



INVESTIGATING STEAM HEAT RECOVERY SYSTEMS (INCLUDING SUPERHEATED STEAM SYSTEMS FOR TURBINE GENERATION) AND THEIR APPLICABILITY TO THE RED MEAT PROCESSING INDUSTRY

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1.0 EXECUTIVE SUMMARY

This project investigated the feasibility of proven and novel steam heat recovery systems in Australian red meat processing facilities. The scope of this project was superheated steam for turbine generation and concentrated solar thermal systems, considering how these may be implemented to reduce operating costs of heat and power.

The objectives of this project were to add to knowledge through detailed technical and commercial analyses of heat recovery and steam raising systems, giving insight into the viability of these systems to meet the operating, scale, and financial requirements of Australian RMPFs. Another significant objective of the project was to discover previous projects and plant that could be utilized in this industry, highlighting improvements in productivity, utilization, and efficiencies for thermal heat and power.

A technical specification and basis of design was developed for a typically sized facility in Australia, before turn-key budget submissions were retrieved from the market. Cost-benefit and sensitivity analyses were then run to determine the economic viability of these technologies in this context.

The key findings of this project were:

- // The table below summarizes the findings for generation of 130 kW of net power from high pressure steam for a “typical” 625 head per day facility operating for 2 shifts per day, 5 days per week.

Table 1: Key findings for generation of 130 kW of power

Scenario	Fuel	Cap ex	Simple payback
New high pressure boiler and 130 kW turbine	Coal	\$3.174 mil	Not in life of plant (39 years)
	Swapping from coal to woodchip		20 years
	Swapping from natural gas to woodchip		5 years
Replacing end of life boiler (or utilizing existing 24 barg steam) and 130 kW turbine	Coal	\$0.975 mil (i.e. additional cap ex compared to like-for-like replacement)	12 years
	Swapping from coal to woodchip		6 years
	Swapping from natural gas to woodchip		2 years

- // When implementing a new boiler (i.e. not replacing an end of life boiler) and integrated backpressure turbine, simple payback periods are unfeasible for coal and woodchip (i.e. plant may not achieve payback within life of plant), however replacing a natural gas boiler shows strong economics. When the only additional capital is the turbine (that is, a high-pressure boiler already exists or the current boiler is at the end of service life thus being replaced anyway), simple payback periods become viable for all fuel substitutions for woodchip.
- // The economics are improved by increasing plant utilization i.e. where a RMP is generating steam for a larger number of hours in the year (e.g. continuous rendering) rather than running for only 16 hrs per day, 250 days per annum.
- // The economics are improved for high power prices or where power prices are increasing over time.
- // A reintroduction of carbon emissions pricing, which is highly feasible within the life span of any new boiler, further improves the economic viability for a woodchip boiler with turbine i.e. replacing a coal or natural gas boiler.
- // Coal fired boilers replaced by Concentrated Solar Thermal (CST) systems with a turbine deliver a simple payback period of 26 years. The payback to off-set gas usage with CST with a turbine is estimated to yield an 11 year simple payback. A 5 year payback is achieved where CST offsets fuel at \$30/GJ (e.g. LPG).

The benefits to industry of moving to a woodchip or CST solution is a decoupling of the red meat industry from fossil fuels and also from the volatility of fuels that are now exposed to the pricing of international energy markets. Renewable energy solutions have the additional benefit of contributing to maintaining Australia's "clean and green" image and the image of the red meat industry as a responsible corporate citizen.

2.0 INTRODUCTION AND BACKGROUND LITERATURE

AMPC identified the need to consider the technical and commercial feasibility of novel steam heat recovery systems to provide a heat supply adequate to the requirements of Australian red meat processors. Particular interest was in superheated steam turbines for generation systems and concentrated solar thermal systems.

MLA report A.ENV.0095 advises that the combined factors of continually increasing energy costs and environmental policy, both current and future, justify close inspection of energy usage and energy sources for the Australian meat industry (MLA, 2010)¹. MLA, AMPC and industry partners acknowledge that reducing energy consumption is an important challenge for the industry, and aim to achieve a 10% reduction in consumption (among other environmental objectives)² within the next few years, by a combination of projects and initiatives³.

Cogeneration is one energy strategy that can be implemented. It is also known (particularly overseas) as combined heat and power (CHP). Simply defined, cogeneration is the coproduction of two forms of useful energy, most commonly electrical and thermal, from a single fuel source; offering increased energy efficiency and operational benefits in economic and environmental terms.

The NSW Government Office of Environment and Heritage outlines the following general indicators that a cogeneration project will be successful at a particular site (NSW Government, 2014)⁴:

1. When there is significant and simultaneous need for thermal and electrical energy.
2. Thermal requirements greater than electrical loads.
3. Constant loads and long operating hours.
4. Access to a “free” energy source.

When considering the feasibility of implementation of cogeneration with greater specificity, AMPC 2013.5011 reports that for each meat processing facility there will be a minimum value for cogeneration to become technically viable, and that larger scale shows more scope for the feasibility of implementing cogeneration. Ongoing rises in energy costs and greater competition by equipment manufacturers both increase the attractiveness of cogeneration.

¹ Meat & Livestock Australia Limited, 2010, *Renewable Energy and Energy Efficiency Options for the Australian Meat Processing Industry*

² Australian Meat Processor Corporation, *Energy*, available <http://www.ampc.com.au/site/assets/media/Factsheets/Food-Safety-Meat-Science-Market-Access-Marketing-Consumer/Energy-environmental-best-practice-manual.pdf>

³ Meat & Livestock Australia Limited, 2014, *Energy Consumption*, available <http://off-farm.mla.com.au/Environment/Energy-consumption>

⁴ NSW State Government Office of Environment and Heritage, 2014, *Cogeneration Feasibility Guide*, available from <http://www.environment.nsw.gov.au/resources/business/140685-cogeneration-feasibility-guide.pdf>

Although the energy demand of a meat processing plant is obviously dependent on throughput and on-site operation (e.g. with or without rendering), the most recent KPIs developed by MLA give a mean of 3,389 MJ per tHSCW (ranging from 2,000-6,000)³, of which electricity accounts for approximately one third, steam approximately one half, and hot water the remainder⁵.

A thorough literature review of steam heat recovery technologies that are currently available and being implemented around the world for steam turbine power generation was determined to be a prior requirement to concept level plant design and economic viability analysis. Previous AMPC works have highlighted the variability of power and steam loads in a typical facility throughout an operational day with a simultaneous over capacity of the steam header and generating equipment that is available on most sites, in terms of both tph steam and pressure rating.

This observation is also supported by AMPC's *Energy Consumption Guide for Small to Medium Red Meat Processing Facilities*, which suggests that in the area of cogeneration, significant improvement can be made in the area of system sizing, matching output with demand to avoid oversupply of energy. When considering existing oversized boiler plant, it is evident that significant heat reclamation opportunities during steam generation, distribution, and usage exist at such plants⁶.

MLA report A.ENV.0102 describes the following potential benefits of implementing cogeneration technology in a meat processing facility (MLA, 2010)⁷:

1. Reduced on site energy costs through increased energy efficiency.
2. Increased reliability, security, and quality of electricity supply.
3. Reduced GHG emissions.
4. Less sensitivity to future electricity price increases.

Opportunities to move towards more decentralised electricity generation, meeting site needs while also providing high efficiency, flexibility, and avoiding transmission losses.

Previous works on the topic of heat recovery for generation in red meat processing facilities include AMPC project 2016.1002 *Investigation into Modular Micro-Turbine Cogenerators & Organic Rankine Cycle Cogeneration Systems for Abattoirs*, where a similar methodology to this project was applied to the focus area of modular gas microturbines, organic rankine cycle (ORC) systems, and simple reciprocating engines for cogeneration in red meat facilities.

⁵ Colley, T, 2007, *Meeting Heat and Power Loads Down Under – Australian Meat Processing Plants are a Fine Match for Cogeneration*. Available from <http://www.cospp.com/articles/print/volume-8/issue-6/features/meeting-heat-and-power-loads-down-under-australian-meat-processing-plants-are-a-fine-match-for-cogeneration.html>

⁶ Australian Meat Processor Corporation, *Thermal Energy Use in Meat Processing Plants*, available <http://www.ampc.com.au/site/assets/media/Climate-Change/Energy-Efficiency-Research/8.-Thermal-energy-use-in-meat-processing-plants.pdf>

⁷ Meat & Livestock Australia Limited, 2010, *Economic and Technical Potential for Cogeneration in Industry*

Trigeneration – heat, power, and cooling, but was not a part of the scope of this project. The results of this project were that none of the considered systems returned an acceptable payback period when natural gas is used as a fuel due to a combination of high capital, high fuel costs, and low costs for thermal and electrical power. When free-issued biogas (that is, biogas that is currently flared from an existing covered anaerobic lagoon (CAL)) is used as the fuel in these systems, the simple payback period became fairly attractive, particularly for reciprocating engines.

Whilst biogas is a technically and economically viable fuel at a RMP facility, it is estimated to only provide up approximately one third of the required thermal heating (where all available organics generated on-site are processed on-site). Further, when combusted in a cogeneration system, the biogas has a value up to 5 times that if it is just burnt in a boiler (assuming \$0.20 / kWh, 35% cogen engine efficiency, all thermal energy used to off-set boiler steam). For these reasons, biogas was not analyzed in detail as part of the project scope.

3.0 PROJECT OBJECTIVES

The objectives of this project are:

- // Adding to knowledge, through a detailed technical and commercial analysis, of proven and novel steam heat recovery and steam raising systems (including waste heat recovery and concentrated solar thermal).
- // Review, via the use of a cost-benefit analysis, options for heat and power that meet the operating, scale and financial requirements of Australian red meat processing facilities
- // From detailed cost-benefit analyses, recommendations can be made by All Energy Pty Ltd as to technically and economically viable options for the Australian red meat processing industry.
- // Contribute to understanding of underutilized steam systems and other on-site steam generation options that can be effectively employed by Australian red meat processors for power generation.
- // Via the use of case studies, outline previous works (e. g. in other industries and internationally) and how these could be implemented for the Australian red meat processing industry.
- // Provide a platform for highlighting improvements in productivity and efficiencies for thermal heat and power.
- // Facility readiness considerations for superheated steam systems
- // Preliminary design and associated capital cost estimation.
- // Case study generation to run a specific business case analysis for calculation of payback periods and rates of return.
- // Requirements of automated metering/sensing/control (e. g. heat availability, generation, predicted heating, current power loads, predicted power loads, power billing implications) and Energy Management Systems in order for any new equipment to be run in an optimized fashion and for operating anomalies or opportunities to be determined in real time.

4.0 METHODOLOGY AND BASIS OF DESIGN

4.1 Matching Cogeneration to Energy Use in a Typical Meat Processing Facility

As mentioned earlier, superheated steam backpressure turbines and concentrated solar thermal systems can be developed at a range of scales and configurations. Technical and commercial success will be achieved when each configuration is matched closely to the energy needs of the meat processing facility. A “typical facility” was described as below.

4.2 Meat processing facility basis of design – typical facility

A “typical facility” for an Australian meat processing facility is outlined in Table . A mass and energy balance was developed by AEPL for this facility as the basis for the characterization and comparison of cogeneration systems.

Table 2: Basis of design: A "typical" red meat processing facility

Basis of Design			
General			
Site Location		Qld, Australia	8
Head Processed per day	Head pd	625	9
HSCW tonnes / head		0.24	8
Plant Operating Schedule			
Available operating hours per day	h	16	8
Available operating days per year	d	250	8
Operating hours per year	h	4000	6

4.3 Electrical Power load profile

A typical energy consumption profile for a 2-shift-per day facility (corresponding to the plant present in Table above) was developed based on averaged weekday and averaged weekend data. The maximum load occurs when boning periods, initial stages of carcass cooling and ambient conditions are hottest, in particular from 11am to 5pm, Monday-Friday. The weekend electricity consumption was approximately half that of a weekday profile.

Table 3: Electrical consumption data - typical facility

Basis of Design			
Plant Operating Schedule			
Available operating hours per day	h	16	8
Available operating days per year	d	250	8
Operating hours per year	h	4000	6
Electrical Supply System			
Source		Grid	8
Unit cost	\$/kWh,	23	8
Unit consumption	kWh/t HSCW	kWh/t	317.2
Total consumption		kWh/day	47580
Total Consumption Continuous equivalent	eMW	1.98	
Total Consumption- during shift	eMW	2.97	

Table 4: Power requirements in a typical meat processing facility⁸.

Power load	% of annualized electricity use
Refrigeration	42.6
WWTP: DAF and aerators	11.6
Lighting	8.3
Boning room	8.9
Rendering plant	6.8
Compressors	5
Boilers	3.7
Value add	2.4
Water dist.	2.3
Kill floor	1.3
Admin	0.9
Other	6.2

Daily electrical demand profiles are shown in **Error! Reference source not found.** and Figure 1: *Weekday demand profile for a typical facility.*

, for a typical meat processing plant operating on a weekday and weekend, respectively.

⁸ AMPC / MLA Report A.ENV.0090 Env Data Analysis July 2011.

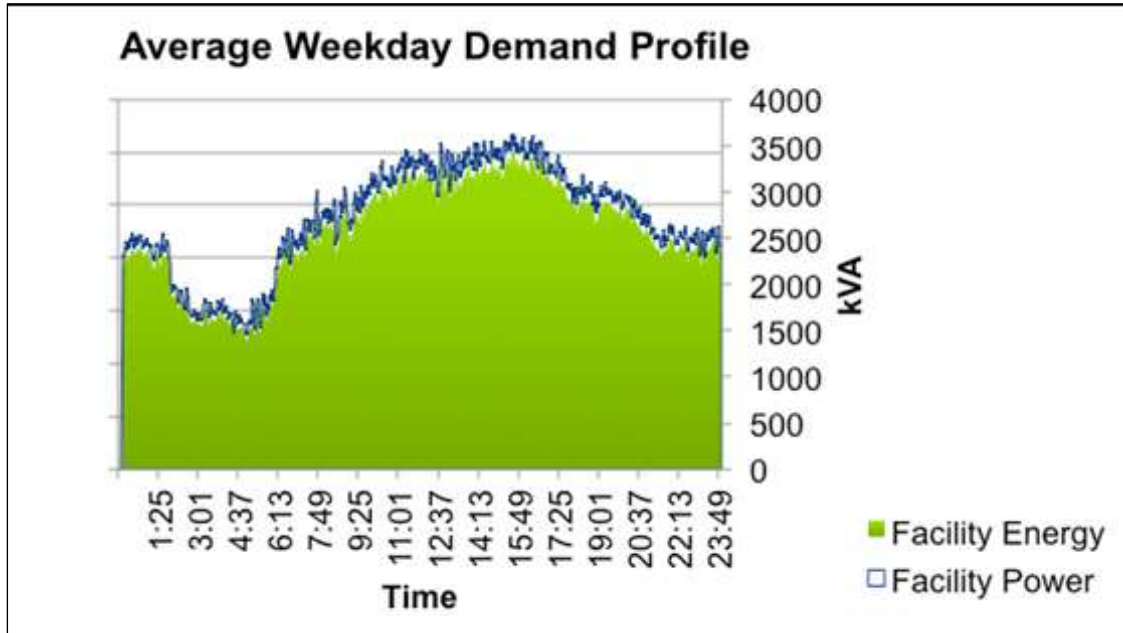


Figure 1: Weekday demand profile for a typical facility.

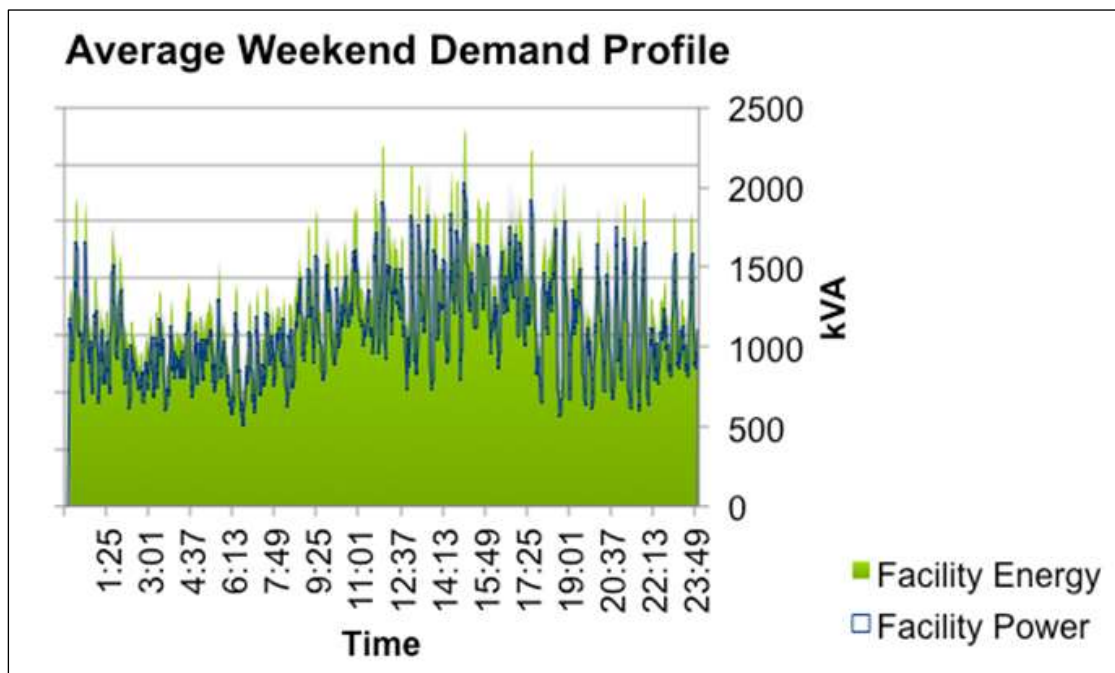


Figure 2: Weekend demand profile for a typical facility

If on-site electrical generation is being considered, it can be seen from the figures above that the scale of the generating equipment will have a large impact on its utilization. Consider three different plant sizes for electricity generation:

- a) A unit capable of providing 3,500 kVA (net) will supply all electricity for the peak load on this site. In theory, there would no longer be a need for electricity to be purchased from the grid. However, for much of the shift, this large generator would only be partially utilized for on-site power, and at weekends the on-site power needs could be met by the unit operating at less than half its capacity. Such operation would adversely affect the efficiency of the unit.
- b) A unit sized to provide 1,500 kVA will operate at capacity to supply the base load during shift. Peak electrical needs during plant operation will have to come from other sources. In contrast, at the weekend this on-site unit it will be considerably oversized.
- c) A smaller unit, sized to provide approximately 700 kVA, will be able to operate continuously at capacity for the provision of power solely to the meat works.

The larger plants are of interest because they typically offer significant economies of scale, meaning that if operating continuously at capacity they will provide lower cost power. Partial utilization diminishes this benefit. It may be possible to compensate for reduced on-site demand by using excess capacity to generate electricity for sale into the grid, but such “export” sales are likely to be at a much lower value than for the electricity that is generated for on-site use. Also, such sales require a separate power purchase agreement and additional equipment for grid connection.

The smallest plant has the benefits of steady operation for more hours each year, and all of its electricity going to the more valuable use (on-site, rather than export to the grid). Against this, such a generator will be more capital intensive per unit of output.

4.4 Thermal Power Load Profile

Thermal power consumption profiles with the same granularity as above were unable to be discovered in the basis of design formulation of this project.

A thermal schematic of a typical plant is presented in Figure 3. In this traditional plant configuration, steam is produced at pressures well in excess of what is being used, and a series of pressure reduction valves throttle this pressure back at points in the network [5]. The consideration of technologies utilizing superheated steam are based on this general plant set-up.

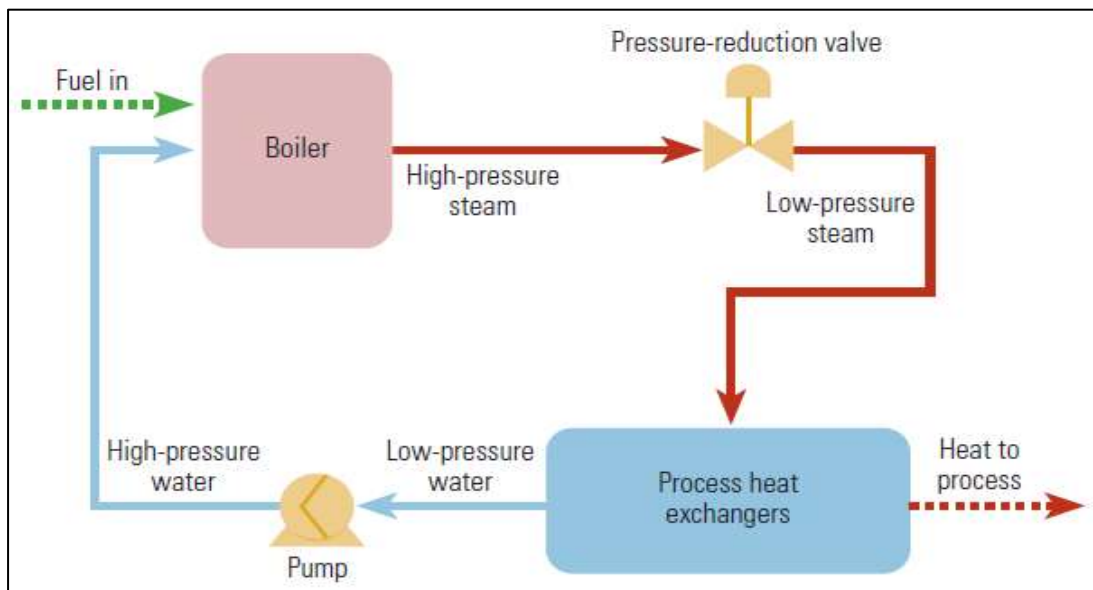


Figure 3: Typical Thermal Plant Schematic (Image Source: Casten, S, 2005, *Recycling Waste Pressure into Electricity*. Turbosteam Corp.)

Previous AMPC studies report for this typically sized facility an equivalent fuel consumption of 84,038 GJ pa, or 5.84 MWt assuming 4000 operational hr pa⁹. Given reported process pressures for rendering of approximately 6 bar and reported draws of 5 tph steam, this suggests an unusually low boiler efficiency of around 65% which does not agree with anecdotal observations by AEPL. It is expected that this error is either due to the case study boilers of A.ENV.0090 being abnormally mismanaged or incorrect recording or analysis of fuel consumption by the undergraduate students conducting the review. At the advice of boiler vendors, submissions for a 4 MWt high pressure boiler were requested rather than 6 MWt.

6.1.2 Thermal Sinks

As can be seen from the high level energy requirements above, there is further need to devolve the thermal and power demands to understand how these change during operating times, weekday non-operational times and the weekends. Tables 5 and 6 below summarize an estimate of the various uses of the thermal heating at a 625 head per day red meat processor and the approximate heating loads assuming a 5 day per week, 16 hours per operational day.

⁹ AMPC Report A.ENV.0090 Env. Data Analysis, July 2011.

Table 5: Steam uses at a 625 head per day facility¹⁰.

Steam heat sink	% heat load	kWt load
Rendering	63.40%	3,696
Hot water make up	11.80%	688
Boiler house losses	10.00%	583
Blood processing	8.50%	496
Piping losses	4.20%	245
Tallow processing	2.10%	122

Table 6: Hot water uses at a 625 head per day facility¹¹.

Hot water heat sink	% hot water consumption	kWt load
Sterilizers	34.10%	235
Hand wash stations	5.70%	39
Kill / evisceration	17.00%	117
Cleaning	28.40%	195
Amenities	5.70%	39
Tripe washing	2.30%	16
Hook wash tanks	1.10%	8
Piping losses	5.70%	39

Figure 2 below shows an indicative thermal profile for a beef processing facility with rendering. Due to a lack of detailed metering, only an indicative thermal load profile is displayed.

One energy strategy that has been suggested to be implemented and is explored for the meat industry is cogeneration, also known as combined heat and power (CHP). Simply defined, cogeneration is the sequential production of two forms of useful energy, most commonly electrical and thermal, from a single fuel source; producing obvious advantages in economic, technical, and environmental terms.

¹⁰ AMPC Report A.ENV.0090 Env. Data Analysis, July 2011.

¹¹ AMPC Report A.ENV.0090 Env. Data Analysis, July 2011.

Recent investigations by All Energy Pty Ltd (AMPC project 2016.1002) in the topic of cogeneration have discovered how meat processing facilities could be underutilizing their boiler capacity.

The indicative thermal profile of a typical plant demonstrates a significant amount of spare boiler capacity due to the oversupply of steam pressure relative to that required for processing (Boiler thermal rating vs Steam Load). The difference between the hot water load and the hot water generated at peak times indicate the presence of spare low-grade heat available once rendering heat recovery comes online. This observation is also supported by AMPC's *Energy Consumption Guide for Small to Medium Red Meat Processing Facilities*, which suggests that with the application of cogeneration, significant improvements can be made in the area of system sizing, matching output with demand to avoid oversupply of energy. When considering existing oversized boiler plant, it is then evident that significant heat reclamation opportunities during steam generation, distribution, and usage could exist in most standard plants¹². As a steam turbine is "baseload" in that it can be run at the same time that steam is generated, it was assumed that a 130 kW turbine at 0.94 power factor could reduce the site-wide kVA demand by 138 kVA.

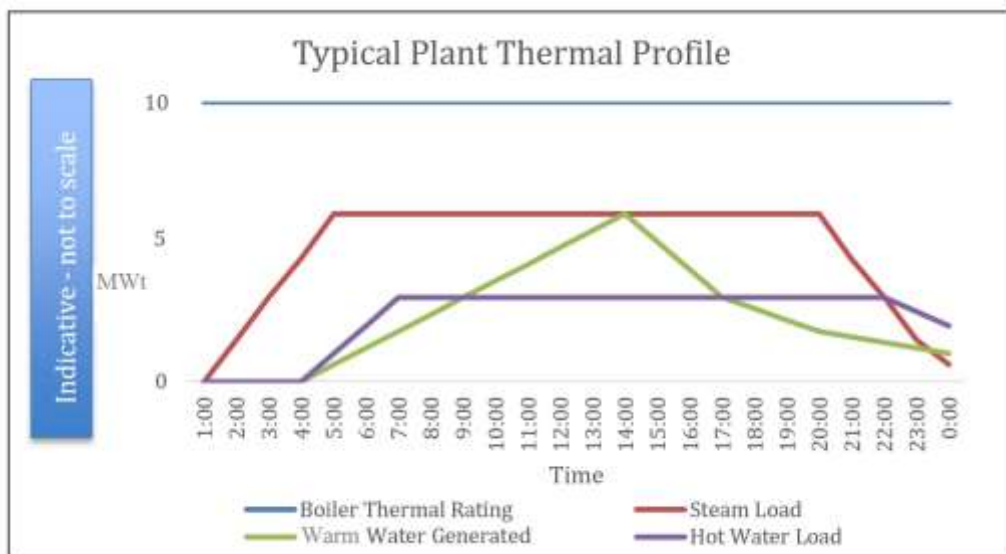


Figure 4: Steam and hot water thermal load profile of a meat processing

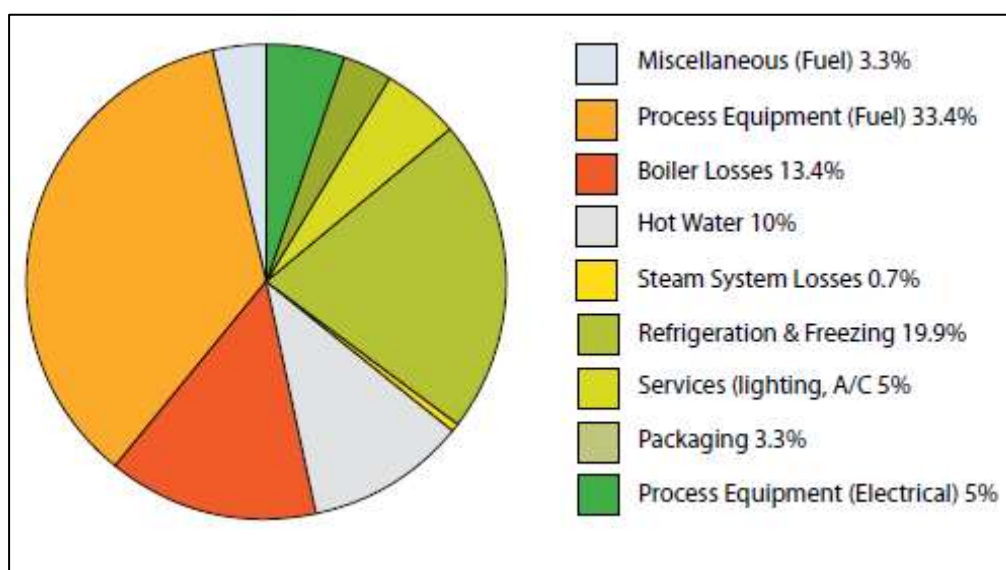
¹² MLA Project A.ENV 0065, (2009).

6.1.4 Assumed Energy Costs

Table 7: Energy Cost Assumptions

BASIS OF DESIGN		
Electrical Supply System	Units	Rate
Electricity unit cost – power	\$/kWh	\$ 0.190 / kWh
Electricity network charge	\$/kVA/yr	\$ 262.308 / kVA/yr
Thermal Energy	\$ / GJ delivered to site (LHV; LOWER HEATING VALUE)	
Coal	4.37	
Woodchip	4.17	
Natural gas (reticulated)	12.00	

Figure 5 presents the energy consumption and losses in the meat manufacturing industry,



showing the potential for boiler waste heat recovery from boiler losses [6]. It should be noted that cross referencing with other AMPC sources indicates that the percentage attributed to steam system loss should read 7% not 0.7%. The US Department of Energy has also classified waste heat by temperature and includes the source, characteristics and associated waste heat to power technologies (available in Appendix 1) [7].

Figure 5: Energy Consumption in the Meat and Meat Products Manufacturing Industry (Source: Australian Industry Group. (2010). Saving Energy in Abattoirs & Meat Processing Facilities).

5.0 PROJECT OUTCOMES

5.1 Technology Review – Backpressure Turbine Cogeneration

The terms ‘micro-turbine’ and ‘pressure reduction micro-turbine’ may be used to refer to small steam turbines that capture energy during pressure reduction in steam lines. In the typical meat plant, steam is produced at pressures in excess of process requirements, and a series of pressure reduction valves (PRV) reduce this pressure at various points in the steam network. The case for cogeneration here is that since the boiler follows the transient need for process heat in the facility, there is underutilised boiler capacity in most meat processing plants, where efficiency gains can be achieved by operating the boiler closer to its capacity and using the additional fuel energy to drive a backpressure turbine.

A diagram of a high-pressure backpressure steam turbine generator is shown in figure 6.

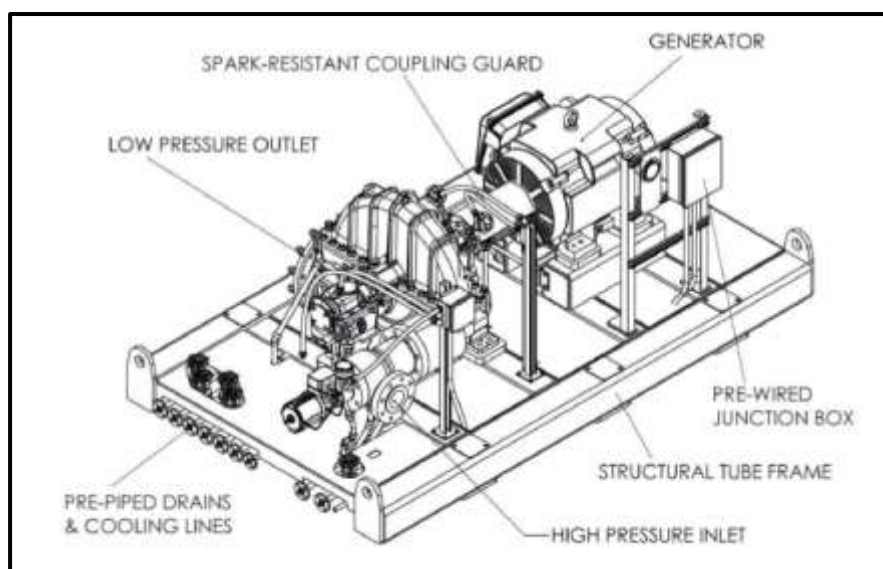


Figure 6: High Pressure Steam Backpressure Turbine Generator; Inlet of 5 tph 24 Barg steam, outlet at 6 Barg, 130 kWe power outlet¹³.

A “bottoming cycle” is where fuel is first used to make thermal heat, followed by heat recovery from the flue gas (e.g. to heat thermal oil or raise steam) for the generation of electricity. A bottoming cycle works well where large tonnages of high temperature fluids are available (e.g. from an exothermic process) or where a low cost fuel is available that is not suited to direct firing within a prime mover (e.g. a solid fuel such as wood chip or coal; pyrolysis gas; syngas containing high molecular weight volatiles). Examples of “prime mover” technologies for a bottoming cycle are organic rankine cycle (ORC), steam turbines and reciprocating steam engines. Thermal heat is also used within the co-located plant.

¹³ Image courtesy of Northmore Gordon Group, <http://www.northmoregordon.com/>

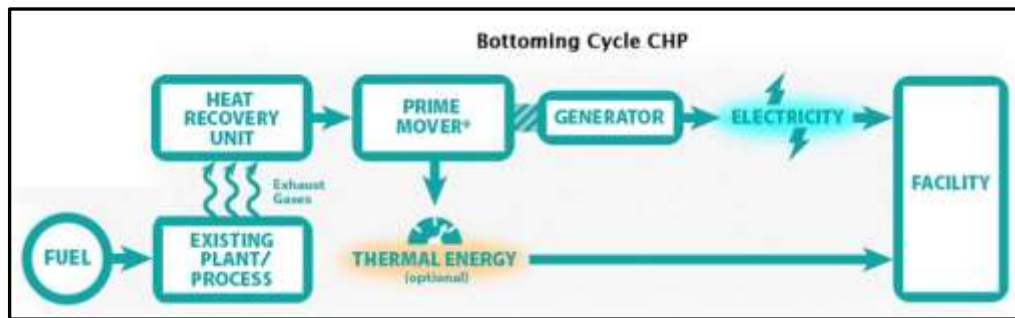


Figure 7: Combined heat and power “Bottoming Cycle” where power is generated from heat recovered from hot fluids⁸.

Advantages of a steam turbine are high overall efficiency, ability to pair with boilers firing a variety of gaseous, solid, or liquid fuels, ability to service more than one required heat duty, long working life and high reliability, moderate capital intensity, modularity, low integration difficulty, and variable power to heat ratio. Disadvantages include slow start up times, low power to heat ratio, and the requirement of a boiler or steam source.

Back-pressure turbines are contrasted to extraction-condensing in that the entire flow of steam into the turbine is exhausted to the industrial process creating the thermal load, at temperatures and pressures specified by the required operating conditions of the process thermal load. With commercial operation of backpressure turbine-generators dating back to 1886, this technology has a very low technical risk. When compared with an extraction-condensing turbine, a back-pressure turbine has significantly reduced power generation capability per tonne of steam due to this lower enthalpy drop and may only achieve an isentropic efficiency of 15 – 47%^{14,15}. However, the lower isentropic efficiency is offset by the following advantages of back-pressure turbines [8, 11]:

1. Simple configuration with few components
2. Low capital cost
3. Reduced or eliminated need for condenser cooling water
4. Higher efficiency compared to condensing turbines if the outlet steam can be utilized within an industrial processes.

That is, backpressure turbines can exhaust steam at a pressure which can still be used within an industrial process (e.g. 6 Bar steam for a rendering process).

AMPC 2013-.5011 reports the following with regard to back-pressure micro-turbine cogeneration:

- // Moderate capital investment
- // Strong feedstock matching
- // Strong application matching

¹⁴ University of Illinois, 2004, *Industrial (Steam)*, available from http://www.steamforum.com/pictures/060216_Industrial_Steam.pdf

¹⁵ http://invenoinc.com/file/Inveno_Techsheets_6.pdf, accessed 29 Nov 2016.

- // Possibility of modular implementation
- // Low integration difficulty
- // Ease of installation
- // For a particular plant case study, an IRR of 23.5% (When integrated with a wood chip-fed boiler, the payback period of steam turbine cogeneration in a Swedish meat processing facility has been reported at around 4 years.
- // For a condensing turbine, for each 1 MWe, 4.8 MWt energy is required and a further 3.75 MWt of cooling, and around 65 kW of parasitic load for pumps and fans, equating to an efficiency of around 19%.

From a high level, if steam can be raised in a solid fuel boiler at \$5 / GJ, at an overall efficiency of 40% for a backpressure turbine, it would be expected that a backpressure turbine could generate electrical energy at \$12.50 / GJ, or \$0.045 / kWh in energy costs. If the steam costs \$14 / GJ to generate, the power is generated at a cost of \$0.126 / kWh in energy costs. Where the high-pressure steam is otherwise reduced in pressure via the use of a pressure-reducing valve, then the steam energy may be considered “free issue”, however the capital and operating costs must be taken into account.

Modern solid fuel boilers include economizer sections to recover as much thermal energy as possible with flue gas temperatures approaching dew points, hence new boilers have minimal to no economic driver for waste heat recovery due to low flue stack gas temperatures. Other sources of waste heat are generally of too low a temperature to provide energy for the creation of steam (e.g. rendering plant condensate at 60 °C).

5.1.1 Case Studies

There are numerous operating case studies of steam heat recovery in a wide range of industries worldwide. A few examples to prove the technological and commercial readiness and discussed here.

California State University Sacramento Central Utility Plant (CUP)

At the end of equipment service life, and recognizing that the 40-year old plant in place could not approach the efficiencies of modern equipment and control systems, the state of California took the opportunity to cut power costs and provide for expected growth. \$181 million was spent on six new high efficiency RENTECH gas fired boilers providing 383,000 lb total steam per hour at 250 psi with associated cooling plant with variable speed electric chillers and cooling towers, photovoltaic panels, and hot water. The boilers also power a 2.9 MW steam turbine generator for backup power. The steam plant was oversized deliberately, with a turndown ratio of 6:1. This facility operates 24/7.



Figure 8: CSU Sacramento CUP

UMass Amherst Combined Cycle CHP

The prime mover installed here was a 10 MW combustion turbine, with a RENTECH heat recovery steam generator (HRSG) generating 120,000 lb/hr steam at 600 psig, operating in parallel with three 125,000 lb/hr boilers, 1 at 600 psig and the other two at 200 psig. Backpressure turbines were integrated with boiler plant, 3.5 MW 200/15 psig (from existing plant) and a new 2 MW 600/200 psig unit. The cost of this plant was in excess of \$150 million.

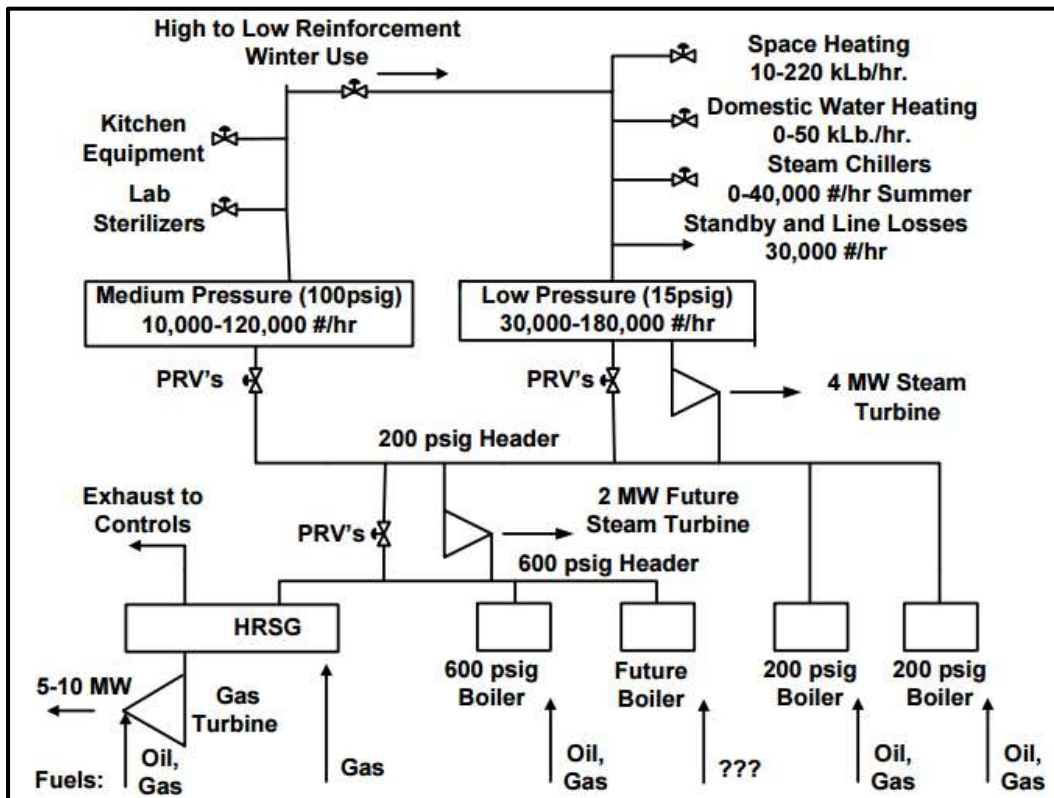


Figure 9: UMass Amherst Combined Heat and Power (CHP) Facility.

Kimberley Clark, Everett, Washington

This mill located in Everett, Washington runs a cogeneration boiler with a 52 MW generator, heat recovery boiler, and three auxiliary boilers. The total cogeneration plant cost \$115 million, and produces superheated steam for generation in a condensing turbine, with extraction at 300 and 40 psig for use as process steam. A lesson learned from this project is that appropriate design and sizing of boilers is crucial for successful economic return of these type of projects.

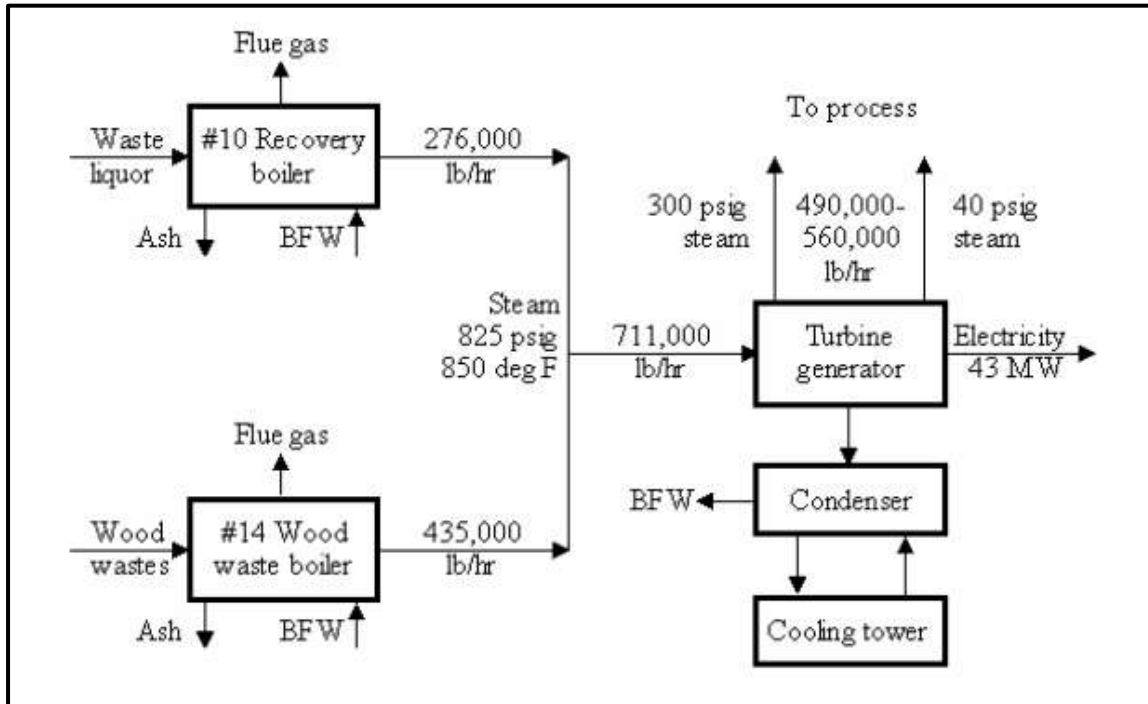


Figure 10: Kimberley Clark Everett Combined Heat and Power (CHP) Facility.

5.2 Technology Review – Concentrated Solar Thermal (CST)

Concentrated solar thermal (CST) uses mirrors known as heliostats to track the movement of the sun, concentrating sunlight into a preset central point, where large amounts of heat are produced – with working fluid temperatures reaching up to 1000°C in extreme cases. CST has many possible applications, including driving chemical reactions, steam production for electricity generation, and process steam generation.



Figure 11: CST System generating up to 39 MWt for water desalination, greenhouse heating and power generation (1 MWe) at Sundrop Farms, South Australia^{16, 17}.

Since CST systems operate on the transfer of heat, maximum efficiencies are thus achieved in very hot, arid areas with high amounts of solar intensity. It can then be deduced that Australia has very high potential for CST effectiveness.

Similar to power, heat produced by CST systems can be stored by molten salt in insulated tanks. This allows thermal or power generation at night, or to adjust output to meet peaks and troughs in demand.

5.3 Budget Pricing Requests for Quotation

Quotations of fully installed capital cost budget pricing was requested from organizations with an Australian presence and local experience with high pressure boilers, backpressure turbines, and CST systems. Since this was a desktop feasibility study, only one quotation was requested per company.

5.3.1 Boiler - Air Clean Technologies

A boiler submission was received from ACT Group¹⁸. A moving grate solid fuel boiler, 26 barg, 4 MWt and 5 tph steam unit was costed fully-installed, turn key at \$AUD 1.9 mil. This boiler has the significant advantage of being able to utilize multiple fuels such as woodchip, grain wastes, shells and coal.

¹⁶ <http://www.aalborgcsp.com>, accessed 4 July 2017.

¹⁷ www.aph.gov.au/DocumentStore.ashx?id=d64ebae3-045e-40ec-824c-a020a532c692, accessed 4 July 2017.

¹⁸ www.alternativecleantechnologiesgroup.com.au

It was assumed that all services (water, power, steam header) are available within 1 meter of agreed connection points and that appropriate fire services are in place; a factor of 7% was applied for insulation and a further 10% contingency applied bringing the Total Capital Investment estimate to \$2.2 mil.

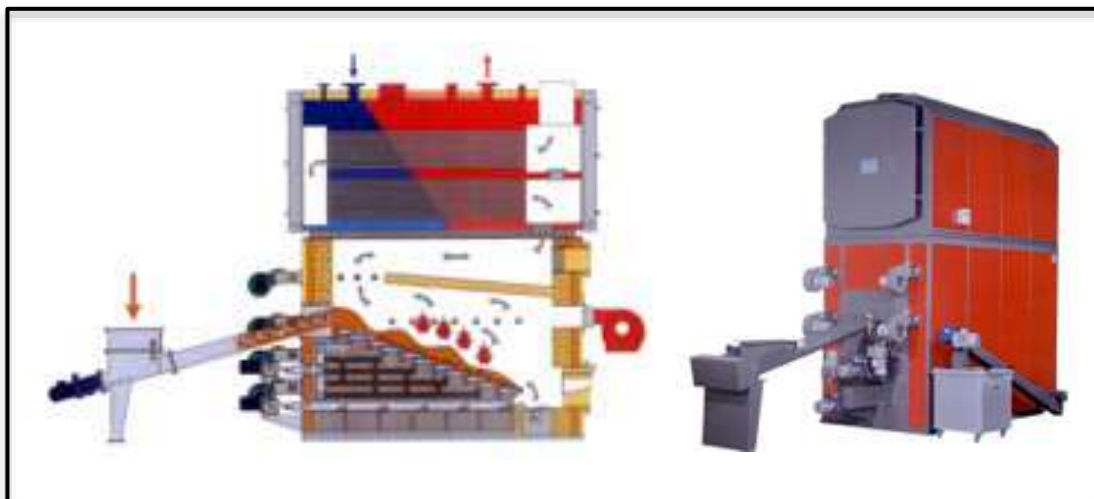


Figure 12: Moving grate solid fuel boiler, 26 barg, 4 MWt and 5 tph steam recommended by received from ACT Group¹⁹.

5.3.2 Backpressure Turbine

For seamless integration, turbine plant by Northmoregordon²⁰ was recommended by ACT Group. A backpressure turbine rated to 130 kWe was selected. At an exchange rate of \$AUS 1.353 per \$US²¹, equipment supply was estimated at \$AUS 0.385 mil. Turn-key including full installation, start-up and commissioning assistance plus a 10% contingency brings the Total Capital Investment estimate to \$0.975 mil.

5.3.3 Concentrated Solar Thermal

A submission was received from Impacts Solar²² for a CST system capable of providing 4 MWt steam load of 5 tph during peak sun conditions. Fully installed capital was estimated at \$AUD 8 mil. Annual operating cost estimates were also quoted by Impacts as \$AUD 68,372 pa.

5.4 Cost and Revenue Analysis

Backpressure Turbines

Annual repair and maintenance for the entire integrated plant was estimated as 5% of equipment supply costs. A thermodynamic analysis showed that an additional 10.9% of fuel is required for raising the higher pressure steam.

¹⁹ www.alternativecleantechnologiesgroup.com.au

²⁰ <http://www.northmoregordon.com/>

²¹ <http://www.xe.com/currencyconverter>, accessed 12 May 2017.

²² <http://impacts.com.au/>

Revenue was expected to come from offsetting electricity charges at \$0.16 / kWh. When the fuel used in the boiler is from a renewable source (woodchip or similar biomass, biogas, or CST) this scenario had the benefit of generating renewable energy generation credits.

Table 8: Cost and Revenue Analysis for Back Pressure Turbine (BPT) Scenario

Op ex	Rate	Unit	\$ pa
Maintenance and Repair of turbine	5% of equipment supply cost	\$ pa	\$21,182
Fuel - coal	\$4.37 / GJ	55,978 GJ pa	\$234,656
Fuel - woodchip	\$4.17 / GJ	55,978 GJ pa	\$233,427
Fuel – natural gas	\$12.00 / GJ	55,978 GJ pa	\$671,731
Cost Saving / Revenue Item			
Electricity Volume Offset	\$0.180	\$/kWh	\$83,200
Electricity Capacity Offset	\$263.308	\$/ kVA pa	\$36,337
RECs – Biomass only	\$60	\$/MWh	\$31,200
Emissions Reduction Fund (ERF)	\$8.274 ($\11.82 April 2017 ERF result ²³ minus 30% administration and set-up costs)	\$/ t CO ₂ -e	Coal to woodchip: \$43,145 Gas to woodchip: \$24,370

Findings – Simple Payback Period

The simple payback period compares a base case scenario for coal where there is no payback against a scenario where a payback on additional investment can be achieved. For investing in a new boiler and turbine, there is no motivation for running a turbine with steam raised from coal, however a 20 year payback can be achieved using woodchip and a 5 year payback can be achieved for swapping from natural gas to woodchip. However, where a boiler has been completely depreciated, the existing boiler is at end of life and/or additional boiler capacity is required, the economics are improved where installing a suitable boiler and turbine for coal has a 12 year payback, for woodchip a 6 year payback and for natural gas a 2 year payback is achieved. The parameter which has a large influence on the economic viability of the project is the power costs, hence the next section considers the impact of power pricing on the simple payback period.

²³ <http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/april-2017>, accessed 12 May 2017.

Table 9: Cost and Revenue Analysis for Back Pressure Turbine (BPT) Scenario

Scenario	Fuel	Cap ex	Simple payback
New high pressure boiler and 130 kW turbine	Coal	\$3.174 mil	Not in life of plant (39 years)
	Swapping from coal to woodchip		20 years
	Swapping from natural gas to woodchip		5 years
Replacing end of life boiler (or utilizing existing 24 barg steam) and 130 kW turbine	Coal	\$0.975 mil (i.e. additional cap ex compared to like-for-like replacement)	12 years
	Swapping from coal to woodchip		6 years
	Swapping from natural gas to woodchip		2 years

Sensitivity Analysis and Additional Scenario Development

For the scenario where an end of life boiler is replaced (or additional boiler capacity is required) and a backpressure turbine is installed, Figure 2 below shows a sensitivity analysis based on the value of the power that is off-set (e.g. grid power).

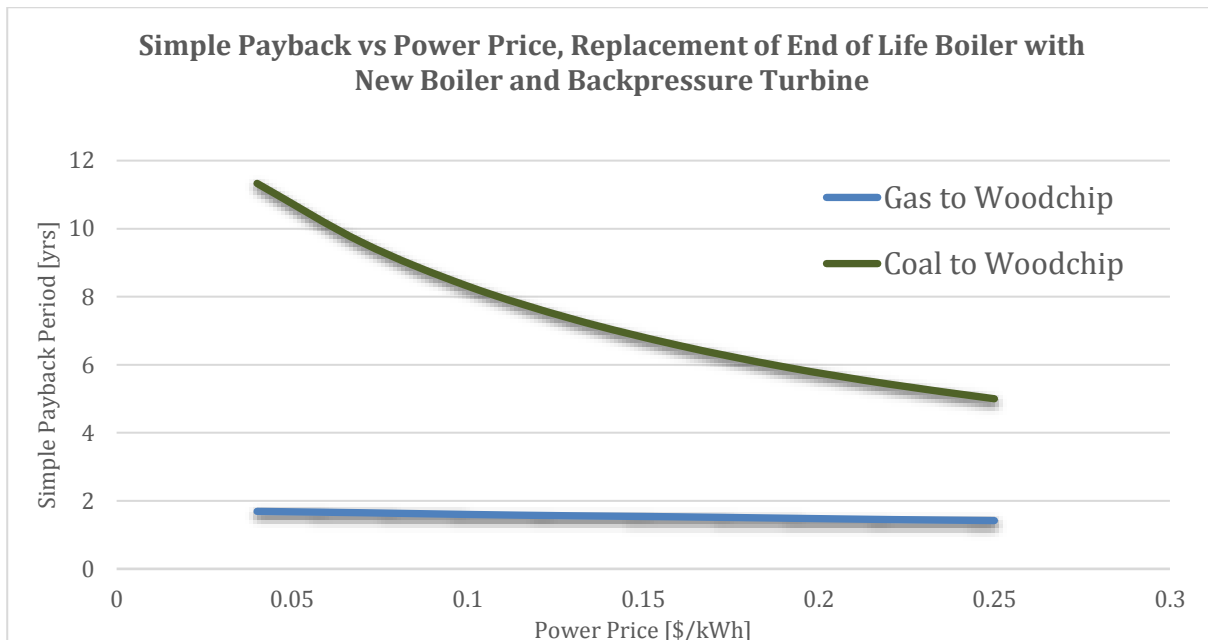


Figure 13: Sensitivity Analysis to Power Price – Back Pressure Turbine (BPT)

It may be concluded that companies should give serious consideration to a woodchip boiler and associated backpressure turbine where biomass can be procured at around \$4 / GJ, in particular where the main source of current thermal energy is natural gas and/or where power is at around \$0.20 / kWh or higher. An external factor such as the reintroduction of a carbon pricing mechanism will significantly improve the feasibility of using biomass as a fuel. Consideration will need to be given to the length of time and amount of revenue that can be generated via schemes, with those considered in this report being the Renewable Energy Target Largescale Generation certificates (LGCs) and the Emissions Reduction Fund.

Developing this scenario for biomass fired operation, annual t CO₂-e reductions were calculated using the National Greenhouse and Energy Reporting (Measurement) Determination²⁴ for bituminous coal.

Sensitivity to the availability of RECs, as it provides a not-insignificant contribution to revenue, should also be considered. The value of LGCs is supported via Federal Government legislation. Therefore, if LGCs were to drop in value or the scheme be halted, the project economic viability would be degraded.

For a plant where rendering is run continuously for 5 days of the week and where an end of life coal fired boiler is replaced by a woodchip boiler with turbine, a simple payback of 5 years is achieved and 1.4 years where a gas boiler is replaced.

Concentrated Solar Thermal (CST)

Annual operating cost for a CST system was quoted by the vendor at \$68,372 or approximately 1% of total Cap Ex. Revenues from abated fuel are calculated as per Table 2.

Table 10: Fuel Cost Savings Analysis for CST System Scenario

Abated fuel	Fuel Cost	\$ pa
57,600 GJ pa	Coal: \$4.37 / GJ	\$ 288,000
57,600 GJ pa	Gas: \$12.00 / GJ	\$ 691,200

At a Total Installed Capital estimated at \$AUD 9 mil for a “typical” red meat processing facility for a boiler and 130 kW turbine resulting in a 12 year payback in comparison to natural gas, it can be seen that CST is unlikely to be a viable replacement for conventional solid fuel steam generation. A recommendation to be made regarding CST is to monitor the technology until it becomes sufficiently mature that the Total Installed Capital is at an acceptable level. Schemes such a grant from the Australian Renewable Energy Agency (ARENA) could assist with reducing capital costs. Coal fired boilers replaced by Concentrated Solar Thermal (CST) systems with a turbine deliver a simple payback period of around 30 years.

However, for a regional facility paying high fringe of grid prices or running a diesel gen set (e.g. power at \$0.28 / kWh) and using a high cost fuel to raise steam (e.g. LPG at \$30 / GJ) a 5 year payback could be achieved. Some remote area and regional feedlots may fit into this category.

²⁴ National Greenhouse and Energy Reporting (Measurement) Determination 2008, made under subsection 10(3) of the National Greenhouse and Energy Reporting Act 2007, Compilation 1 July 2016.

6.0 DISCUSSION

6.1 Major Variables for Cogeneration

The theory behind cogeneration is quite straightforward, however the optimal utilisation and commercial viability of equipment will vary with the source of energy and client requirements. The development of commercially viable projects for the red meat industry can utilise experience and equipment already in use in other industries. But success will also depend on a range of factors that are specific to this industry, including:

1. Variability of use for both electricity and heat within the abattoir over each day – a cogeneration plant represents a significant capital cost and its commercial viability is improved if its hours of operation at, or close to, capacity are maximized. Its integration into an abattoir should seek to achieve this. A related issue is whether the cogeneration unit is sized to address base energy load or peak energy load for the abattoir.
2. Scale – larger cogeneration systems generally offer lower unit costs because they achieve economies of scale (although this is less so for micro-turbine plants, which normally achieve scale via duplication and not by larger individual units). However, building a larger cogeneration plant may also mean that for extended periods it only achieves partial utilization on energy needs within the abattoir. It is possible to sell excess electricity via the grid, but the associated complexities, grid connection costs, and lower returns for such wholesale electricity sales versus on-site use, can mean that such export may not be worth pursuing.
3. Abattoir configuration – in particular whether it operates a rendering plant and has on-site refrigeration and exporting facilities.
4. The ability of the abattoir's existing boiler(s) to meet current, and future, energy needs. As previous reports have noted, cogeneration has a better chance of commercial viability if it is introduced to coincide with planned system change and capital expense. Units can be sized to provide all heat and power, however some technologies are driven by heat while others are fuelled directly by.
5. Electricity to heat ratios differ for different technology choices. So the relative costs for heat and power within the abattoir and the ability to satisfy base load for one or the other will influence the choice (and size) of equipment.
6. Available space, within or adjacent to existing energy plant. Most units can be presented in modular fashion. Gas, electricity and steam lines can all be extended if a new plot is needed for the cogeneration plant, however the cost of such works must be included in the planning and financial evaluation for the project.
7. Planning and permits – only equipment and systems that are capable of meeting necessary requirements will be considered in this report.
8. Units available –Each of these technologies at different available scales have a different peak efficiency, and the electrical efficiencies will generally reduce during operation at partial load and optimization for electricity and heat recovery as opposed to only electricity generation.

7.0 CONCLUSIONS/RECOMMENDATIONS

This report investigated the feasibility of superheated steam power generation and concentrated solar thermal steam raising systems in Australian red meat processing facilities. The findings were that unless a facility was currently operating a natural gas fired boiler, purchase of a new high pressure, woodchip fired boiler and backpressure turbine generation plant may not be feasible. However, where a boiler has been fully depreciated, the existing boiler is at "end of life" or additional boiler capacity is required, shifting from coal to a woodchip fired with a turbine may have a simple payback of 6 years whilst shifting from natural gas to woodchip may have a simple payback of 2 years. Regulatory and policy environments should be monitored closely as removal of the existing Renewable Energy Target of Emissions Reduction Fund (ERF) will erode the economic viability of the project, however increasing power prices, increasing margins between the \$/GJ for an existing fuel versus woodchip and/or the reintroduction of a price on carbon will all strengthen the economics of a woodchip fired boiler coupled with a backpressure turbine.

Due to the combination of high capital investment required and relatively cheap power, concentrated solar thermal systems are not likely to be viable for facilities located in metropolitan areas in the short term. For facilities with exceptionally high power (e.g. remote area grid or diesel gen sets) and high boiler fuel prices (e.g. LPG), a CST feasibility could deliver towards a 5 year payback. As the maturity and market penetration of a larger number of CST technologies increases, costs will come down so feasibility should be reviewed at 1 to 2 year intervals.