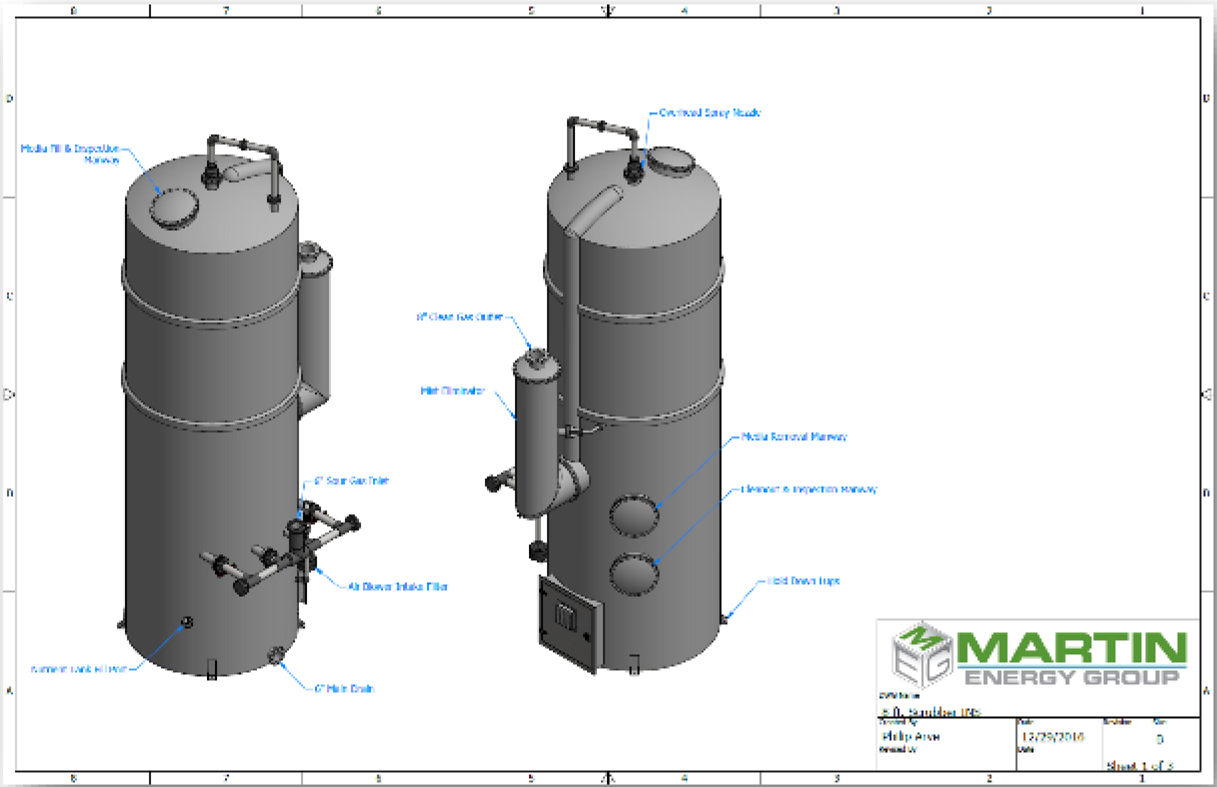

Figure 155: Example schematic of a concurrent flow biogas scrubber, source: Martin Energy Group

The suitability of a biological scrubber for biogas purification depends on:

- biodegradability of the pollutants
- sufficient concentration of pollutant-reducing microorganisms in the bioreactor
- sufficient oxygen and nutrient supply for the microorganisms
- defined process prerequisites (humidity, temperature, pH value etc.)
- subcritical concentration of inhibitors/ toxic substances in the exhaust air/ waste gas flow.

To ensure a high density of microorganisms in the bioreactor, the latter is packed with a matrix for immobilizing the microorganisms. Natural substances (compost, bark mulch, timber chips, etc.) or packing made of plastics, ceramic, porcelain may serve as substrates. Depending on the aquifer system, the biochemical pollutant degradation can be performed in biofilters, bio-scrubbers, or biological trickle-bed reactor systems.

Inside the biofilter, the exhaust air to be purified flows through wet packing colonized with micro-organisms, which at the same time provides the nutrients for the micro-organisms. In addition to carbon from the packing matrix, bacteria may use CO2 in the biogas as a carbon source, reducing the content at the outlet. The exhaust air is usually saturated with water vapor produced by the oxidation of H2S; if the exhaust is not saturated, either a humidification process of the exhaust air must take place before the biofilter or the filter material must be equipped with a sprinkling device. This is to ensure that the oxidation reaction of elemental sulphur is complete. The pollutant components are dissolved and then microbially decomposed by oxidation.

1) Direct oxidation

$$H_2S + 2\ O_2 \rightarrow H_2SO_4$$

2) Oxidation with elemental Sulphur as intermediate

$$2\ H_2S + O_2 \rightarrow 2\ S + 2\ H_2O$$

$$2\ S + 2\ H_2O + 3\ O_2 \rightarrow 2\ H_2SO_4$$

Inside the bio-scrubber, the pollutants are first absorbed in a washing liquid (normally H_2O) which is afterwards regenerated by microbial degradation of the dissolved pollutants. The body of the micro-organisms in the bio-scrubber is suspended and not immobilized on substrates as in a biofilter where bacteria adsorb onto the packing matrix. Only corrosive gas components that are sufficiently soluble in the washing liquid (hence usually water-soluble contaminants) can be decomposed in the bio-scrubber.

5.2.3 Biogas Cogeneration Engine

For biogas applications, reciprocating engines operating on the Otto cycle are preferable to Brayton cycle turbines or Stirling engines due to several advantages. Reciprocating piston engines have a simpler design and are a much more commercially mature technology, reducing capital, installation, and maintenance costs compared to turbines and Stirling engines; turbines in particular anecdotally suffer from a high susceptibility for unscheduled downtime and limited skill supply for maintenance. It has been reported that biogas reciprocating engines are now achieving thermal efficiencies of up to 42%. An example of a biogas engine suitable to this application is given in Figure 16.

Figure 166: Evo Heat 2G Avus 1000cc 1200 kWe biogas reciprocating engine.

Discussions with Gaia EnviroTech on the configuration of their multi-stage digestion system and its benefits reported a general improvement in CH_4 biogas quality of 70 mass% compared to 60 mass% usually observed in single stage CSTR systems. This improvement translates to recoverable energy in a reciprocating engine of 1.1 MWe versus 1 MWe. To streamline the RFQ process within timelines and pressure due to the COVID19 lockdown, All Energy Pty Ltd estimated the biogas clean-up and generation plant for every submission received.

5.3 OpEx and Revenue Analysis – Anaerobic Digestion

5.3.1 List of Assumptions

- 14 hrs per day manned production
- 300 days per year typical production
- Thermal energy charged at $3.0 / GJ
- Power charged at $0.20 / kWh inclusive of volume and demand charge
- Recoverable thermal energy kWt = 1.1 * kWe as 95 DegC hot water
- No gate fee received for piggery wastes
- RET LGCs redeemable at 30 $ / MWh until 2030
- Emissions reduction credits redeemable at 12 $ / t CO_2-e until 2030
- 2% indexation on general costs (CPI), 5% indexation on energy costs
- 3.63% discount rate applied
- Facility commences operation 1 Jan 2021
- 25 year digestion plant lifespan
- 15 year cogeneration engine lifespan
- Engine run during manned production hours, switched off outside of this period
- Delivery from piggery to abattoir $50 / t[16], 5030 tonnes of piggery waste
- Digester maintenance at 1% of capital per annum
- Engine maintenance contracted to vendor at $0.028 / kWh
- Half of a FTE required for monitoring plant
- Disposal costs
    - Piggery blood $200 / tonne
    - Paunch $60 / tonne
    - Piggery guts $60 / tonne

5.3.2 Operating Costs

The critical cost item in operating these plants is the cost of delivery of wastes to site, at around 60% of total costs. The next most sensitive cost item is engine maintenance at around 25% of total costs, however this figure is backed by a subcontract to the vendor at $0.028 / kWh so is not expected to vary significantly.

[16] http://www.freightmetrics.com.au/Calculators/TruckOperatingCostCalculator/tabid/104/Default.aspx

5.4 Viability – Anaerobic Digestion

Table 11: Economic viability of proposed plants

	Energy 360	Biogass	Gaia
CAPITAL			
SIMPLE PAYBACK	5.7	6.1	8.7
IRR	21.6%	20.4%	14.9%
NPV	$ 20,317,784	$ 19,890,693	$ 16,962,238
DPP	5.6	6.0	8.4

With the above economic feasibility, this appears to be an attractive option to offset electrical and thermal energy costs, reduce site Scope 1 and Scope 2 emissions, improve energy security, and provide a more sustainable approach to waste management. It is recommended to invest in this opportunity and progress to detailed design.

5.5 Sensitivity Analysis

As discussed above, the key cost and revenue items affecting the economic viability are

- Cost per tonne for delivery of piggery wastes to site
    - This cost is varied from the assumed value of $50 / tonne, up to 150% of the assumed value at $75 / tonne. This is value may be manipulated by purchasing a truck for this project and factoring purchase price, insurance, wages, fuel costs, and maintenance into a levelized cost of trucking estimate; however has been assumed this will be subcontracted to a third party.
- Cost of power $/kWh factoring volume and demand charges
    - This revenue item is varied from the current inclusive charge of $0.20 / kWh, down to $0.10 / kWh (50% of baseline value) to reflect a scenario where the site kVA demand spikes outside of the engine operation period, meaning only kWh and not kWh + kVA are offset. This may happen due to a DOL stop-start in a large motor or motor system (e.g. the refrigeration system) on a Sunday where site demand spikes.
- Cost of disposal per tonne of piggery wastes
    - These revenues are varied from the current quoted figures of $200 / tonne for blood and $60 / tonne for guts down to 50% to reflect the possibility of the market for rendered porcine products picking up again after African Swine Fever.

Table 12: Sensitivity to variation in delivery, power, and piggery waste disposal cost

Sensitivity Analysis	Delivery Cost		Power Cost		Piggery Waste Disposal Cost	
Change in Key Cost/Revenue Item	NPV	IRR	NPV	IRR	NPV	IRR
-50%			$ 8,881,200	12.6%	$ 15,324,334	16.8%
-40.0%			$ 11,083,099	14.3%	$ 16,237,606	17.5%
-30.0%			$ 13,284,998	15.9%	$ 17,150,878	18.3%
-20.0%			$ 15,486,896	17.5%	$ 18,064,150	19.0%
-10.0%			$ 17,688,795	19.0%	$ 18,977,421	19.7%
0.0%	$ 19,890,693	20.4%	$ 19,890,693	20.4%	$ 19,890,693	20.4%
10.0%	$ 19,375,698	20.0%				
20.0%	$ 18,860,703	19.6%				
30.0%	$ 18,345,708	19.2%				
40.0%	$ 17,830,712	18.8%				
50.0%	$ 17,315,717	18.4%				

It can be concluded from the above sensitivity analysis that the economics of this plant are most sensitive to variation in the value of power offset. The economics are relatively robust against significant variations in piggery waste delivery cost and disposal cost, giving good confidence in the viability of this plant over a long term where market conditions may change.

5.6 Financing

Relative to many red meat processor anaerobic digestion plants, this project has particularly strong economics due to the aggregation of high opportunity cost wastes from a piggery. This makes an attractive financing deal able to be structure, further enhancing the discounted economics. One such provider is Verdia[17], who have quoted the following deal for this project.

- Monthly payment in advance, payments fixed for the term
- 120 month term
- 3.44% interest rate
- $62,473.36 payment per month ex GST

With the above calculated discounted monthly net benefit of $66,302, this means that under this deal the project can be implemented with an instant payback. After the 120 month term, the system is handed over for a nominal fee of typically $1, then for the remaining 15 years of the equipment life, the system returns a positive cash flow of $66,302 per month.

5.7 Aggregation of Additional Wastes

Anaerobic digestion of additional wastes will require an expansion of digester capacity. The main additional wastes considered were:

- FOGO: this is the Food Organics / Green Organics portion of Municipal Solid Wastes. For the local Council 20,000 person population this was estimated at 59.5 tpw FOFO or 3094 tonnes per annum.
- Solids recovered from paunch water and saveall overflow.
- Additional solids from other businesses such as sale yards and food processing which may not attract a gate fee but can provide additional energy.

The cost of an additional 2500 m^3 digester was estimated at $1.65 mil (including supply of digester and balance of plant, delivery, installation, and commissioning). It is estimated that an additional 709 kWe of electricity can be generated by taking council MSW, at an engine cost of $1.49 million installed. The discounted economic analysis (NPV, IRR, and DPP) of the expansion module depend primarily on which year the plant is expanded, as the high indexation of energy costs is greater than the nominal discount rate and CPI escalation, meaning that this is the dominant factor in calculating the NPV, IRR, and DPP. An expanded digestion plant and additional engine is estimated to generate a net revenue of $830,736 with a simple payback of 3.8 years, indicating that as additional organic wastes become available, the site should consider expanding the digester plant.

5.8 OpEx and Revenue Analysis – Biomass Combustion

[17] www.verdia.com.au leverages Westpac funds to finance renewable energy projects with low interest rates. For customers who bank with ANZ, additional Clean Energy Finance Corporation (CEFC) funds can be leveraged to further reduce the interest rate.

5.8.1 List of Assumptions

- Life of plant 25 years.
- Feedlots milling for 6 hours per day, 365 days per annum
- Processor rendering for 16 hours per day, 300 days per annum
- Air-dried hardwood chip procured and delivered to site for $3.48/GJ (18.19 MJ/kg; delivered for $63.30 / tonne)
- 7800 tpa of paunch produced at 20% moisture.
- Paunch LHV 1.7 GJ/t
- fluidised bed boiler 80% thermal efficiency.
- New biomass boiler at 85% thermal efficiency.
- No additional maintenance costs or FTE equivalent for new boiler compared to existing boiler.
- Paunch waste management costs of $299,387 p.a. (2019 data).

5.8.2 Summary of OpEx, Revenue, and Viability

Table 13: Biomass combustion OpEx, revenue, and viability

	Feedlot 1	Feedlot 2	Processor	Processor
Current $/t Steam [fuel only]	$ 83.15	$ 85.24	$ 14.58	$15
Current $/GJ [fuel purchase only]	$ 26.96	$ 27.64	$ 4.20	$4
GJ burned pa	18,169	18,740	191,988	191,988
Steam tpa	5,891	6,076	55,306	55,306
steam tpd	16	17	184.4	184
steam tph	2.69	2.77	11.5	12
Steam overall GJ/t	3.084	3.084	3.471	3
Estimated current boiler efficiency	75.0%	70.0%	80.0%	80%
Technology	Multifuel biomass boiler; Understoked.			
Vendor	Visdamax			
MWt Rating	2.5	2.5	12	12
Delivery Model	Turn-key. Cap ex estimate below:			
Biomass tpa	790	883	11,509	10,665
Fuel	Cotton Gin Trash with 200t waste grain	Woodchip with 100t waste grain	Woodchip	Woodchip mixed with 7800t paunch
Biomass fuel $/GJ	$ 1.36	$ 3.48	$ 3.48	$ 3.48
Fuel Costs pa	17,371	48,204	628,286	285,998
Fuel Costs_15 years	$ 260,565	$ 723,054	$ 9,424,294	$ 4,289,974
$/t 7bar Steam ["fully inclusive"]	$ 17.00	$ 21.56	$ 15.43	$ 9.24
% Thermal Load Offset	100%	100%	100%	100%
$ pa Cost Savings	$ 472,488	$ 469,737	$ 178,104	$ 520,392
Simple Payback - Years	2.63	2.64	18.95	6.49

As shown above, offsetting the very expensive thermal energy from LPG at Feedlots 1 and 2 with biomass has very good economic viability. A key improvement for paunch utilisation is to reduce the moisture content. By reducing the moisture content from ~80% to ~50%, the energy in paunch increases from ~13,260 GJ pa to ~25,428 GJ pa LHV. Due to the low value of heat from the coal at the processor, the payback period for paunch dewatering is ~15 years (for a rotary fan press at ~$750k CapEx).

Where a mechanical press can dry paunch to 50% solids, the net calorific value is estimated at 7.84 GJ/tonne interpolated from the lab data in this report or at 7.43 GJ/tonne from the literature[18].

[18] https://phyllis.nl/Browse/Standard/ECN-Phyllis#grass, accessed 10 August 2020.

An option to improve the viability of the system is to dewater the paunch then backload cattle trucks with 50% moisture paunch to a feedlot, thereby supplying all of the boiler fuel required for the feedlot.

Table 14: Feedlot 1 taking processor paunch biomass boiler feasibility

	F1 + RMP Paunch
Current $/t Steam [fuel only]	$ 83.15
Current $/GJ [fuel purchase only]	$ 26.961
GJ burned pa	18,168.872
Steam tpa	5,891
steam tpd	16.1
steam tph	2.7
Steam overall GJ/t	3.084
Estimated current boiler efficiency	75.0%
Technology	Multifuel biomass boiler; Understoked.
Vendor	Visdamax
MWt Rating	2.5
Delivery Model	Turn-key. Cap ex estimate below:
Biomass tpa	3120 tpa 50% moisture paunch
Fuel	Paunch transported at $0.08/tonne km
Biomass fuel $/GJ	
Fuel Costs pa	-242977.4
Fuel Costs_15 years	-$ 3,644,661
$/t 7bar Steam ["fully inclusive"]	-$ 18.705
% Thermal Load Offset	100%
$ pa Cost Savings	$ 732,836
Simple Payback - Years	2.72

Backloading cattle trucks with paunch results in a similar simple payback period, however provides an overall much high net present value due to the year on year reduction in paunch waste management costs; with the undiscounted NPV for a CGT fuelled boiler at $5.8 mil after 15 years and that for a paunch fuelled boiler at $9.0 mil after 15 years.

5.8.3 Internal Rate of Return Calculations

Assumptions:

- Nominal discount rate: 3.63% p.a.[19]
- LPG fuel cost inflation: 7.35% compound price increase period March 2010 to March 2020[20]
- CAPEX $1.242 mil; fuel cost savings $470k pa (accounts for additional fuel consumption).
- All other costs the same as a "business as usual scenario".

[19] https://www.ipart.nsw.gov.au/files/sharedassets/website/shared-files/local-government-contribution-plans-research-net-present-value-modelling-2015-onwards/fact-sheet-local-government-discount-rate-february-2020.pdf
[20] https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/6457.0Mar%202020?OpenDocument

IRR = 42.8% over 25 year life of plant.

Thermal Energy and Power

For Feedlot 2:
Boiler and ORC CAPEX: $3 mil
Fuel savings: $465k pa
Power Savings: $145k pa (~145 to 175 kW)
Simple payback: 4.9 years

Hence, whilst there is a technical viable opportunity to produce steam and power, there is stronger financial viability to install a biomass boiler at each of the feedlots.

To "future proof" the installation, a boiler that can produce towards 22 Barg steam could be procured at minimal additional CAPEX which would allow the production of higher temperature steam in the future for power generation when this option is considered financially viable.

5.8.4 Financing

Table 15: Feedlot biomass combustion financing

	Feedlot 1		Feedlot 2	
	Value	Comment	Value	Comment
10 year financing on a biomass boiler	$13,012	Per month	$13,012	Per month
Biomass costs per month	$1,448	Per month	$4,017	Per month
TOTAL Biomass boiler costs	$14,460	Per month	$17,029	Per month
Savings per month 10 year equipment finance	**$26,362**	**Per month**	**$26,133**	**Per month**
5 year finance on a biomass boiler	$23,322	Per month	$23,322	Per month
Biomass costs per month	$1,448	Per month	$4,017	Per month
TOTAL Biomass boiler costs	$24,770	Per month	$27,339	Per month
Savings per month 5 year equipment finance	**$16,052**	**Per month**	**$15,823**	**Per month**

The inordinately large LPG costs paid by the feedlots results in a 5 year, 60 month financing term is able to be structured while providing instant payback. Less expensive fuels such as pipeline natural gas, trucked natural gas, and coal are expected to require a longer term financing deal to match the above economic viability.

5.8.3 Feedlot 1 Expansion

It is planned for Feedlot 1 to expand from the current 30,000 head towards 50,000 head. The table below shows the economics of a 2.5 MW boiler that runs for more hours in the day (rather than a larger tonnes per hour steam rate being required to complete milling within the same time period). As can be seen, the payback period reduces for a biomass boiler as the LPG and hours per day utilization increases.

Table 16: Feedlot 1 expansion effect on biomass boiler viability

	F1 @ 30k SCU	F1 @ 40k SCU	F1 @ 50k SCU
Current $/t Steam [fuel only]	$ 83.15	$ 83.15	$ 83.15
Current $/GJ [fuel purchase only]	$ 26.96	$ 26.96	$ 26.96
GJ burned pa	18,169	24,225	30,281
Steam tpa	5,891	7,855	9,819
steam tpd	16	22	27
Boiler operation hours per day	6.0	8.0	10.0
steam tph	2.69	2.69	2.69
Steam overall GJ/t	3.084	3.084	3.084
Estimated current boiler efficiency	75.0%	75.0%	75.0%
MWt Rating	2.5	2.5	2.5
Delivery Model	Turn-key. Cap ex estimate below:		
Biomass tpa	790	1,119	1,449
Fuel	Cotton Gin Trash with 200t waste	Cotton Gin Trash with 200t waste	Cotton Gin Trash with 200t waste
Biomass fuel $/GJ	$ 1.36	$ 1.36	$ 1.36
Fuel Costs pa	17,371	24,628	31,885
Fuel Costs_15 years	$ 260,565	$ 369,420	$ 478,274
$/t 7bar Steam ["fully inclusive"]	$ 17.00	$ 13.67	$ 11.68
% Thermal Load Offset	100%	100%	100%
$ pa Cost Savings	$ 472,488	$ 628,517	$ 784,546
Simple Payback - Years	2.6	2.0	1.6
Support from AMPC/MLA PIP	$ 200,000	$ 200,000	$ 200,000
Simple Payback - Years with PIP	2.2	1.7	1.3
Monthly costs via 10yr equipment financin	$ 10,900	$ 10,900	$ 10,900
Monthly savings - CASH FLOW POSITIVE	$ 28,474	$ 41,476	$ 54,479
$ pa Saved accounting for OpEx	$ 341,688	$ 497,717	$ 653,746
Savings as a % of the fuel bill	69.8%	76.2%	80.1%

6.0 DISCUSSION

6.1 Effect of Electro Coagulator Commissioning on Designed Plant

During the site visits by All Energy, it was observed that the electro coagulator was not operational after considerable problems during installation and commissioning. It did not appear from discussions with abattoir and tannery staff that there were any plans to re-commission the unit in the foreseeable future.

Sampling and testing of the tannery wastewater proved that this will not be a viable digestion feedstock due to the presence of Cr and 4,3-CMP fungicide inhibiting methanogenic bacteria. It is not expected that when the EC is operational that the recovered tonnage of Cr salts from processing tannery wastewater will be significant enough to impact the technology choice.

6.2 Practical Benefits of W2E Plants

The practical implications of W2E are:

- Reduced power costs

    - Expensive grid tariffs and the compounding year on year increases in prices present a significant risk to processors. W2E can deliver power cheaper over the life of plant, reducing operating costs.
- Reduced thermal energy costs
    - For RMPs on the east coast purchasing natural gas or LPG as a thermal fuel, this is a very large operating cost and continuity risk, able to be offset by burning biogas or syngas from gasification.
- Reduced waste disposal costs
    - AD and gasification can reduce the waste disposal costs paid by RMPs, particularly those located in metro areas or Queensland, where landfilling costs have suddenly increased by $75/t as of 1/7/2019, increasing by $5/t every year until 2023.
- Improved environmental outcomes and social license to operate
    - There is pressure from within the industry and the community to maintain the clean and green image of Australian red meat; W2E can aid in progressing towards the broad CN30 industry goal, individual business targets, international sustainability accreditation and circular economy solutions.
- Decreased reliance on fuels hauled / reticulated to site: onsite W2E provides energy security and a reduced reliance on fuels from third parties and / or energy utilities.
- Reduction in scope 1 and scope 2 greenhouse gas emissions
    - Scope 1 emissions may be reduced by offsetting thermal fossil fuels; scope 2 emissions may be reduced by reducing grid electricity consumption.
- Additional saleable products such as soil conditioner at a retail standard

7.0 CONCLUSIONS/RECOMMENDATIONS

All Energy has received three proposals from the market for aggregating piggery and red meat processing wastes, anaerobically digesting, and using the recovered biogas for power offset. The economics of the 3 proposals are summarized below.

	Energy 360	Biogass	Gaia
CAPITAL			
SIMPLE PAYBACK	5.7	6.1	8.7
IRR	21.6%	20.4%	14.9%
NPV	$ 20,317,784	$ 19,890,693	$ 16,962,238
DPP	5.6	6.0	8.4

Sensitivity Analysis	Delivery Cost		Power Cost		Piggery Waste Disposal Cost	
Change in Key Cost/Revenue Item	NPV	IRR	NPV	IRR	NPV	IRR
-50%			$ 8,881,200	12.6%	$ 15,324,334	16.8%
-40.0%			$ 11,083,099	14.3%	$ 16,237,606	17.5%
-30.0%			$ 13,284,998	15.9%	$ 17,150,878	18.3%
-20.0%			$ 15,486,896	17.5%	$ 18,064,150	19.0%
-10.0%			$ 17,688,795	19.0%	$ 18,977,421	19.7%
0.0%	$ 19,890,693	20.4%	$ 19,890,693	20.4%	$ 19,890,693	20.4%
10.0%	$ 19,375,698	20.0%				
20.0%	$ 18,860,703	19.6%				
30.0%	$ 18,345,708	19.2%				
40.0%	$ 17,830,712	18.8%				
50.0%	$ 17,315,717	18.4%				

The key sensitivity is to variation in power cost in a scenario where the site kVA demand spikes outside of the engine operation period, meaning only kWh and not kWh + kVA are offset. This may happen due to a DOL stop-start in a large motor or motor system (e.g. the refrigeration system) on a Sunday where site demand spikes. It should be checked that site refrigeration plant and any other large motors are fitted with variable speed drives, voltage optimization, and site power factor correction to ensure that the plant continues to deliver savings as expected.

All Energy recommends to invest in this opportunity and progress to detailed design.

8.0 BIBLIOGRAPHY

References are contained within the body of the report as footnotes for ease of following sources.

9.0 APPENDIX

9.1 AACE Accuracy of Feasibility Study

The following table defines the approximate accuracy of this feasibility study, as aligned with the method of the American Association of Cost Estimation Engineers (AACE) classification system for process industries, TCM Framework 7.3, Practice No. 18R-97. Relevant extracts of the AACE system are provided in the following tables:

Table 17: Indicative estimate classification project data and deliverables

	ESTIMATE CLASSIFICATION				
General Project Data:	**CLASS 5**	**CLASS 4**	**CLASS 3**	**CLASS 2**	**CLASS 1**
Project Scope Description	General	Preliminary	Defined	Defined	Defined
Plant Production/Facility Capacity	Assumed	Preliminary	Defined	Defined	Defined
Plant Location	General	Approximate	Specific	Specific	Specific
Soils & Hydrology	None	Preliminary	Defined	Defined	Defined
Integrated Project Plan	None	Preliminary	Defined	Defined	Defined
Project Master Schedule	None	Preliminary	Defined	Defined	Defined
Escalation Strategy	None	Preliminary	Defined	Defined	Defined
Work Breakdown Structure	None	Preliminary	Defined	Defined	Defined
Project Code of Accounts	None	Preliminary	Defined	Defined	Defined
Contracting Strategy	Assumed	Assumed	Preliminary	Defined	Defined
Engineering Deliverables:					
Block Flow Diagrams	S/P	P/C	C	C	C
Plot Plans		S	P/C	C	C
Process Flow Diagrams (PFDs)		S/P	P/C	C	C
Utility Flow Diagrams (UFDs)		S/P	P/C	C	C
Piping & Instrument Diagrams (P&IDs)		S	P/C	C	C
Heat & Material Balances		S	P/C	C	C
Process Equipment List		S/P	P/C	C	C
Utility Equipment List		S/P	P/C	C	C
Electrical One-Line Drawings		S/P	P/C	C	C
Specifications & Datasheets		S	P/C	C	C
General Equipment Arrangement Drawings		S	P/C	C	C
Spare Parts Listings			S/P	P	C
Mechanical Discipline Drawings			S	P	P/C
Electrical Discipline Drawings			S	P	P/C
Instrumentation/Control System Discipline Drawings			S	P	P/C
Civil/Structural/Site Discipline Drawings			S	P	P/C

Table 18: Indicative estimate classification primary and secondary characteristics

	Primary Characteristic	*Secondary Characteristic*			
ESTIMATE CLASS	**LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/ Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100