final report

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Conversion of Biomass to Renewable Energy at a Feedlot

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Executive summary

The red meat supply chain spends an estimated $1.3 billion per annum on fossil fuel energy, of which $512 million or 39% of all of the energy costs may be attributed to energy used at feedlots[1]. Whilst feedlot energy contributes only 26% of all energy usage from production through to retail ready products (i.e. excluding cold chain and transport post-processing plant), due to feedlots being in regional and remoter areas means that the available energy sources are more expensive compared to processing plants (i.e. high grid power costs per unit; higher boiler fuel costs per unit due to haulage of fuel to site).

Due to rising fossil energy costs, falling capital costs for renewable technologies, support for renewable power and/or future potential greenhouse gas emissions costs, and the goal of the red meat industry being carbon neutral by 2030, it is recommended that the red meat industry rapidly transition to renewable energy.

This project assumed a 20,000 head of cattle feedlot with co-located steam flaking / grain milling operations. For this site LPG fuel for raising steam represented 74.8% of energy costs for the mill facility operations with the balance being grid power.

The key findings were that renewable energy solutions exist which can immediately save energy costs at feedlots without the need for any capital outlay. The table below summarizes the most competitive submissions received. The highly-innovative concentrated solar thermal/power proposal that was received is also presented here in the executive summary, to show the relative standing amongst less technically complex plant. Feedlots and the wide industry will benefit by seeing that the falling costs of renewable technologies coupled with innovative business models can immediately reduce energy costs with low operational risk and no capital outlay.

Not itemized separately in the table below, a biomass boiler can be procured to generate steam at around 24 barg with a minimal overall impact on the capital cost of the boiler (e.g. 5%). This higher pressure steam can be run through an expanding screw or backpressure turbine to create power. Thermodynamic modelling shows that the feedlot considered would be able to generate approximately 100 kW of power or around one third of its power requirements via abackpressure turbine. Taking capital costs for a backpressure turbine into account, an additional 9% fuel consumption due to raising the steam to 24 barg rather than 7 barg, and Renewable Energy Credits at $60/MWh, the LCoE over a 15 year period for a backpressure turbine was estimated at $0.12 / kWh.

Solution	**Woodchip only biomass Boiler & PV Solar BOOT**	**Multi-fuel biomass boiler**	**Biogas fired boiler and cogeneration engine**
Head of cattle at feedlot	20,000	20,000	20,000
Tech Class	99 kW Solar PV for power + Biomass boiler (woodchip only) for steam	Multi-fuel boiler (cotton gin wastes, grain wastes, manure, wood); 24 barg steam that is “turbine ready” (can generate power via a backpressure turbine); ability to attract third party R&D funding.	Continuous stirred tank reactor; biogas fired boiler; biogas fired cogen engine. Not suited to all feedlots as relies upon suitable pens and associated collection method. Advantages of odour and vector reduction.
Delivery Model	15 yr Build-Own-Operate-Transfer (BOOT).	Equipment financing, analysed over first 15 years.	No capital outlay due to equipment financing; financed over an 8 year period; able to immediately start saving operating costs as financing costs are less than energy cost savings; scenario analysed over first 15 years.
% Thermal Load Offset	100%	100%	100%
% Electrical Load Offset	Towards 70%	N.A.	100%
% saving in annual site-wide energy costs	38.8%	36.2%	39.4%

[1] MLA project V.SCS.0003, 2017.

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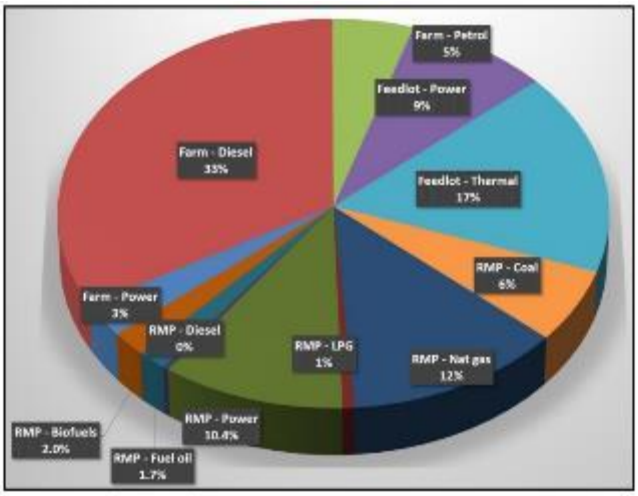
1 Background

There exists the opportunity for the red meat industry to reduce power and thermal energy costs via the use of on-site renewable energy technologies[2,3]. Further, energy efficiency has been considered in various MLA and AMPC projects, demonstrating the breadth of energy cost reduction strategies for agribusiness[4],[5]. These projects showed that energy efficiency gains are the “low hanging fruit” as efficiency measures incur little to no capital cost and thus can deliver the most rapid payback periods in the order of <1 year to days.

All Energy Pty Ltd has undertaken a range of works on feedlot energy from individual operations through to full industry supply chain modelling. The data below summarises findings from the MLA project V.SCS.003 which shows that whilst feedlots may only consume 26% of the energy from producer through to the end of processing (i.e. not including transport and cold chain for retail ready products), due to the remote area operations and high regional area power costs feedlots represent 39% of the red meat supply chain energy costs. However, feedlots are in a strong position to make use of disruptive technologies due to buffer zones / land available for PV solar and concentrator systems, availability of biomass from within supply chain and closely located agri-businesses and energy storage.



Area of Energy Use	$ pa energy cost	GJ pa
Farm - Power	71,187,726	1,335,244
Farm - Diesel	298,337,099	15,689,117
Farm - Petrol	44,410,528	2,336,677
Feedlot - Power	273,415,322	4,101,230
Feedlot - Thermal	238,836,326	7,961,211
RMP - Coal	15,137,898	2,845,925
RMP - Nat gas	74,680,295	5,849,956
RMP - LPG	10,091,932	316,214
RMP - Power	277,990,032	4,901,315
RMP - Diesel	3,198,393	158,107
RMP - Fuel oil	7,568,949	790,535
RMP - Biofuels	Excluded	948,642
TOTALS	1,314,854,499	47,234,172 (47 PJ)

Figure 1: Current estimated annual energy use throughout the RMI supply chain and associated annual energy cost for farm, feedlot and red meat processor (RMP) energy demands. Source: MLA project V.SCS.003 (Sept 2017).

V.SCS.003 also discussed what a completely off-grid feedlot would look like, what technologies, capital investment, savings, and payback could be expected. The technologies that were highlighted were solid biomass (i.e. woodchip, cotton gin trash, grain waste, straw) boilers, solar PV, and anaerobic digestion for biogas boilers and biogas engine cogeneration.

The benefits to industry of this project are practical solutions to the rising costs of grid power in Australia, and methods to shield against these cost increases, carbon price liability, and the demand from consumers and stakeholders for a ‘clean and green’ red meat industry with a lower environmental impact. A recent survey of Australian consumers showed 76% would choose companies that used renewable energy over ones that did not, and that 64% of consumers would be willing to pay a premium for products made with renewable energy[6]. The same survey showed that 46% of businesses were using renewable energy.

[2] MLA/AMPC Report P.PIP.0526, 2016.
[3] MLA Report V.SCS.001, 2016.
[4] MLA/AMPC Report P.PIP.0739.
[5] AMPC Report 2017.1029, 2017.
[6] https://arena.gov.au/assets/2017/07/AU21476-ARENA-Corporate-Report-REVISED-v1-1.pdf, accessed 28 May 2018.

2 Project objectives

The project objectives, as worded in the research agreement are as follows:

M1: Complete a technical and financial feasibility of a biogas energy option will be compared to a solid fuel boiler (biomass / coal) with associated generation of power via an expanding screw / backpressure turbine via a cost-benefit analysis. The advantage of making power from steam raised from biomass is that RECs can be generated, thereby improving the economics. A capital cost and associated op ex analysis will be completed with a target accuracy of +/- 20%.

M2: Biomass sampling and analysis for: manure, wood chip, forestry mulch, cotton gin waste, grain wastes.

M3: Consideration of third party funding options for the facility from state government, federal government and private sectors.

M4: "Fixed and firm; lump sum" capital cost estimation for a feedlot energy solution in keeping with decision made at M1. Appropriate feedlot staff will be involved in the data gathering, interviewing process to determine the "business as usual" case.

M5: Complete final report and business case / cost-benefit analysis. Submit a company specific report to site and MLA for review and approval. In addition, the provider will submit a final report with the exception of information that is commercially sensitive.

3 Methodology

To address the above milestone achievement criteria and project objectives, the following methodology was formulated and applied.

A mass and energy balance was formulated based on available operating data to understand the key metrics for the energy usage and energy costs associated with a 20,000 head feedlot with co-located grain flaking. The key projected metrics of interest were GJ thermal energy procured (lower heating value), kW electrical energy procured / generated (gross), and steam mass flow (tonnes per hour of milling). Using LPG and diesel as the base case for thermal and electrical demand respectively, a range of fuels were considered and required amounts calculated.

Requests for budget pricing were then made from a long list of fuels, fuel vendors and boiler equipment vendors to obtain a fully costed delivered to site cost for every fuel option on a $/GJ LHV basis. As approximately 90 to 95% of the cost of running a boiler over its life span (depending upon boiler efficiency and boiler technology) is contributed by fuel, very close attention was paid to fuel options.

Similar request for budget pricing and associated analysis was completed for a long list of power generation fuels and equipment considering grid, diesel gen-sets, liquid natural gas (LNG), liquid petroleum gas (LPG), biogas, backpressure turbines, wind, PV solar and organic rankine cycle (ORC) engines to estimate power generation costs via a Levelized Cost of Electricity (LCoE) calculation.

From the thermal and power energy submissions, a short list of solutions was created that were of highest interest to the feedlots. A detailed Technical Specification was created taking into account current and future thermal and power loads (refer Appendix 8.1). Requests for quotation (RFQs) were made for boiler plants with a specific interest on solid fuel boilers capable of utilizing several biomass fuels. Where vendors had made certain unnecessary or out of scope inclusions/exclusions, these were factored into or out of the capital estimate. A fully costed $/tonne of steam generated was calculated to allow comparison between the range of fuels and vendors which was then compared to the $/tonne for a base case of LPG (fuel costs only, hence assuming capital equipment is fully depreciated) with an associated calculation of per annum savings on boiler costs.

Likewise, a detailed power Technical Specification was created with RFQs sent to a short listed vendors for proposals for power generation options. Due to the range of different commercial submissions covering turn-key / lump sum, build-own-operate (BOO), build-own-operate-transfer (BOOT), and power purchase agreements (PPA) the most suitable analysis was decided to be a Levelized Cost of Electricity (LCOE) $/kWh calculated over a 15 year time period which was then compared to a base case of diesel gen sets fuel costs only (assumes capital is fully depreciated) and current grid power costs. An associated calculation was made of per annum savings on power costs.

Working around constraints of minimised upfront capital, where proposals were not received as either a power purchase agreement (PPA) or build-own-operate/transfer (BOO/T) arrangement, submissions were revised by vendors as required or external third party financiers were consulted to design suitable equipment financing submissions.

4 Results

4.1 Energy Demand –Basis of design for 20,000 head facility

Power factors at milling operations have previously been reported as 0.73[7]. Power factor in simple words is a measure of electrical efficiency and can be improved by connecting capacitors or batteries in parallel to the load. This reactive power compensation has many benefits including constant voltage profiles, less wear on motors, reduced total power losses, and system capacity is increased (i.e. can run bigger and more motors on the same gen sets). Any inaccuracy in the power factor will impact the accuracy of the kWh per year consumption estimated presented in this report. Hence, a critical element of any future detailed design will be to measure PF and then consider PF correction, capacitor banks, batteries, voltage optimization and other elements of power quality. A PF of 0.6 was nominated by the electrical engineer that completed the electrical and control system installation; literature confirms that facilities of this nature are in the 0.45[8] to 0.73[9] range. The RFQ presented data in kVA and there was an assumed PF of 0.6; further to this, the gen set amps on each phase were considered and modelled. The gen set testing and ratings data were undertaken / calculated by the OEM at a PF = 0.8[10]. Hence, the modelling presented has been in kVA (at an assumed PF = 0.6 when converted to kW).

Installing power factor (PF) correction to improve PF from 0.6 to 0.8 could reduce the kVA load by 25%. This would be highly recommended where a single gen set is nearing 100% load in order to operate a single gen set as efficiently as possible (rather than running two gen sets inefficiently). The most direct impact of better PF in gen set systems is that more loading can be done on the same gen set hence allowing for better capital utilization and lower operational expenses; correction of PF leads to less current per unit power delivered having an exponential effect in reducing the associated copper loss; due to reduced currents in the total system, overheating and voltage fluctuations induced in the windings and transmission network due to shuttling of loads is reduced which further saves power losses. An overall reduction of 5-7% of energy cost from the gen set is achieved from 10-12% improved efficiency (hence 25%

[7] https://www.scribd.com/document/323048786/
[8] http://www.eaton.com/ecm/groups/public/@pub/@electrical/documents/content/sa02607001e.pdf
[9] https://www.scribd.com/document/323048786/
[10] Caterpillar Sales order 170067890/100; gen set C18 PGDT.

improved PF could yield around 12% or more fuel savings). Depending on total hours of running, a conservative estimate of 0.5 to 2 years payback is achieved for PF correction.

Scenario Modelling – Grid and Renewable Power: A composite power load analysis was created by averaging power load data for a typical week (refer yellow line in Figure 2 below), where the large step change in the middle of the day is for a 300 kW hay buster (tub gribder). By utilizing an approximate 400 kW PV Solar array, all of the site's power could be met via a small grid connection (500 kVA three phase overhead, pole mounted transformer) plus PV solar system. An area for consideration is how the power output from a PV solar array changes throughout the year. Figure 2 below shows the average output over a 12 month period for a 400 kW systemin orange (accounting for changes in season; cloudy days, etc). The straight orange line shows the maximum output level of a 400 kV system in the height of summer on a clear day.

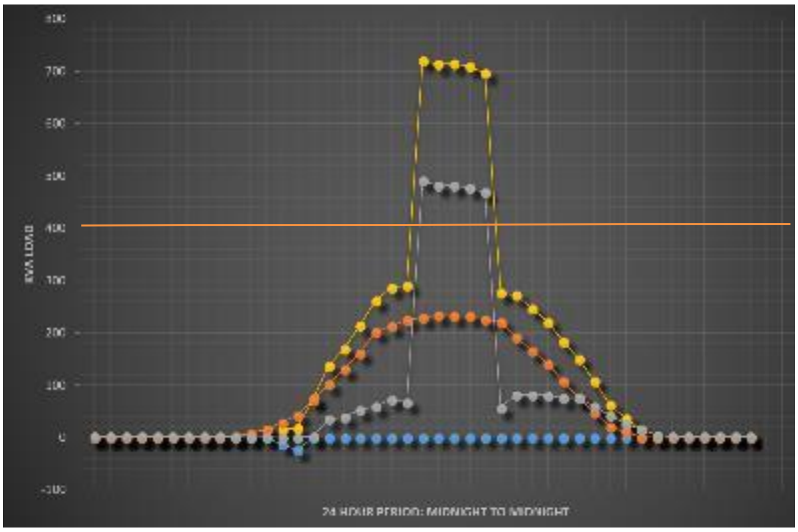


Figure 2: Power load scenario for a feedlot with grain flaking with a 300 kW hay buster load applied in the middle of the day. Total load is in yellow, grid is in grey, 400 kW PV Solar in orange (average power generated over a 12 month period). Blue represents the "balance" which shows a slight excess of power which could be stored in a small battery system to regulate loads (e.g. 19 kWh).

4.2 Fuel Long List and Thermal Energy Fully Costed

As 90 to 95% of the cost of running a boiler over its equipment life can be attributed to the fuel that the boiler uses, very close attention should be paid to fuel selection, local fuel options and $/GJ costs for these fuels. For a feedlot, it is estimated that towards 20% of boiler fuel for a mixed biomass boiler could come from onsite grain mill wastes (husks, clean outs, spoiled materials) which can be supplemented with local and low cost biomasses (e.g. forestry industry residues, cotton gin wastes, etc) to achieve fuel cost savings of 80 to 93% and paybacks in the order of 2 years (compared to LPG). Table 2 below shows the long list of available fuels, energy content, quoted supply costs, and calculated supply only $/GJ cost.

Table 1: Long List of Boiler Fuel Options, 2017.

Fuel	Units	Quote #1	LHV MJ/kg	$/GJ - calculated; fuel supply only
Cotton Gin Wastes (high seed content) - ginning season only approx. Apr-Aug	per tonne delivered	22	16.2	1.36
Biomass - air dried hardwood sawmill residue ~30mm	per tonne delivered	55	15.1	3.62
Coal	per tonne delivered	118	25.9	4.37
Biomass - air dried cypress grindings 50mm top size	per tonne delivered	65	10.0	6.50
Biomass - air dried woodchip	per tonne delivered	95	10.7	8.88
Extract fuel oil	per Litre	0.41	37.28	11.82
SORBO 15	per Litre	0.53	41.51	13.88
Diesel (Delivered to site minus ATO fuel tax credit)	per Litre	$0.978	42.61	27.49 [note: as high as $37.01/GJ CYTD]
LNG	$/t	805.63	48.63	16.57
Business as Usual - LPG (Propane)	per litre	0.622		26.96 [note: as high as $27.64/GJ CYTD]
Biogas – 3 Modules (for providing power and steam for ~25,000 cattle operation)	Assumes 10 year life of plant for on-site generation from grain wastes and manure.			7.62
Biogas – 2 Modules (for providing steam for ~25,000 cattle operation)				10.81
Biogas – 1 Module (for providing power for ~25,000 cattle operation)				18.89

With the introduction of a state based landfill levy in Queensland to align with all other mainland states, recycled construction and demolition wood will be a very low cost source of fuel. Assuming that the fuel is "free issued", the main cost will be haulage to site from council landfills (estimated at $2 to $3 / GJ). This material can be sorted and chipped at landfills then transported to the point of use. Due to not being a single source agri-derived fuel, it is anticipated that additional council and/or state level approvals may be required however recycled wood is anticipated to be the lowest cost source of biomass available throughout the entire year. However, an advantage is that it is routinely low in moisture hence has a high heating value per tonne. It is a foreseeable scenario several years into the future that, given a sufficiently high landfill level (e.g. $80 / tonne or higher) that a feedlot could generate a small gate fee by utilizing recycled wood in on-site boilers.

It can be seen that the current business as usual practice of using LPG for boiler fuel in feedlots is second only to diesel as most expensive fuel option, meaning that the industry is paying significantly more for steam than is necessary, and that there are great savings to be achieved by re-thinking this aspect of operating costs and considering solid fuels such as woodchip, biogas, gin trash, straw, and grain wastes (where available).

4.3 Preliminary Renewable Electricity Long List

The following calculated metrics are for fully costed prices for power generation technologies where the Table 4 results are presented from lowest to highest levelized cost of electricity (LCOE).

Table 2: Long List of power generation options

Power Generation Technology	LCOE $/kWh – Fully Costed Over 10 Years
Fast deployment ground mounted PV Solar array of 11 to 98 kW	0.017 to 0.025
PV Solar - roof mounted, > 100 kW. INCLUDES RECS (large scale) received annually.	0.054
Cogen run on biogas from 2 modules (~40 SCUs). INCLUDES RECS.	0.059
Backpressure turbine / expanding screw – biomass fired solid fuel boiler. INCLUDES RECS (large scale) received annually.	0.061
PV Solar - roof mounted, < 100 kW. INCLUDES RECS (small scale) received upfront.	0.085
PV Solar - ground mount, >100 kW. INCLUDES RECS (large scale) received annually.	0.086 to 0.94
Cogen run on biogas from 1 module (~24 SCUs). INCLUDES RECS.	0.124
Backpressure turbine / expanding screw – coal.	0.142
Battery – 16.3 kWh usage charge, 6000 cycle warranty, Li-ion	0.143
Battery – 13.5 kWh Li-ion	0.194
PV Solar - pen shading. INCLUDES RECS (large scale).	0.199
Batteries - 40' container flow cell.	0.244
Containerized cogen gas engine run on LNG.	0.257
Cummins Ecogen Gas Engine with engine heat recovery.	0.358
Capstone turbine.	0.382
CAT – Diesel.	0.656
Wind Turbine - 10 kW. INCLUDES RECS.	0.963
Business as Usual – Diesel Reciprocating Engine	0.395 (23 May 2018 pricing)
Business as Usual - Grid	0.304 – 0.49 (depending on tariff class)

As with thermal fuels, Table 4 shows that the business as usual practice of either diesel reciprocating engines for on-site power or connection to grid (where location and infrastructure permits) is among the most expensive options. The justification for PV solar, backpressure turbines from superheated steam, and biogas cogeneration engines is thus clear. Since feedlots tend to be in rural or semi-rural regions where power quality is low, and brownouts / blackouts are frequent, servicing more of a site's load behind the meter has the added benefit of improving reliability and quality in an industry where interruptions to power supply can mean tens of thousands in lost revenue from sub-optimal feed conversion ratio, or increased costs of purchasing pre-milled grain.

Long term trends are for increasing grid power costs, increasing fossil fuel costs and electrification of light and heavy vehicles. Hence, feedlots should develop strategies for generating low cost power onsite that does not require fossil fuel with a vision of generating sufficient electricity for all milling, feedlot operation and transport

Solar PV is particularly suited to the rural and semi-rural areas in Queensland and New South Wales where beef is produced, as it can be seen in Figure 6 that these areas have high solar radiation intensity throughout the year. A strong recommendation is that **all** beef feedlots and processing facilities in these areas should have some PV solar installed capacity, as large savings per kWh from solar PV can be achieved when compared to diesel generation sets, or the retail power grid.

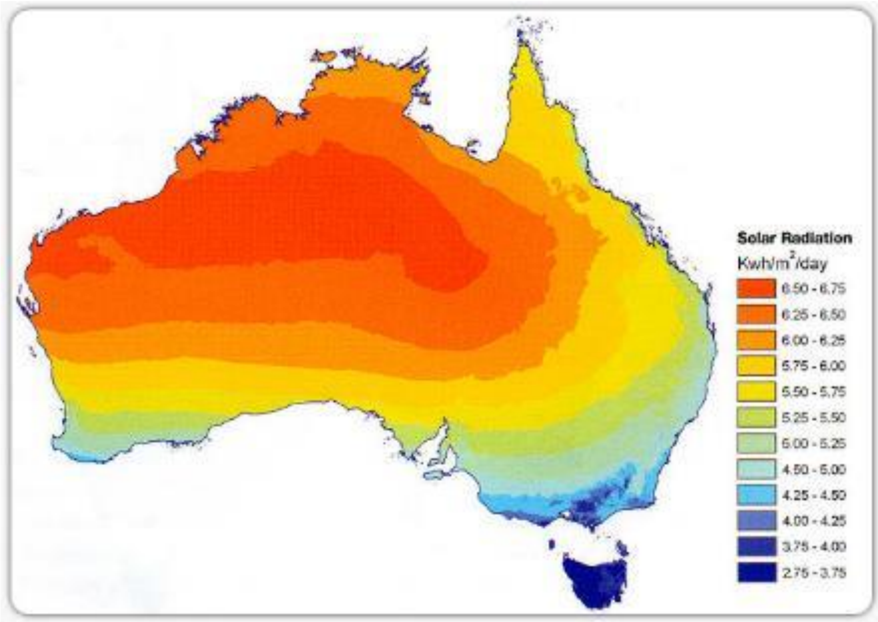


Figure 3: Solar Radiation Map of Australia.

4.4 Renewable Energy Short List

Based on the findings from the thermal fuel analysis and renewable energy Levelized Cost of Electricity calculations, the Project Team decided upon technology classes to receive more detailed submissions on. The following Table 5 summarizes the key technologies considered.

Table 3: Long List of power generation options

<table>
<tr><th>Technology & description</th><th>Image</th></tr>
<tr><td>Biomass, multifuel fired boiler. The fuel hopper / fuel storage system can be a horizontal arrangement or make use of a walking floor / fuel storage bay or day hopper arrangement (where on-site front end loader is available).

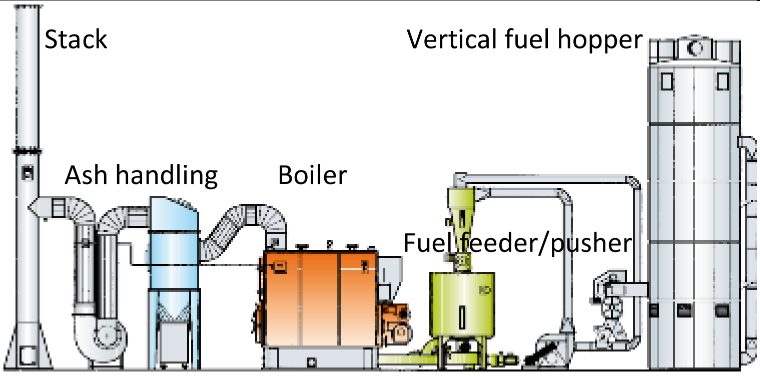
Image source: ACT Group / Uniconfort; uniconfort.com</td><td>
</td></tr>
<tr><td>Bio-waste (manure and crop residues) to biogas to a biogas boiler and biogas fired reciprocating cogeneration engines. Annotations: CHP – combined heat and power; Technology container 1: Digestate handling / recycling system.

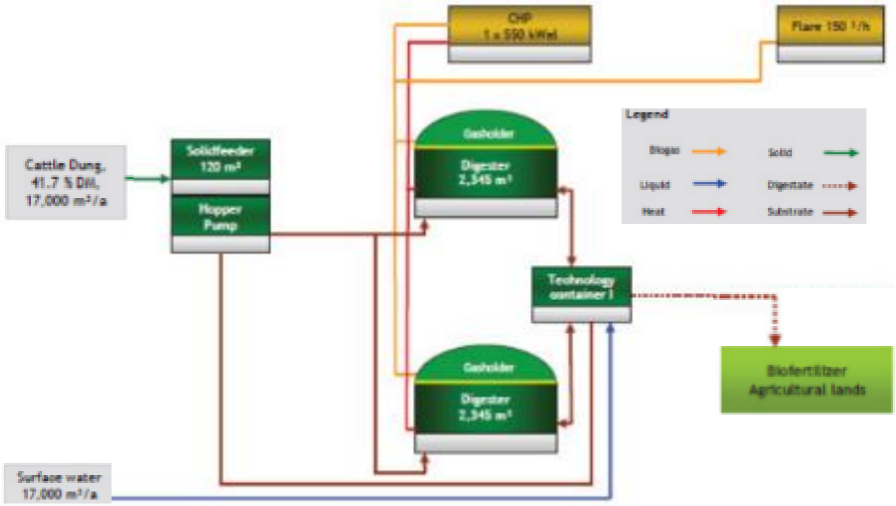
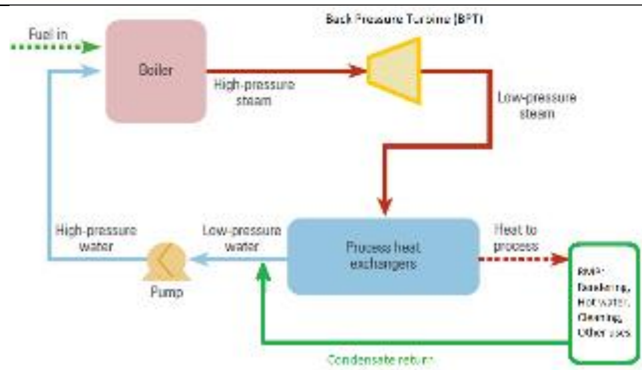
Image: block diagram of a waste to energy facility. Source: Okobit (2016).</td><td>
</td></tr>
<tr><td>Backpressure turbine suited to 24 barg steam.

Image: Schematic of a back pressure turbine (BPT) coupled to a typical Red Meat Processor (RMP) plant steam system[11]. Adapted from “Typical Thermal Plant Schematic”, Casten, S, 2005, Recycling Waste Pressure into Electricity, Turbosteam Corp.</td><td>
</td></tr>
<tr><td>Concentrated solar thermal / Concentrated solar power (considered as part of wider due diligence) utilizing parabolic troughs, stream generation and thermal oil storage (not shown). Image source: IES / AALBORG; aalbordcsp.com</td><td> </td></tr>
<tr><td>Innovative, rapid deployment ground based PV solar suited for high dust environments (considered as part of wider due diligence).
Image source: 5b Australia Pty Ltd, 5b.com.au</td><td></td></tr>
</table>

[11] Adapted from “*Typical Thermal Plant Schematic*”, *Casten, S, 2005, Recycling Waste Pressure into Electricity, Turbosteam Corp.*

4.5 Biogas Facility Submissions

Submissions for “turn-key” / EPC anaerobic digestion waste to energy facilities were sought from 3 companies to provide sufficient biogas for providing power for a feedlot. Of interest is that all submissions received were for in-vessel, continuous stirred tank, site erected stainless steel panel tank systems i.e. not covered anaerobic lagoon systems. It was estimated that a biogas system would not require all of the manure generated to provide sufficient biogas for all boiler and power requirements (e.g. estimated at 83% of total available manure if collected at an average age of 42 days[12]; hence a lower percentage is required if fresher manure can be collected).

Biogas systems have a clear advantage of economy of scale, in that the more biogas that is required the lower the $/kWh for power and $/GJ for steam that is produced. The ability to easily generate steam (via a boiler with a suitable burner) and power (via a containerized cogeneration engine) results in the overall economics of this system being strong as it can offset 100% of the thermal and power loads and can be utilized 24/7.

A biogas system is not suited to all feedlots as it relies upon suitable pens (e.g. with a compact crushed gravel based to prevent mixing of manure with soili) and associated collection method (e.g. laser and GPS guided collection to ensure newest manure is scraped first then delivered to a walking floor at the biogas facility). The cost of manure collection has not been accounted for in this study, however most feedlots will have costs associated with collection and transport of manure to a central location (e.g. for composting). The opportunity cost of using manure for biogas has not been account for, however a byproduct of digestion is a high nutrient, biologically available liquid fertilizer which can be pumped to co-located cropping land or mechanically dewatered to create a 20 to 30% solids soil conditioner or composted further with manure not used in the digester. Advantages of odour and vector reduction.

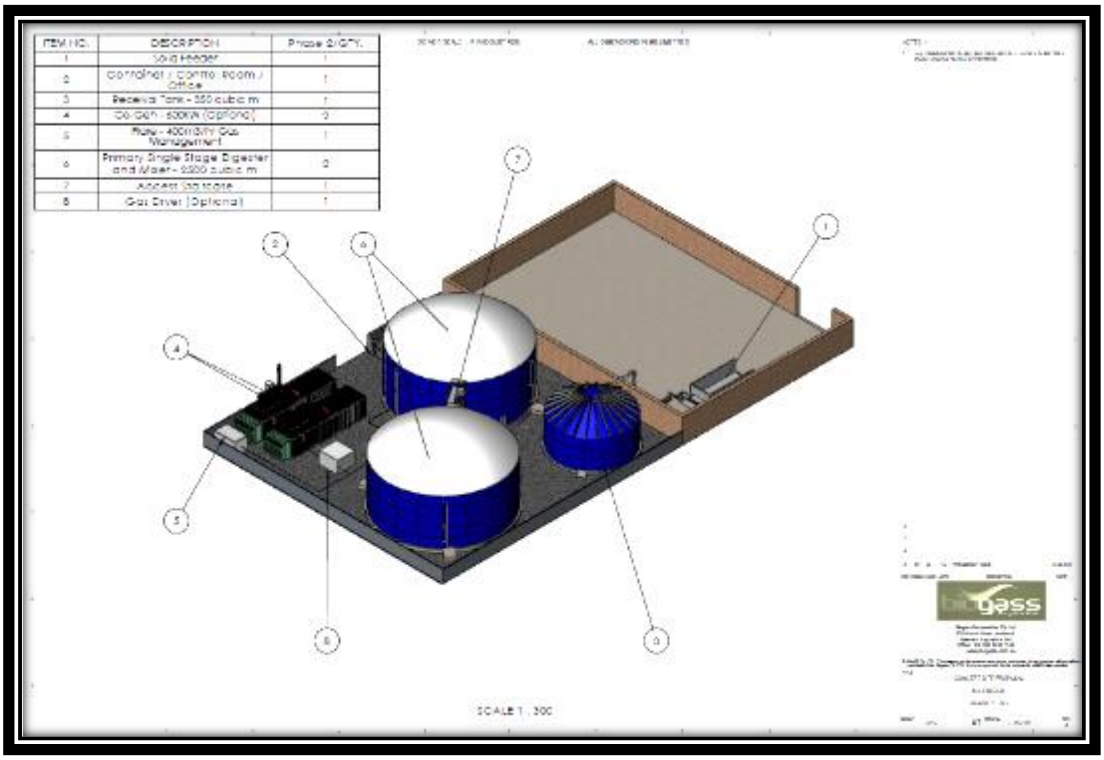


Figure 4: 3D rendered image of a feedlot waste to energy facility suitable for generating ~600 kWe of onsite renewable electrical power.

[12] MLA report B.FLT.0385_Final_Report, Feasibility of using feedlot manure for biogas production (2015).

4.6 Biomass fired multi-fuel boiler

A wide range of multi-fuel boilers were considered including ACT Group/Uniconfort, Hi-Tech (ACTOM / John Thompson), Visdamax, Javelin/Justsen and O'Brien.

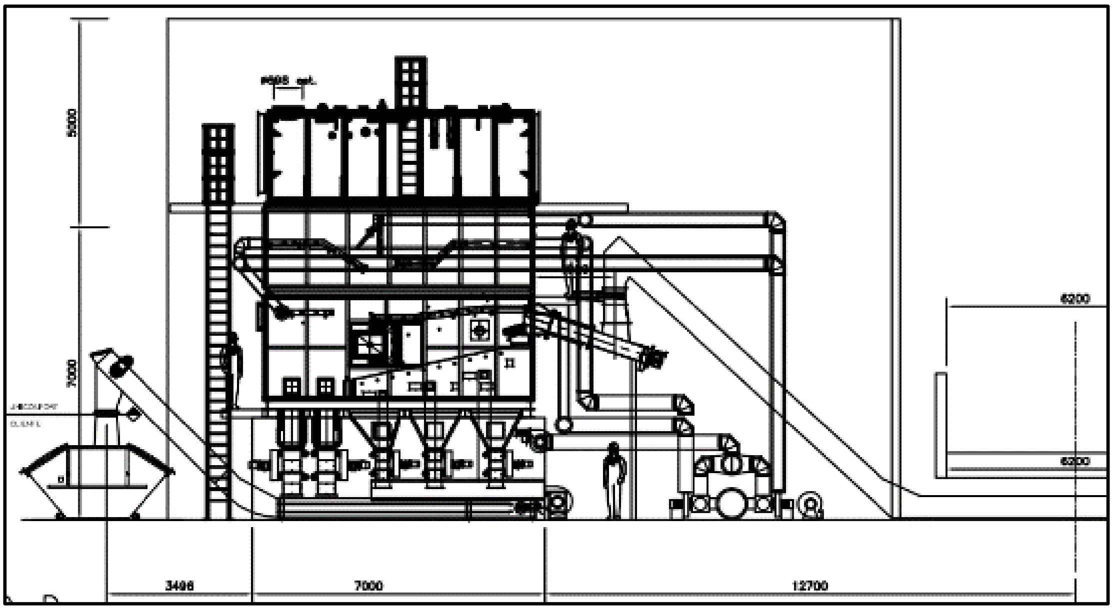


Figure 5: Sample elevation of a solid fuel biomass boiler. Source: uniconfort.com

Biomass and biomass-capable dual or multi-fuel boilers have the advantage over coal or natural gas boilers in that they partially or wholly offset fossil fuels and shield from emissions liability; provide a lower cost fuel (up to 90% of lifetime costs of a boiler are spent on fuel); and give greater fuel security by using local biomass rather than fossils that are subject to international fuel cartels' supply, international politics, or domestic policy forcing coal mines to move further and further away from consumption points.

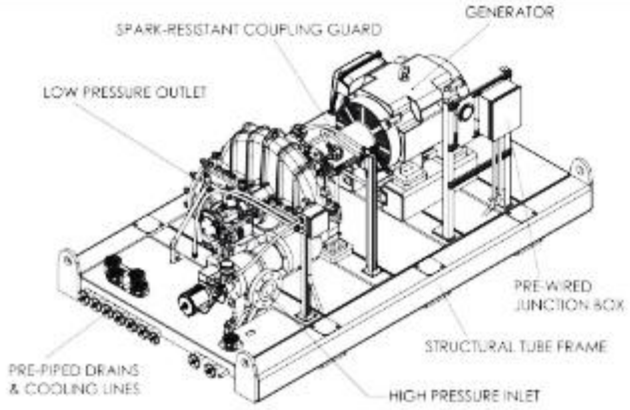
A key takeaway on the subject of biomass boilers is that regardless of threshold and pricing points and mechanisms, it is likely that within the lifetime of a boiler plant installed in 2018, that there will be the reintroduction of a carbon or broader greenhouse gas emission pricing system in Australia. This then presents a very strong justification for the industry as a whole, and for feedlots and processors in particular, to switch from fossil fuels to low-carbon emissions options such as biomass, biogas and/or solar.

4.7 Power generated from high pressure steam

Steam flaking operations can improve overall efficiencies and achieve targeted temperature set-points within the steam chests using less steam by utilizing high quality seam (i.e. no condensate; generating at a high pressure such as 7 barg then passing through a pressure reducing valve so that steam at the sparges is at 3 barg without condensate).

There is minimal capital cost implication to specify and procure a boiler capable of generating steam at approximately 24 and 26 barg as opposed to the desired 7 barg (e.g. a lower pressure boiler may only save 5 to 11% of equipment supply costs or less than $100,000). Hence, there exists an opportunity to generate steam at a higher pressure to then run through a backpressure turbine / expanding screw to generate low cost power at a feedlot. Thermodynamic analyses show that for a typically sized 20-25,000 head feedlot, using approximately 3 tph of steam at 7 bar, the additional fuel cost to raise steam to 24 bar for power generation is only 2-3%. This is because the fraction of energy content of steam as the latent heat of vaporisation (energy required to turn liquid water into steam) is the vast majority of the heat load when compared to the sensible heating from 7 up to 24 bar.

Technologies considered for power generation were supplied by Siemens, Northmoregordon / Air Clean Tech, and Hi-Tech / ACTOM.



Mass Flow (kg/hr)	Inlet Pressure (Barg)	Inlet Temp (C)	Exhaust Pressure (Barg)	Power Output (kWe)
4,400	24	224	7	103

Turbine model	S28
Inlet connection size and class	DN 100/PN 100
Inlet connection location*	LH
Exhaust connection size and class	DN 250/PN 20
Exhaust connection location*	RH

Figure 6: Sample steam turbine module. Source: Air Clean Tech.

Thermodynamic modelling shows that the feedlot considered would be able to generate approximately 100 kW of power or around one third of its power requirements via abackpressure turbine. Taking capital costs for a backpressure turbine into account, an additional 9% fuel consumption due to raising the steam to 24 barg rather than 7 barg, and Renewable Energy Credits at $60/MWh, the LCoE over a 15 year period for a backpressure turbine was estimated at $0.12 / kWh.

The detailed RFQ shortlist above shows that solar PV and biomass boilers are both financially viable technologies for implementation in Australian feedlots, achieving steam and power prices towards almost half the current business as usual costs.

Where no grid access is available, batteries must be included with solar PV if full grid disconnect is the objective. Without battery support, existing diesel generators will need to continue to be run at their minimum throttle ratio (in the order of 60-65%), meaning that the savings are mitigated and the maximum power offset on a kWh basis achievable with solar PV only is between 35-40%. In 2018, batteries may not yet be at the financial maturity and price point where they a viable inclusion into a solar PV system, as shown by the Elgas PPA price of 30 c/kWh compared to the PHP PPA price of 20-22 c/kWh.

Concentrated solar thermal and power (CST/CSP) is a novel, innovative technology that may be technically suited to the high solar intensity, regional areas of Australian feedlots and capable of providing all of a site's steam and power load from the sun. As this is a relatively unexplored technology in Australia (similar plants exist in Europe), the high capital cost means that the estimated steam $/t or power c/kWh price is higher than other available technologies. The economics for CST / CSP can be improved by various state and federal grants and support, and the structuring of long-term PPAs.

5 Discussion

5.1 Future Emissions Pricing

The benefits of decoupling from fossil fuels and grid power are shielding operations from rising power prices and the anticipated reintroduction of emissions pricing, leading to reduced future operating costs and improved profit margins, and developing the image of the Australian RMI as a clean and green, responsible corporate citizen. A recent survey of Australian consumers showed 76% would choose companies that used renewable energy over ones that did not, and would be willing to pay a premium for products linked to renewable energy[13].

It is likely that a carbon pricing regime will be introduced within the life of plant of any major equipment installed today. It is very difficult to predict exactly when this will happen, since it is a strongly partisan issue, with additional intra-party conflicts. The Australian Government's Productivity Commission in its 24 Oct 2017 report called for Australian governments to "work cooperatively to resolve the issues currently confronting Australian energy markets. They must: stop the piecemeal and stop-start approach to emission reduction, and adopt a proper vehicle for reducing carbon emissions that puts a single effective price on carbon"[14]. The Turnbull Government's budget of 8 May 2018 put aside $0.9 million for modelling of a broad based carbon pricing regime.

The EU level of CO2-e was trading at 7.70 Euros ($AUS 12.08) at the end of 2017 but has historically been as high as EU21.03 ($AUS 36.13)[15].

[13] http://www.theage.com.au/business/energy/somebodys-got-it-wrong-on-renewables-20170717-gxclo8.html
[14] https://www.pc.gov.au/inquiries/completed/productivity-review/report/5-improving-markets, accessed 29 Nov 2017.
[15] https://www.investing.com/commodities/carbon-emissions-historical-data, accessed 27 Nov 2017.

5.2 Future Fossil Fuel Pricing

All open source data suggests rising LPG and diesel prices due to recent OECD supply restrictions and continued upward demand[16]; in summary supply will continue to be constrained putting upward pressure on prices for the foreseeable future.

5.3 Power Quality

If there is no isochronous generator in the system that sets microgrid frequency and voltage, a "master inverter" with battery storage can be selected that will provide this function. Inverters, in conjunction with a system supervisory controller, should be capable of bi-directional real and reactive power flow.

If a power purchase agreement or other performance contract is involved and savings are based on real power, then PF correction or VAR support needs to be accounted for.

Voltage optimization would also reduce kVA and kW loads. A 1% voltage increase leads to 1% increase in energy consumption and 1.7% or more increase in reactive power consumption, with VO install estimated at $36,250 for a 250 kVA install[17].

The demand for improving power quality is low when diesel gen sets at below 80% loading. Once a gen set is nearing full loading and/or a power purchase agreement is received, a more detailed cost-benefit analysis on power quality can be completed.

6 Conclusions and Key Messages

6.1 Key Messages:

- **The red meat industry must immediately decouple from imported fuels (i.e. diesel and LPG)**
  - Imported fuels are subject to high price volatility from international politics (e.g. OPEC and Middle East politics). This also threatens the fuel security of these fuels. Local biofuels are lower cost and higher security as there are multiple available supply streams within a short radius of feedlot locations.

- **The red meat industry must immediately decouple from fuels exposed to international pricing mechanisms (i.e. nat gas)**
  - Domestic natural gas pricing is being driven upwards from demand in Japan, China, and Korea, where high LHV Australian gas that was historically available domestically for a comparatively low price is being locked up into long-term export contracts with Queensland LNG export projects. This is bringing wholesale gas prices in Australia closer to parity with the Asian markets, resulting in significant year on year increases in the price of natural gas to consumers in the Australian red meat industry.

- **The red meat industry must decouple from emissions intensive fuels (i.e. fossil fuels) within 5 years**
  - When emissions pricing mechanisms are reintroduced into the Australian market, whether these take the form of broad based emissions pricing, narrower scope pricing, or emissions trading schemes, larger emitters of GHGs in the Australian RMI may be liable and vulnerable to a significant annual cost increase. All biological fuels or sources of energy, including woodchip, manure, biogas, straw etc are counted by the Clean Energy Regulator as "zero emission" as any carbon emitted via combustion is not being added to the atmosphere, only recycled.

[16] Singapore price trends, https://www.globalpetrolprices.com/Singapore/diesel_prices/; Global price trends, http://abc7chicago.com/travel/gas-prices-rising-drivers-facing-most-expensive-driving-season-in-years/3411160/

[17] https://www.ampc.com.au/2018/05/Investigation-into-Voltage-Optimisation-Technology-for-Abattoirs

- **The red meat industry must have strategy to buffer against rising grid power costs**
  - The effects of rising transmission and distribution costs, shrinking spare capacity and rising spot market pricing can be seen via the uptick in retail pricing (refer fig. 10 below). With a precedent for such increases and continued increases in time-of-use tariffs in regional areas charging as much as 50 c/kWh, with these transient tariffs expiring before 2020 where consumers will then be charged 60 c/kWh, it can be seen why medium-large consumers in the Australian supply chain must have a strategy to manage rising grid power. Options include:
    - investigate renegotiating the tariff class. A recent calculation by All Energy found that switching from one tariff to another for a 20,000 head feedlot could save over $40,000 per annum with minimal effort and risk.
    - On-site power generation.
    - Improve power quality: PF, voltage optimization.
    - Disconnect from the grid via on-site generation and storage.

6.2 R&D and Innovation Opportunities

The innovative aspects of a feedlot renewable energy solution could form the basis of an MLA R&D project, including:

- Multi-fuel boiler: most boilers are designed and fabricated for one fuel. Modern, European designed boilers are more flexible in the fuel that can be utilized. It would be highly innovative to have a boiler that could utilize a range of low cost fuels including waste grain material, cotton gin wastes, wood (green and air dried), manure, pelletized paunch, and straw.
- Backpressure turbine run off high pressure steam from the boiler.
- Site-wide energy management system to manage multiple embedded generation technologies: grid, PV, backpressure turbine and kVA loads throughout the plant.
- The installation of a biomass boiler provides the opportunity for the site to move from approximately 100% “black” energy (grid power and LPG) to approximately 90% green energy on a gross energy delivered to site basis. A digester to produce biogas for an engine and for a boiler enables the site to progress towards 100% renewable energy.

7 Bibliography

All references are provided within the document as footnotes.