Final Report

Pinch Analysis & Heat Integration Opportunities

Red meat processors, process heat studies

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2021-1182

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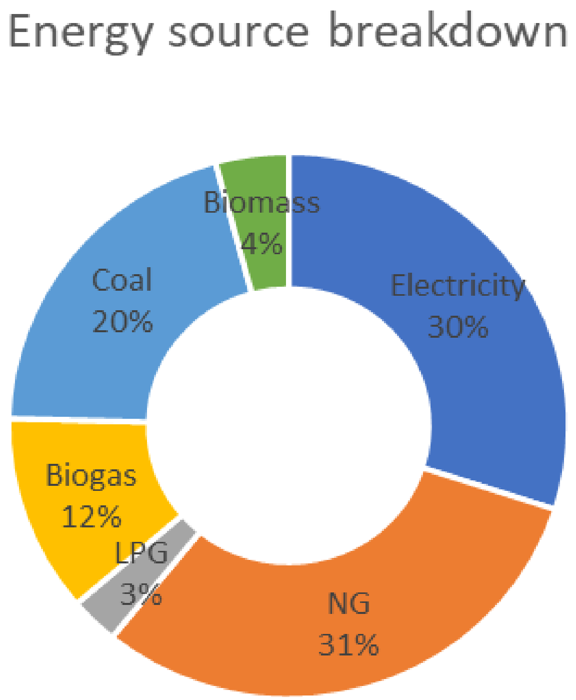
1.0 Executive Summary

Seven red meat processor sites across 5 states were selected to participate in the Australian Meat Processor Corporation (AMPC) process heat study program to support its members in achieving their carbon neutrality commitments (e.g. CN30). The study initially intended to conduct an energy balance and a pinch analysis on the process heating system and based on this investigated heat recovery and renewable energy technologies to transition to renewable energy for process heating. However, due to lack of availability of granular, historical, time series data at most sites, a full pinch analysis could only be conducted for one facility. For those sites where a pinch analysis could not be conducted, the assessment focussed on energy efficiency and productivity opportunities, as well as the next steps needed to be taken in order to be ready for renewable energy projects. Confidential site specific reports were issued to each participant following site inspections and individual workshops.

The following graph illustrates the breakdown of total energy use by source across the 7 participating sites. Currently, 58% of the sites energy consumption comes from fossil fuel and only 12% from renewable, zero-emission sources (Biogas). The 30% grid electricity is not considered renewable energy, due to the low penetration of renewables in most distribution networks (Tasmania being the exception, where most grid electricity is supplied by renewables).



Assessment of each of the 7 participating sites showed that there were several energy efficiency measures with consistent good uptake. These include installation of variable speed drives (VSD) on compressors and motors and power factor correction, although the latter is an energy cost saving measure only. Heat recovery systems were most observed within the boiler room, recovering heat from blowdown, flue gas and the like. Outside the boiler house, passive heat recovery was rarely used, despite the low capital and operational costs of such an installation.

The following areas for improvement were identified across the participating sites.

- Comprehensive sub-metering system, connected to a smart monitoring platform which is regularly used in every day operational management of the site. This is discussed in more detail below.
- Formalised sustainability and/or net zero targets and action plan, adopted and supported at an executive level. While most facilities demonstrated general recognition of and movement towards more sustainable energy and carbon practices, the businesses who had made the most progress towards net zero operation had quantified emissions reduction targets to which they had publicly committed.
- Budget and staff capacity dedicated to sustainability, emissions reduction projects and/or energy and process efficiency improvement.

Although pinch analysis could not be conduct for most sites due to the lack of granular, historical, time-series data, the following energy efficiency and renewable energy opportunities were identified:

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Annual GHG emissions including fugitive (ton CO2-e/yr)	13,673	49,706	10,278	20,480	51,480	5,536	61,786
Energy Efficiency and Heat Recovery Opportunities (% reduction in total annual emissions)							
Economizer				1.0%	1.0%		
De-superheater	2.5%	3.4%	0.9%	4.5%	5.1%	12.5%	4.6%
Thermosyphon heat recovery	2.1%						
Rationalization of Steam Network		0.1%					
Insulation		8.7%					
Rendering Cooker Heat Recovery		1.8%				16.5%	1.2%
Wastewater heat reclaim			0.9%				
Re-tune boiler	1.3%						
New boiler configuration							17.5%
Condensate recovery							2.9%
Renewable Energy Opportunities (% reduction in total annual emissions)							
Solar PV	(Already in progress)	8.6%	18.8%	12.2%	3.7%	36.1%	3.0%
Heat pump on refrigeration system	n/a*	No payback	2.2%	1.5%	No Payback	24.2%	
Biogas capture			78.6%				
CAL					7.0%	26.8%	
Biomass boiler						60.2%	
Cogeneration	7.0%						

**As the technology is not yet commercial for steam production heat pumps, the specific reduction has been difficult to quantify; however it is expected to be a positive reduction.*

Note that total site emissions figures in the above table include fugitive methane emissions from open, on-site wastewater treatment facilities as well as emissions from direct energy consumption. This is different from the total emissions values in Section 5 of this report, which deal only with those emissions associated with direct energy consumption.

Legend	
	Simple payback ≤ 5 years
	Simple Payback > 5 years
	Site has an open effluent pond

In conclusion, the following recommendations are proposed to assist the red meat processor sector transition to net zero:

- Member business energy maturity categorisation
- Business case for net zero
- Metering and monitoring – focus on meters in the right places and smart monitoring and analysis
- Net zero strategy development support

2.0 Introduction

The 2020 Environmental Performance Review for the Australian red meat processor sector confirmed that emissions intensity had fallen by 28% since 2010, however combustion of fossil fuels on-site for process heat requirements still comprises around 50% of the sectors total energy. With the commitment of the red meat industry to achieving carbon neutrality by 2030 (CN30) there is a need for R&D that enables more efficient and productive thermal energy sources for sectoral process heat requirements.

In addition, the cost of natural gas, coal and LPG will remain volatile with increasing calls from customers and market authorities for reductions in food product GHG emissions. Consequently, there are both strong environmental and economic benefits for processors who make certain they are creating process heat in the most efficient and productive manner possible.

In August 2021, seven red meat processor plants were selected to participate in the Australian Meat Processor Corporation (AMPC) process heat study program, to be delivered by pitt&sherry. AMPC developed this project to support its members in achieving their renewable energy and carbon abatement strategies. The initial scope was to conduct a pinch analysis on the process heating system and based on this, investigate new technologies to reduce energy consumption and enable the transition to renewable energy for process heating. However, most of these sites did not have sufficient time-series data available for the key areas of thermal flow required for a full pinch analysis.

3.0 Project Objectives

This study has been conducted for an in-depth thermal balance and pinch analysis of some selected red meat processor plants to identify the specific heat recovery/replacement opportunities and how they might be integrated into existing processes. The combination of these two analytical tools was to develop a robust understanding of each site’s energy loads, identify potential loss reduction opportunities, develop a concept design of an optimum heat recovery network, and identify further opportunities to replace gas driven steam/hot water with electrified heat pumps. To round out the analysis, renewable energy assessments were completed to identify the potential for each site to generate its own electricity. For each opportunity, the quantification of energy replacement/reduction, GHG impact, and economic analysis for site integration was developed.

Seven (7) AMPC members were selected through an EOI process to participate in the project. A variety of factors such as: participation in sectoral Environmental Performance Reviews; the size of the plants; energy source; data availability; and SCADA system were included in the selection process to provide a good basis for the study. The outcome of the study from these representative sites was planned to be a benchmark to inform the sector of the total opportunity.

The main objectives of the project were:

- Complete a thermal energy balance and pinch analysis at the participating AMPC member sites
- Summarise the common energy intensity patterns and identify any potential or specific areas of loss
- Identify opportunities to reduce energy consumption
- Identify opportunities for passive heat recovery
- Identify opportunities to upgrade waste heat to useful heat using heat pumps
- Identify opportunities to replace electrically driven refrigeration with biogas fuelled absorption chillers
- A business case for each identified opportunity
- Assess the opportunities which are the most economically feasible options, and which will create the greatest reduction in GHG emissions.
- Identify any restrictions or risks to the implementation of each opportunity
- Identify the capacity to self-generate renewable energy to displace grid electricity
- Combine these measures to quantify how far they progress the site toward GHG reduction

However, during the study it was revealed that the pinch analysis could not be carried out in most of the sites because of lack of enough information. The objective of this project was therefore pivoted to focus on reducing existing energy consumption and increase energy productivity while moving away from traditionally sourced fossil fuels to renewable energy. It is worth noting that in some cases, pitt&sherry was able to gather enough data to complete a thermal mass balance which identified the thermal load for each area and associated improvement opportunities.

4.0 Methodology

Note that the pinch analysis was not able to be carried out for all 7 sites, as the sub-process time series data required to inform this level of detailed analysis was not available. Instead, the 6 sites without adequate available data were assessed for energy efficiency opportunities and provided with a metering and monitoring plan. The process for progressing from the energy efficiency stage through to pinch analysis and investigation of renewable energy opportunities was also laid out, to provide a clear pathway towards emissions reduction for sites at all stages of energy and carbon maturity.

The steps for this altered methodology were as follows:

1. Project kick-off meeting
2. Collection of the following data:
    a. P&IDs for ammonia, glycol, hot water, and steam systems
    b. Process flow diagrams for each process
    c. Boiler and refrigeration plant commissioning documents (functional descriptions) and operations and maintenance manuals
    d. Boiler plant production volume and temperature
    e. Refrigeration chilled water supply volume and temperatures from the central plant
    f. Refrigeration condenser water supply volume and temperatures from the central plant
    g. List of any site data and metering points that are kept in a SCADA historian
    h. Corresponding gas/LPG/coal and electrical submetering data
    i. 12-months of gas and electricity bills

3. Site visit
4. Data collected cleaning and verification of validity against known data points such as water, gas, and electricity invoices
5. GHG emission accounting for Scope 1 & 2 emissions
6. Calculation of thermal mass balance for the site
7. Identification of sources of thermal energy loss, energy efficiency and energy productivity opportunities
8. Quantification of identified energy opportunities, including high-level cost benefit analysis and calculation of potential GHG emissions savings
9. Development of a measuring and monitoring plan for the site to collect the data required to perform a full pinch analysis and renewable process heating investigation in the future
10. Provision of a '*Thermal Energy Efficiency and Renewable Process Heating*' report to the site for review
11. Project close-out meeting and issue of finalized report

Only one site had sufficiently comprehensive, established sub-metering systems to supply the granular data required for full pinch analysis assessment. The methodology for this site is consistent with the steps outlined above, but with steps 8-10 replaced by the following:

- Pinch analysis for the major thermal flows for the site, using the thermal load profiles, volumetric flow and temperatures obtained during data collection and thermal energy balance steps
- Quantification of process heat replacement and recovery systems opportunities, using the parameters established in the energy balance and pinch analysis
- Generation of a priorities list of the opportunities which quantified the impact to GHG emissions, provides an action plan for implementation and an economic analysis
- Provision of a costed *'Pinch Analysis and Renewable Process Heating Report'* for review. (Note: accuracy of project quantification can be highly variable and can be impacted by the availability and quality of data collected)

These methodologies are summarised in Figure 1 below.

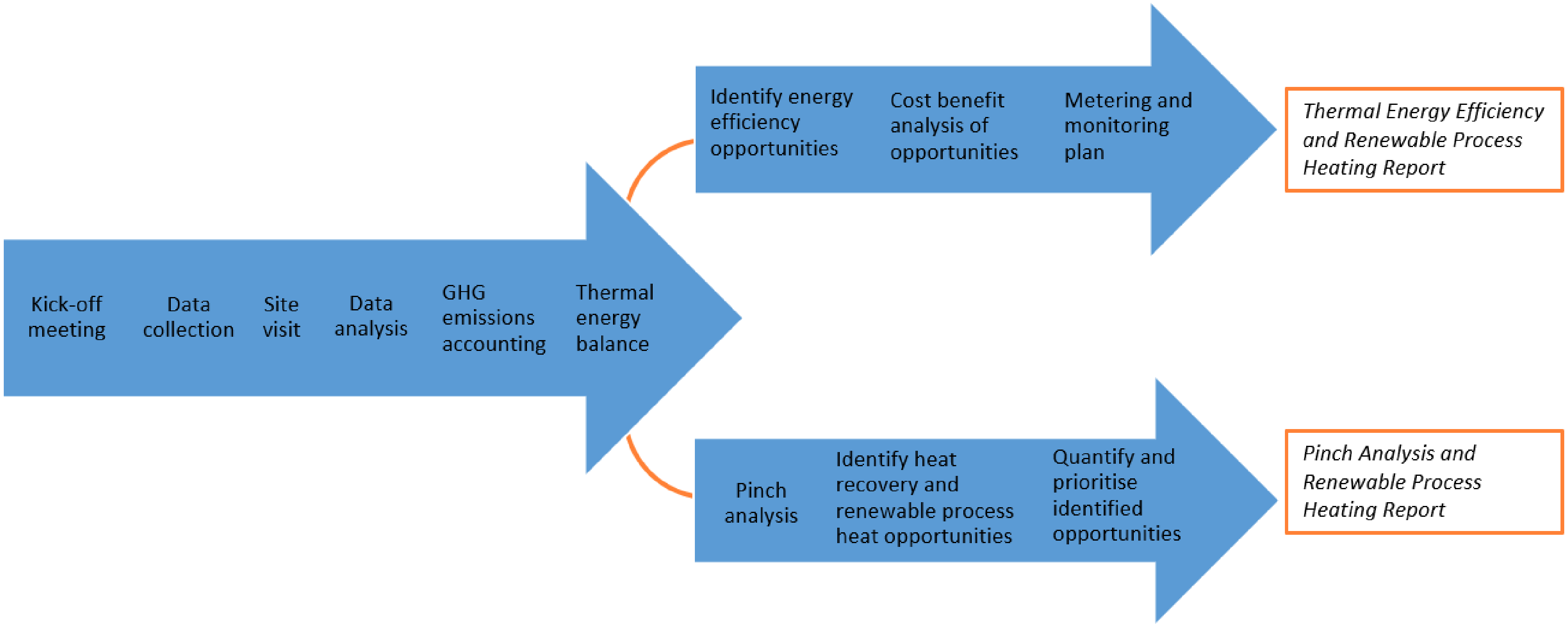


Figure 1: Summary of project methodology, illustrating the 2 different pathways for sites with differing levels sub-metering

5.0 Project Outcomes

Energy consumption breakdown by source for all participating sites is summarised in Table 1. These individual figures are then combined in Figure 2 to give proportional energy consumption by source. This shows that natural gas is the largest source of energy for the 7 sites, closely followed by grid electricity.

Table 1: summary of average annual energy consumption by source at each assessed site

Site	State	Electricity	Fossil fuel	Biogas/Biomass
1	NSW	20%	32%	48%
2	NSW	27%	73%	0%
3	WA	42%	58%	0%
4	VIC	41%	59%	0%
5	VIC	37%	63%	0%
6	TAS	25%	37%	39%
7	QLD	30%	53%	16%
Average		**32%**	**54%**	**15%**

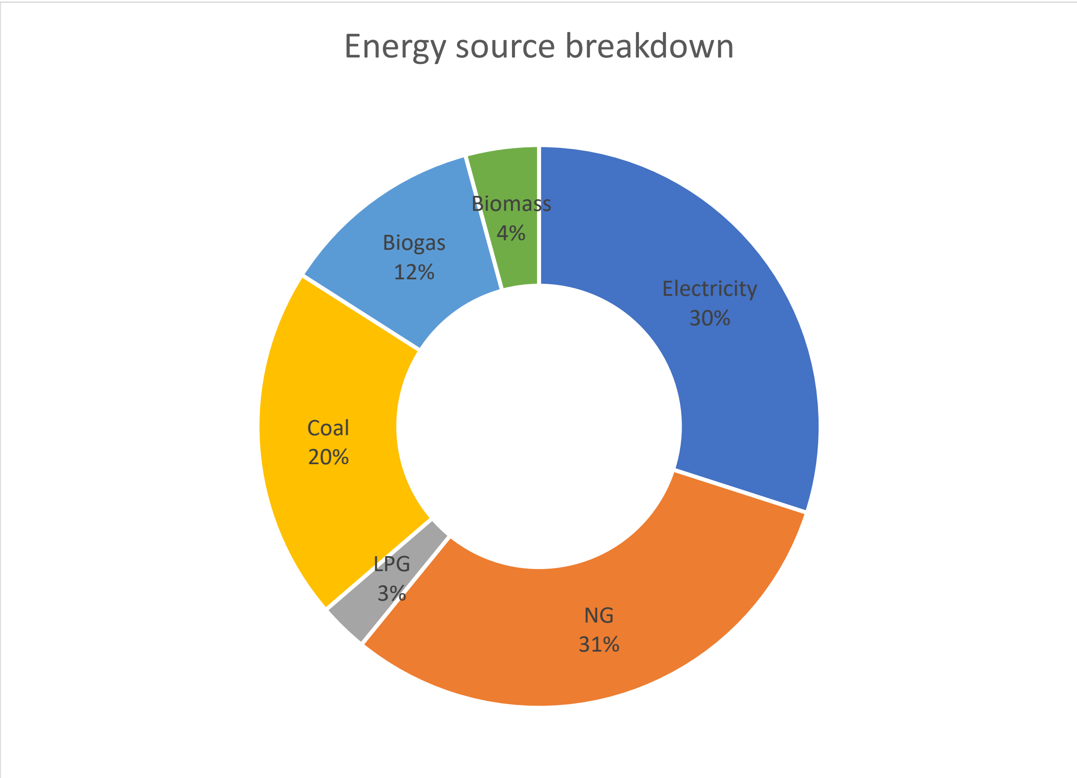


Figure 2: Average energy use breakdown by source across the 7 studied sites

Figure 3 below compares the energy intensity (GJ/tHSCW) and emissions intensity (tonne CO_{2-e}/tHSCW) for each site, with the 20/21 industry average energy intensity of 3.3 GJ/tHSCW also shown for benchmarking purposes. This graph shows that energy and emissions intensity indicators do not exhibit the same proportionality between sites. For example, the ratio of energy to emissions per unit production at site 1 is ~10 GJ/ CO_{2-e}, while site 4 is 6.7 GJ/ CO_{2-e}, meaning that site 4 emits more GHG per unit of energy consumed. This is due to the different energy source make-up of each site. Site 1 sources energy from electricity, natural gas, and biogas while site 4 uses electricity and LPG.

The differing emissions factors for grid electricity between states is also seen to have an impact on relative emissions intensity at the sites. This can be seen by comparing site 5 and site 6, which are in Victoria and Tasmania respectively. Site 6 has a proportionally lower emissions intensity, as Tasmania's grid electricity emissions factor is 0.17 kg/GJ as compared with Victoria's emissions factor of 1 kg/GJ. The difference in grid electricity emissions factor is because Victoria has power plants burning brown coal while Tasmania has a very high renewable energy penetration from extensive hydro and wind power stations.

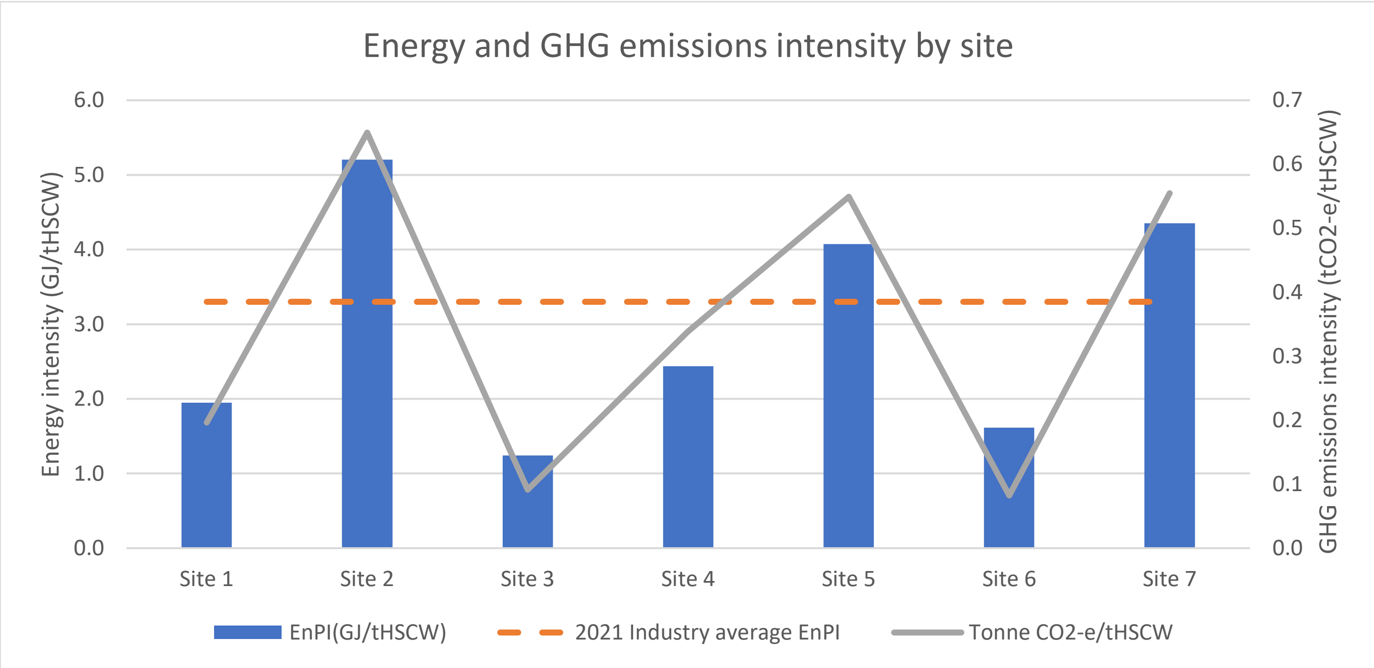


Figure 3: Energy intensity at each site in terms of GJ annual energy consumed per tHSCW produced, against the latest industry average EnPI indicator

A thermal energy balance was completed for each site, to understand the process heating end uses and thermal energy demands throughout the facilities. The uses for heating at each facility varied based on species and processing equipment. Significant differences in the proportional energy consumption of sub-processes were also noted where heat recovery and/or energy efficiency measures had been installed. The energy balancing exercise also identified and quantified areas of thermal energy loss, such as unexpectedly low boiler efficiency or steam pipe leaks at several sites. Indicative examples of hot thermal energy consumption and hot utility use breakdown at two of the participating sites are provided in Figure 4 and Figure 5 below.

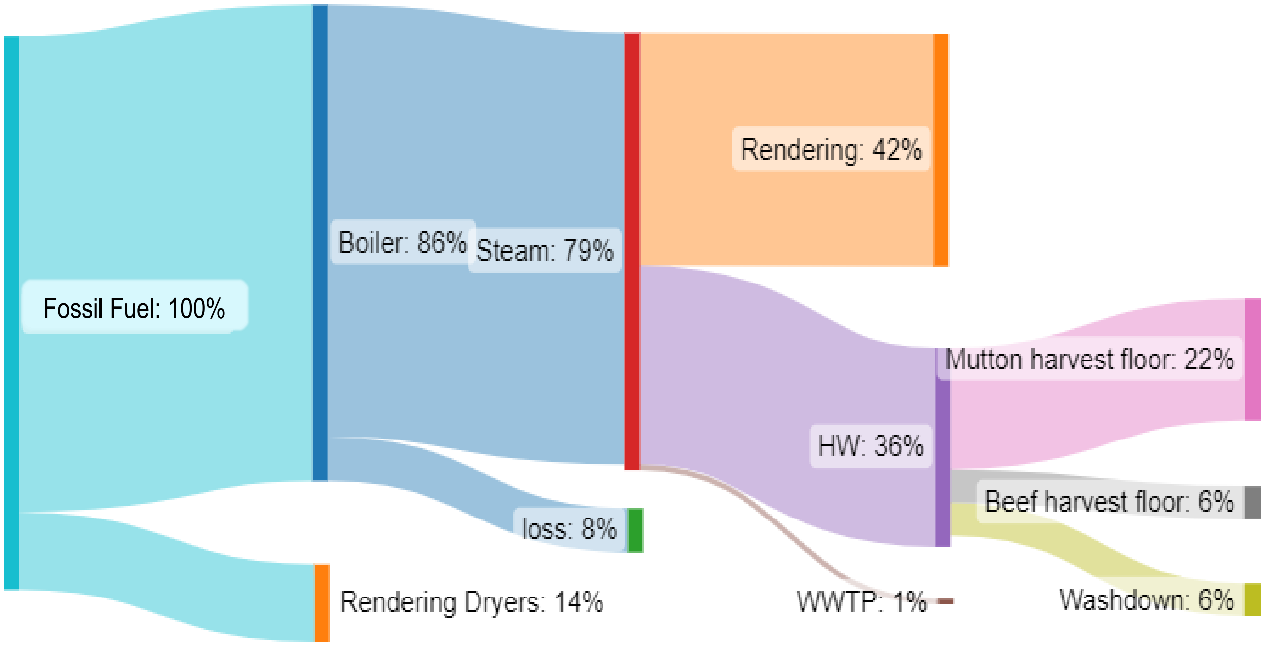


Figure 4: Sankey diagram showing hot thermal energy flow at a multi-species red meat processing plant with rendering

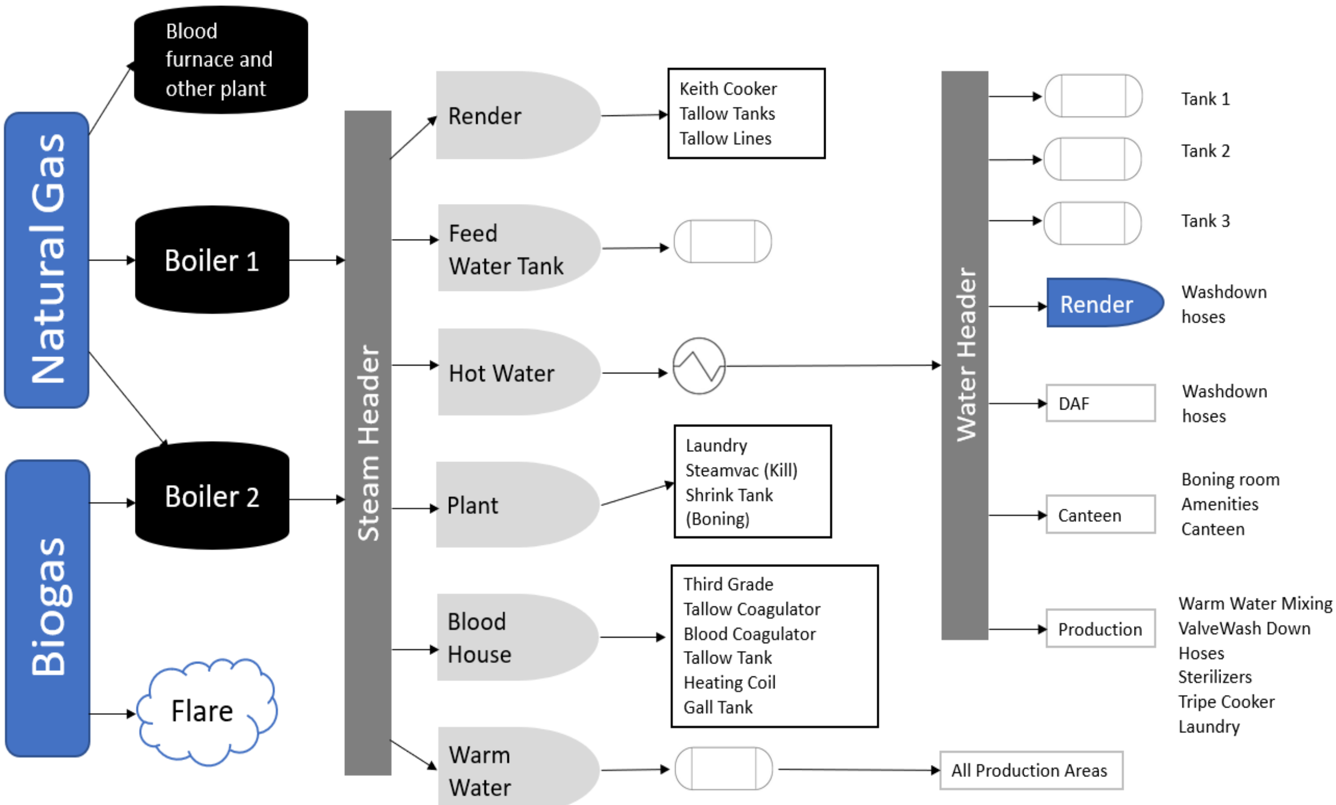


Figure 5: Detailed process diagram of hot utility at a single-species red meat processing plant with rendering and on-site biogas production

5.1 Industry Strengths

Although energy performance and management strategies varied widely across the participating sites, several energy efficient practices were noted to be common to most facilities. Variable speed drive (VSD) technology has been widely adopted, installed on refrigeration compressors and pumps to improve demand response, and reduce energy use during low loading operation. The uptake of VSD's has been supported by wide-spread upgrades of older, less efficient pumps and compressors with newer models that are either compatible with VSD's or come with VSD's built-in.

Power factor correction (PFC) was installed at most remote facilities, to improve power quality of grid electricity supplied to site. It should however be noted that this is an energy cost saving measure only and does not reduce real energy consumption.

It was also observed that waste heat recovery measures were most widely adopted within the boiler room, with systems such as economisers and condensate return loops. Passive heat recovery was less commonly applied on refrigeration, hot water, and wastewater systems, despite the costs and savings of these applications being comparable to those in the engine room. It is posited that heat recovery efforts have been focused on boilers due to the relatively higher focus and familiarity of operational management with the boiler system as compared with other, less critical systems.

AMPC has published a Linkedin page, following nation-wide processor R&D workshops, that contains over 30 individual illustrated Refrigeration Energy Efficiency Opportunities including a series on heat pumps.

5.2 Areas for Improvement

The following key differences were observed between the sites with the most advanced and least advanced energy and carbon performance:

- Comprehensive sub-metering system, connected to a smart monitoring platform which is regularly used in every day operational management of the site. This is discussed in more detail below.
- Formalised sustainability and/or net zero targets and action plan, adopted and supported at an executive level. While most facilities demonstrated general recognition of and movement towards more sustainable energy and carbon practices, the businesses who had made the most progress towards net zero operation had quantified emissions reduction targets to which they had publicly committed.
- Budget and staff capacity dedicated to sustainability, emissions reduction projects and/or energy and process efficiency improvement.

5.3 Metering and Monitoring for Energy Management

Metering and monitoring are now an essential part of good facility management, providing valuable insight into facility and equipment performance, and supporting better energy management. A key finding from this project was that most sites do not currently have the sub-process metering and centralised data monitoring systems required to support good energy management.

Common metering gaps identified during this assessment:

- Flow data for hot water, steam, refrigerant, product, and wastewater at various points throughout processing. The low adoption of flow metering is likely due to flow sensor equipment being relatively more expensive, difficult to install and historically less reliable/accurate than other types of sensors.
- Temperature data for steam, hot water, exhaust gas/vapour, steam condensate, product stream and wastewater at multiple points throughout processing. Whilst temperature is monitored within the boiler and hot water make-up tanks for direct operational control purposes, few sites had meters on other key thermal streams.
- Granularity of time series data. Even where sub-process data was being collected, in some instances the data intervals were too large to provide useful insight and/or data was not collected for a long enough period to be considered representative.

Data monitoring and analysis was also identified as a weak point for most sites, even where sub-metering hardware had already been installed. The key issues encountered were lack of data accessibility due to connectivity, collection or communication problems, and lack of active data monitoring and analysis practice.

For a metering and monitoring system to be effective, the meter data needs to be accessible via a centralised data collection and analysis system connected to all installed meters. This monitoring system should have a clear and useable interface and should be set up with relevant automated analysis processes and alarms to guide every-day operational actions. Finally, all appropriate staff must be fully trained to use the system and formalised processes should be put in place to ensure it is used in practice. The power of data lies in the insights that analysis can provide to guide better business practice – metering equipment in isolation is ineffectual.

6.0 Discussion

6.1 Pathway for Energy and Carbon transition

Figure 6 below outlines the key technical steps for red meat processor sites to decarbonise their process heating and operational energy systems. This action plan was developed to be applicable to all sites across the wide range of energy and carbon performance observed across the industry currently. Individual businesses can use it to quickly assess where they currently sit along the pathway and obtain guidance on the next practical steps to advance their renewable energy transition.

Note that this technical guidance should be viewed in concert with the strategic guidance provided in this report. It is recommended that significant emissions reduction and renewable energy measures be implemented only after the business has adopted a corporate net zero strategy.

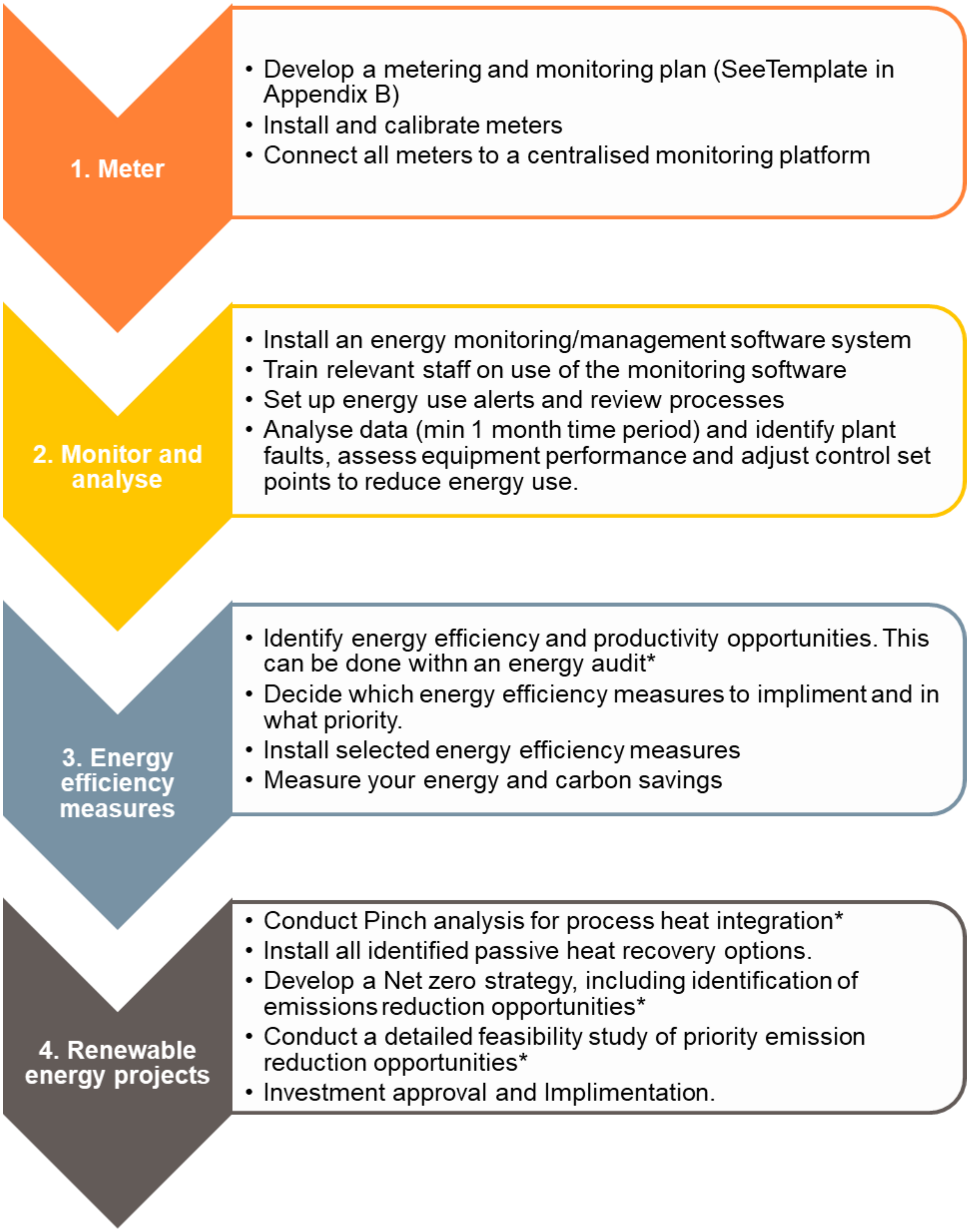


Figure 6: Process for a meat processing facility to transition towards net zero

** Can be conducted in-house if the required capabilities are available, or by an external consultant*

6.2 Energy Efficiency Opportunities

The following energy efficiency opportunities were identified as applicable to red meat processor facilities:

- Adjust set-points and control settings to optimise energy productivity.
- Set alarms to identify equipment faults and inefficiencies so they can be promptly addressed.
- Educate staff on energy saving behavioural measures
- Regular maintenance servicing of high energy consuming equipment, such as the boiler and refrigeration plant.
- Insulate all hot and cold assets to minimise thermal energy loss. Key areas to insulate include the hot and warm water tanks, steam lines, all refrigerated areas, refrigerant lines, hot and warm water lines, the boiler/s etc.
- Rationalise water and steam piping to reduce pumping energy use and transmission thermal energy losses. This includes removing any dead legs, re-routing hot piping passing through refrigerated areas, minimising pipe length/distance, ensuring pipe sizes are appropriate etc.
- Passive heat recovery
- Demand response measures such as VSD on pumps and fans.
- Minimise heat ingress to refrigerated areas, through measures such as replacing worn door seals, installing automated quick-close doors, replacing halogen and fluorescent lights, checking insulation for holes/leaks etc.

6.3 Pinch Analysis

Pinch analysis is a systems engineering technique used to optimise thermal energy recovery in manufacturing plants. It involves identifying key process streams throughout the site which require heating and cooling, calculating thermal energy transfer rate at each stream, calculating the pinch point, and then identifying opportunities to optimise waste heat recovery. The pinch point is the closest point of approach between hot and cold streams. Designing the site’s heat recovery system around the pinch point minimises consumption of utility energy for process heating and cooling.

The following thermal streams were identified for sites with a rendering plant and thermosyphon oil cooling for refrigerant compressors. Temperature and flow rate data is required for each stream to conduct pinch analysis, as well as information on any existing heat recovery systems. The appropriate metering points required to obtain this data are listed in Appendix 1 of this report.

Table 2: Thermal pinch streams for a typical red meat processing site with a rendering plant

Stream Identifier	Product	Stream type
A.1	Ammonia refrigerant cooling (de-superheating)	Hot
A.2	Ammonia refrigerant condensation	Hot
B	Compressor Lubrication oil	Hot
C	Warm water	Cold
D	Hot water	Cold
E	Boiler feedwater	Cold
F.1	Raw material for rendering	Cold
F.2	Render water heating	Cold
F.3	Render water evaporation	Cold

6.4 Process Heat Optimisation Opportunities

The following common passive waste heat recovery opportunities were identified via pinch analysis as applicable to the sites. When cost benefit analysis was conducted for these measures at various of the participating sites, all measures had a simple payback less than 6 years.

- **Desuperheater**

  De-superheaters are liquid-to-liquid plate heat exchangers which take superheated, high-pressure refrigerant from the high-pressure refrigeration compressors and cools it passively using ambient water to saturation temperature. This process concurrently pre-heats the town water used as the heat sink, reducing the site's heating demand which saves gas. Installation of a de-superheater also provides electricity and water savings by improving electrical efficiency of the condenser and reducing evaporative water losses. A de-superheater is applied between the refrigeration compressor outlet(s) and the inlet to the refrigeration condenser/cooling tower. Desuperheaters were found to be a cost-effective energy saving opportunity for all participating sites, as illustrated in Figure 7 below.

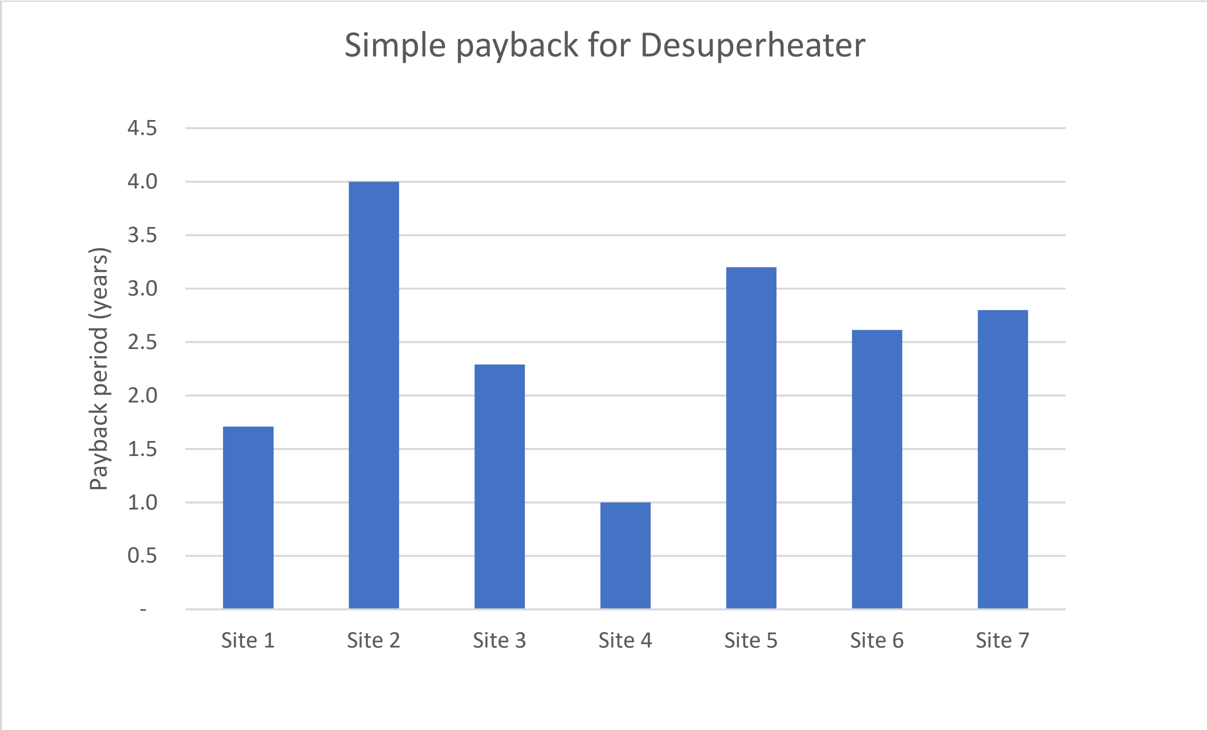


Figure 7: Simple payback periods calculated for installing a desuperheater at each site

- **Economiser**

  An economiser recovers high quality waste heat from boiler flue gas and uses it to heat boiler feedwater. They are capable of supplying water at the required final boiler inlet temperature and are generally installed directly before feedwater discharge into the boiler. Potential energy savings of up to 5% of the initial boiler energy consumption are achievable.

- **Boiler blow-down heat recovery**

  This measure recovers heat from the boiler blow-down, using a flash heat recovery system to pre-heat boiler feedwater. Potential energy savings up to 3% of initial boiler energy consumption.

- **Thermosyphon heat recovery**

  This option is applicable to sites with refrigeration systems including oil cooled screw compressors. Refrigerant in the thermosyphon has a high discharge temperature which can be recovered via a heat exchanger to heat warm water to ~43°C.

- **Rendering plant vapour heat recovery**

  This option is applicable to sites with high temperature rendering plants. High quality heat can be recovered from the vapour outlet of the render cooker to heat water up to 80°C, either for direct hot water processing needs or to pre-heat boiler feedwater. 20% of the thermal energy used in the render cooker is typically lost to atmosphere with the vapour, 75% of which can be recovered using a heat exchanger, buffer vessels, and plumbing.

- **Condensate return / flash steam recovery**

  Steam condensate from all non-direct steam users can be recovered via a return loop to pre-heat boiler feed water. Equipment which should be connected to condensate return loop include the render cooker, hot water heat exchanger and warm water heat exchanger.

Implementation of all these options should be completed before any renewable energy on-site generation system are installed for the site, to minimise the design capacity requirements for such systems. This is consistent with the energy management hierarchy, which suggests that sustainable energy measures be prioritised for implementation as follows:

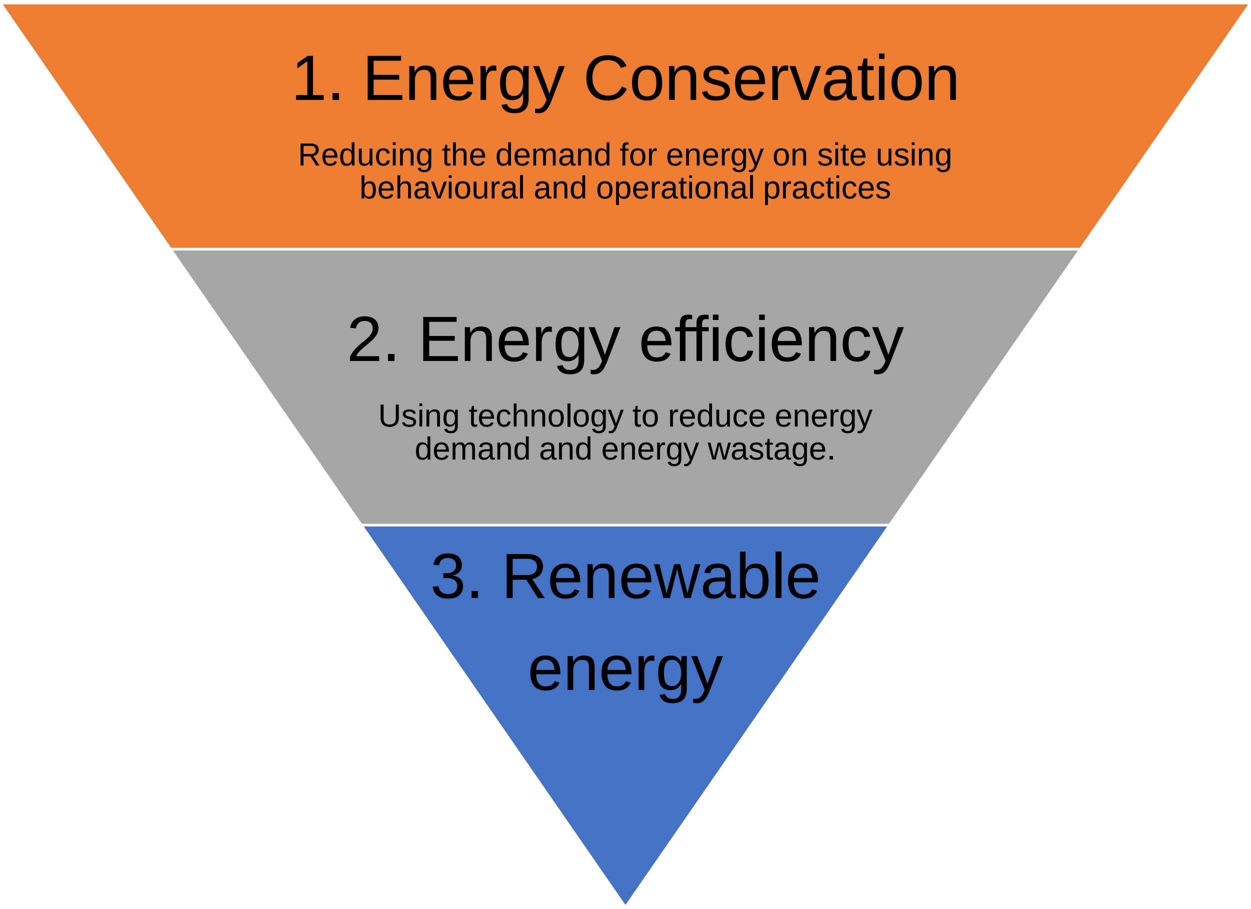


Figure 8: Energy management hierarchy

6.5 Renewable Energy Opportunities

These emissions totals and proportional reduction figures include fugitive emissions from open effluent ponds. Wastewater treatment process in open digestion ponds emit methane, which is a GHG with 28 times the global warming potential as Carbon dioxide. Emissions from uncovered effluent ponds are therefore considered a GHG emission, given in terms of equivalent carbon dioxide emissions. These additional emissions have not been included in the economic analysis as there is not a reliable, established carbon cost in Australia. However, fugitive emissions reductions have been noted in assessment of biogas opportunities, as a significant benefit for those businesses with net zero targets.

The following opportunities to transition from fossil fuels to renewable energy for process heating were identified during this assessment.

Solar PV

On site solar PV generation is widely adopted across the Australian manufacturing sector, and there are already multiple examples of its use in red meat processor plants. Solar PV penetration into residential and industrial power mix has increased exponentially in recent years, in no small part because of the abundant, high quality solar resources available across Australia. The price of solar panels is at an all-time low and equipment servicing, and installation is available widely throughout regional areas, making it an attractive option for red meat processing plants which have high electrical demand and are generally located outside large population hubs. The suitability of solar PV technology to the energy and operational demands of the participating sites was assessed by comparing historical electricity consumption trends with solar PV generation potential modelled for the appropriate location.

Figure 9 shows the average daily electrical load profile of one of the participating sites located in NSW, overlayed with modelled generation of a 4.8MW solar PV system. This graph illustrates the compatibility of solar PV technology with the electrical load profile of a site, as the temporal alignment of demand and solar PV supply maximises self-consumption of solar generated electricity without the need for storage.

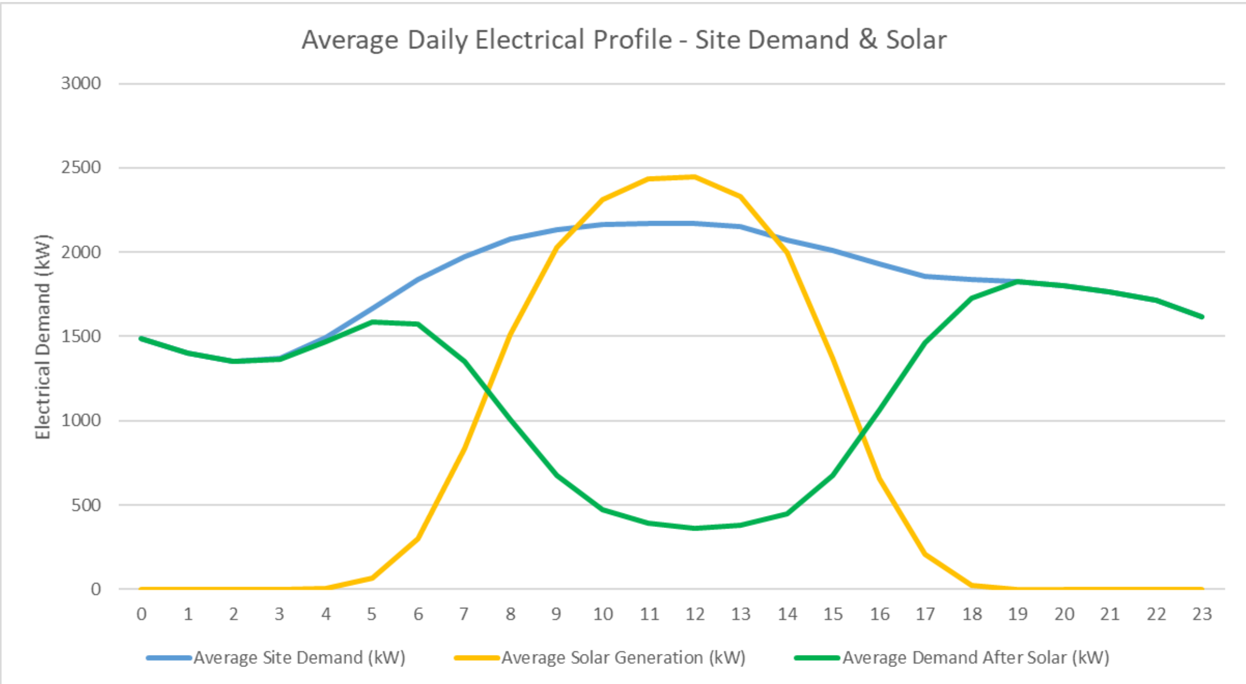


Figure 9: Average daily electrical demand and solar PV generation profiles for a NSW site modelled with a 4.8kW solar PV system.

Solar PV generated electricity is of most economic benefit to sites when it is self-consumed during daylight hours as it offsets grid electricity during peak tariff periods. Solar electricity exported to the grid, meanwhile, would provide little to no income to the business as feed-in tariffs fall toewards zero. In some locations, grid export of excess solar generated electricity may not even be permitted, due to restrictions in the local grid capacity. Any solar PV system for a red meat processor plant should therefore be designed to optimise on-site consumption, unless combined with an on-site storage system.

Heat pump for water heating

Pinch analysis of those sites with adequate data highlighted opportunities for active heat recovery on site, by using a heat pump to absorb low-grade waste heat from heat sources with delivery temperatures too low for passive heat recovery and release it to a higher-temperature heat sink at a useable temperature. Heat pumps are a mature technology and operate similarly to a refrigeration system so they could be serviced by local refrigeration contractors rather than requiring specialist knowledge.

The heat pump application point identified during this project was on the main ammonia refrigeration system. This heat pump system would scavenge waste heat from the high-pressure side of the refrigeration system to heat water to 90°C. It would provide gas savings by replacing the use of steam from the boiler to heat water. Heat pumps do operate on electricity and will therefore increase electrical energy use and costs; however, with potential COP’s over 5 the thermal energy savings would outweigh the increase in emissions associated with additional electricity consumption. Furthermore, electrification of fossil-fuel produced process heat using a heat pump can make it easier to transition to renewable energy supply from mature technologies such a solar PV.

Cost benefit analysis for heat pump actively recovering waste heat to pre-heat hot water was conducted for 5 of the 7 sites and was found to be feasible for only one. One of these sites was expected to make a loss, due partially to high local grid electricity costs and low fossil fuel prices. Three of the sites had paybacks ranging from 10 – 16.2 years and where therefore not considered suitable for heat pump heat recovery. Two of these sites had on-site rendering facilities, which are generally not compatible with heat pump hot water heating since most hot water demand is met by heat recovered from the render cooker. The only site found to be compatible with heat pump application had no rendering, and simple payback was estimated at 3.6 years.

The feasibility of a high temperature heat pump for steam production was also investigated for one site. The intention was to assess whether heat pumps could be applied to sites with limited remaining water heating load, by using waste heat to meet steam loading for equipment like the render cooker. Heat pumps capable of providing steam at up to 175°C are theoretically achievable today, however there are several barriers to implementing them at the analysed meat processing facility. The main challenges are the supply availability of such extra-high temperature heat pump units in Australia and the large temperature lift required to use refrigeration waste heat at 25-35°C as a source to produce 175°C steam. Such high temperature lifts adversely impact the steam pressure and discharge rate as well as the COP able to be achieved by the system. This option is therefore not currently considered to be feasible for implementation on a functioning meat processing facility in Australia. Instead, high temperature heat pumps are suited to demonstration or research projects installed adjacent to facilities, where their performance may be practically tested without risk to whole-of-plant operation.

Biogas

The typical waste stream from meat processing facilities has high calorific value and protein content, making it ideally suited to anaerobic digestion. In a business-as-usual case, liquid effluent is treated on-site by going through a set of large ponds for sedimentation then aerobic treatment. The remaining water is then either disposed of as trade waste or used to irrigate any pasture run by the business. There are several disadvantages to this process; namely due to the gases emitted by the wastewater during treatment. These gaseous emissions not only cause odour problems, but also contain a high percentage of methane, which is a greenhouse gas 28 times more potent than carbon dioxide.

The methane emissions from effluent ponds, known as fugitive emissions, generally contributes more to a red meat processor plant’s annual GHG emissions total than all the energy consumption emissions combined. However, where these methane emissions are recovered and either flared or combusted, it is discounted from the site’s emissions accounting as it is regarded as part of the natural carbon cycle. Moving away from uncovered effluent ponds towards biogas capture therefore has a large impact on site GHG emissions, with potential to more than halve total annual site emissions.

The most common on-site biogas generation technology applied within the meat processing industry is Covered Anaerobic Lagoons (CALs). This is because it is suitable to liquid effluent streams, has the lowest CAPEX costs of any comparable technology, has been widely demonstrated across the domestic industry and generally requires lower levels of specialised expertise for ongoing operation and maintenance. These are physically like the regular waste treatment lagoons used at red meat processing plants but covered with a sealed membrane which captures the gases emitted by the waste sludge during anaerobic digestion. The gas collected in this manner is then collected and scrubbed in a co-located biogas plant, after which it may be combusted in a compatible boiler to produce steam, used to generate electrical power, or flared to atmosphere.

Table 3: Cost benefit analysis for effluent heat recovery and biogas capture via CAL at one of the participating sites

Energy Productivity Opportunity	Capital cost ($)	Payback period (years)	GHG savings (tonnes CO2-e/y)
Wastewater heat recovery	$67,400	3.3	88.3
Biogas capture after passive heat reclamation	$289,176	2.9	8,075

Cogeneration from Biogas

Cogeneration, or combined heat and Power (CHP), refers to the simultaneous production of electrical and thermal energy from a single fuel. There is a range of different technologies available to accomplish this, but for red meat processor sites already equipped with a covered anaerobic digestion system; the generated biogas can be used as a fuel in a cogeneration system. This can be an attractive alternative to using the biogas in a dual fuel boiler to produce steam only. For sites without biogas generation systems, it is recommended that anaerobic digestion or biogas production be pursued as a priority ahead of or as well as CHP.

Based on literature review of previous in-depth analysis of cogeneration applications in the Australian meat processor industry, micro-turbine Cogen technology may be considered by some as the best fit for the biogas feedstock and thermal/electrical demand profiles of a red meat processing plant. For larger installations this technology can be installed as a modular system, which provides the flexibility to install a smaller system initially to demonstrate its operation and identify any integration issues. This system can then be easily expanded as the site becomes more comfortable with the technology, and/or to meet changing demand due to expansion or process alteration at the facility. Simple payback for larger scale micro-turbine cogeneration systems is expected to exceed 7 years. Microturbines tend to have a higher heat production and lower electricity production than reciprocating engines.

Gas-powered reciprocating cogeneration engines are a more established technology within the food processing industry and has an attractive simple payback in the order of 5 years. Operational staff would also be familiar with the basic engine set-up, and therefore more likely to adjust quickly with less risk to plant operation during a learning period. The desirable technology is usually decided by a mixture of site preferences for overall capital investment, maintenance complexity and the payback. Payback is typically the deciding factor and is driven by electricity pricing and alternative heat (natural gas, LPG, etc.) Hence a high electricity cost will tend to favour the technology that produces more electricity at a generally lower capital cost (reciprocating engines).

Tri-generation, or the simultaneous production of electrical energy and both hot and cold thermal energy, also has potential for application within red meat processing plants. Trigeneration adds an absorption chilling component on top of the cogeneration equipment, however this technology is much less mature in Australia. It is more difficult, and likely less competitive, to source and service the equipment as well as capital intensive. Within Australia there is little shared experience for how these systems perform in a manufacturing setting, and what capital costs, savings, co-benefits, and implementation challenges could be expected. Like cogeneration and desuperheating detailed investigation of the localised supply, costing and integration of such technology would need to be carried out to accurately assess the feasibility of tri-generation at a plant. Installation of a tri-generation system would require significant changes to the heating system but adds the complexity of changes to the refrigeration system. In general, the payback appears to be in the 5–10-year timeframe and may be acceptable if a fully integrated trigeneration system can be incorporated. The absorption chilling component of trigeneration systems has featured in reports of equipment failures in the past – usually due to poor initial materials choices by manufacturers or poor maintenance. Hence doubt exists in Australia in particular. If a trigeneration system is determined to be practically achievable at the investigated site, however, this could be a good candidate for funding support as a renewable energy demonstration and knowledge sharing project with organisations such as ARENA. It is also far more likely to be an attractive option for greenfield development, where the challenges involved with retrofitting into an existing system would be avoided.

Future Opportunities

The opportunities investigated for this project were selected based on the immediate readiness of both the technology and the site itself. Considering that most sites are still at the metering and monitoring stage, focus was placed on energy efficiency and heat recovery options. For those facilities further down the track into optimising their energy efficiency, renewable energy for process heating opportunities such as biogas CAL and CHP were identified as the best options currently.

However, things are moving quickly in the renewable energy space, and by the time most sites reach the point of on-site renewable energy generation their options are likely to have expanded. The following developing technologies, although currently non-viable, were identified as potentially applicable to the meat processing industry in the future:

- **Biogas to Biomethane**

  The methane content of biogas typically ranges from 45% to 75% by volume, with the balance made up of CO2 and nitrogen. Biogas with 60% methane typically has a lower calorific value (LCV) of 16 – 28 MJ/m3. Biomethane, however, contains 92% methane, and has a LHV of around 36 MJ/m3 meaning that it is much purer and more energy dense. Also known as ‘renewable natural gas’, biomethane is indistinguishable to natural gas and meets the Australian gas grid quality standards. It can therefore theoretically be used in the gas grid without the need for any changes in distribution infrastructure or end-user equipment and is fully compatible for use in natural gas vehicles.

The potential benefits of upgrading biogas generated on-site to biomethane largely relate to its versatility as a fuel. Biomethane can be cost-effectively stored for long periods for self-use, liquified and used as a transport fuel or injected into the centralised gas grid for a feed-in tariff. The biomethane industry is currently very small, although it is generating growing amounts of interest in several countries for its potential to deliver clean energy to a wide array of end users, especially when this can be done using existing infrastructure.

The process of upgrading biogas to biomethane, also referred to as purification, involves removing the unwanted components such as CO2 to increase the final methane content. The most established technologies for achieving this currently are membrane separation, water scrubbing, chemical absorption and/or pressure-swing absorption.

The key challenges to its industrial use currently are that it is fairly electrical-energy intensive, which would need to be met by low-cost renewable electricity generation for the project to achieve any significant emissions benefit. Also, although the future business case will likely rely on feed-in to a centralised gas grid, regulatory controls have currently not been finalised in this area so consent for connection is uncertain and the application process likely to be protracted.

- **Large-scale battery electric storage**

  With the industry's current energy source and end-use breakdown, thermal storage has proven to be the most effective method of energy storage at red meat processor plants. However, as/if processes are electrified in the move away from fossil fuels, electrical storage will become necessary. In addition, Solar PV is currently by far the cheapest source of renewable electricity but cannot meet the typical plant's significant baseline electricity demand outside sunlight hours without energy storage. There are a range of different electrical energy storage technologies currently available, each with different lifespan, discharge rate, depth of discharge and efficiency characteristics. Local availability, level of commercialisation and available scale must also be considered. It could be beneficial for the industry to monitor the technological and commercial developments in this area, and potentially investigate which type of technology or storage characteristics are best suited to the plants.

- **Solar thermal**

  Australia currently does not have many large-scale solar thermal installations, despite solar thermal's relative efficiency benefits as compared with solar PV. Solar thermal systems are generally more space efficient than solar PV, and the thermal energy it generates it much easier to store than electricity from solar PV. None-the-less solar thermal technology is generally considered less versatile than solar PV, as electricity is more easily and widely applicable in most industries. This is not true in the red meat processing industry, where up to 70% of total site energy demand is for hot thermal energy. Here, a solar thermal system being used to directly meet processing heating requirements could be much more straight forward and efficient than a solar PV system generating electricity which is then used to produce hot water or steam.

  This is a space to watch not due to immaturity of the technology itself, but because it is currently not widely used in manufacturing applications or at large scale in Australia. The best way forwards are likely to engage with suppliers as they emerge, to get an understanding of the current offerings and constraints of the market and monitor progress for when it may become viable at scale.

7.0 Conclusions / Recommendations

The following recommendations are provided in order of priority.

7.1 Business Energy & Carbon Maturity Categorisation

Comparing the 7 participating sites, a large spread is evident in energy performance and net zero awareness. As a result, there are very few practical opportunities or technologies that are applicable to all sites since they were all at differing stages in their energy and carbon transformation. The solutions identified for the sites with lower energy and emissions performance had largely already been implemented by the high performing facilities. Furthermore, the renewable energy opportunities explored could not be investigated for the lagging sites due to lack of metering and monitoring and relative low energy productivity. It is therefore suggested that AMPC adopt a tiered approach, where different suites of information and implementation support are provided in a targeted manner suited to the energy maturity of each business.

It is proposed that AMPC set up a categorisation/rating system, where facilities are allocated into groups based on their current energy and carbon maturity. A sites categorisation could be based on their position along the 'transition to net zero pathway' (see Figure 6). This would allow AMPC to develop/pitch appropriate programs and advice to sites across the wide spectrum of net zero maturity. It could also prevent issues such as those encountered during this project, where most sites turned out not to be ready for pinch analysis. The ability to quickly see which facilities are at which level would streamline site selection/assessment process for AMPC programs.

Each rating level could provide facilities with eligibility for programs suitable to their current development stage. Once a site has progressed to the next level of energy maturity, it will open a new suite of programs, resources, guidance etc. A filter function could be provided for AMPC's research and resources library to allow businesses to search by energy maturity rating, which would pull out resources relevant to them now and filter out those that are not applicable to their site. Detailed action plans could also be developed for each category, outlining step by step how to progress towards net zero from their current situation.

Having all member businesses to allocated to an energy and carbon category would also provide useful information on the state of the industry and its progress towards net zero over time. These insights can then be used to tailor future strategies and support to areas of greatest need.

Figure 10 below is an example of how a red meat processing plant's energy and carbon maturity rating system could look, and what opportunities would be the focus at each level.

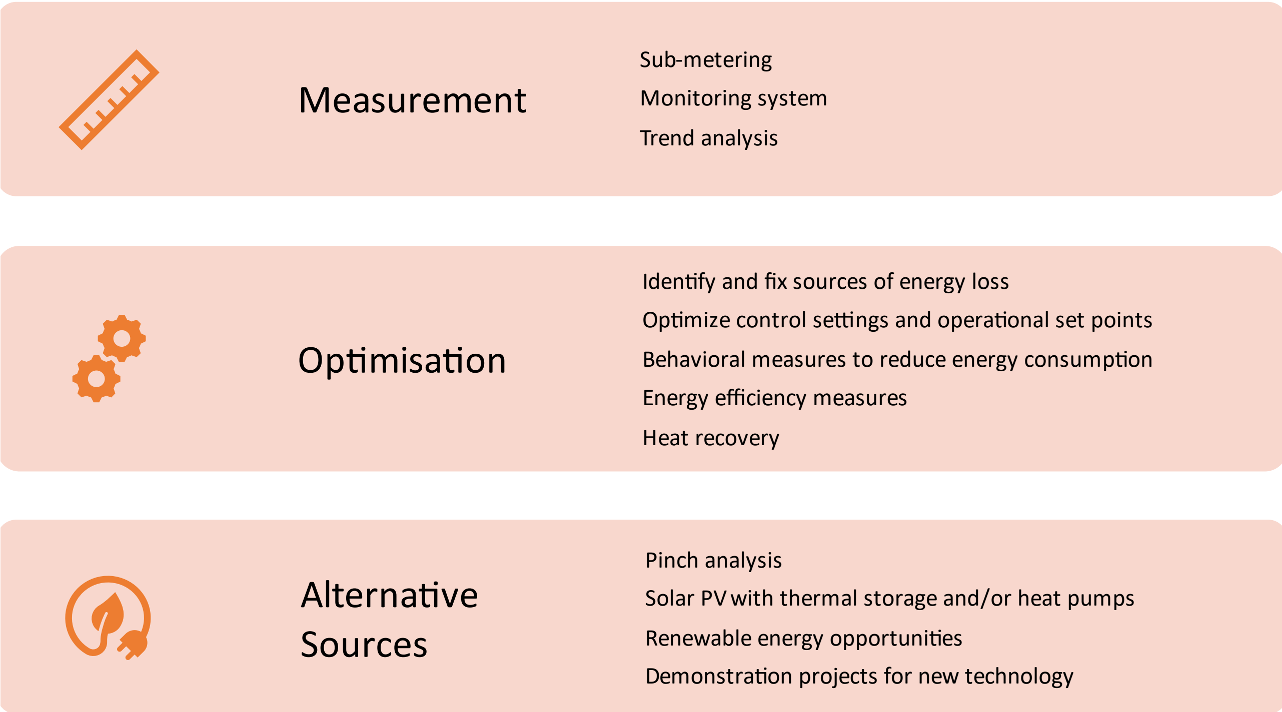


Figure 10: Example structure of an energy and carbon maturity categorisation system

7.2 Business Case for Net Zero

During this investigation, it was noted that few sites were clear on what net zero is, and the potential impacts of accelerating changes in the energy and carbon space. This is likely a key driver of the lack of corporate support and resourcing observed for energy efficiency and renewable energy transition measures. This isn't only true for larger sites, the market forces driving the need for Net Zero planning will affect all market participants and the driver in the near future could be about 'business survival' and not just 'doing the right thing'.

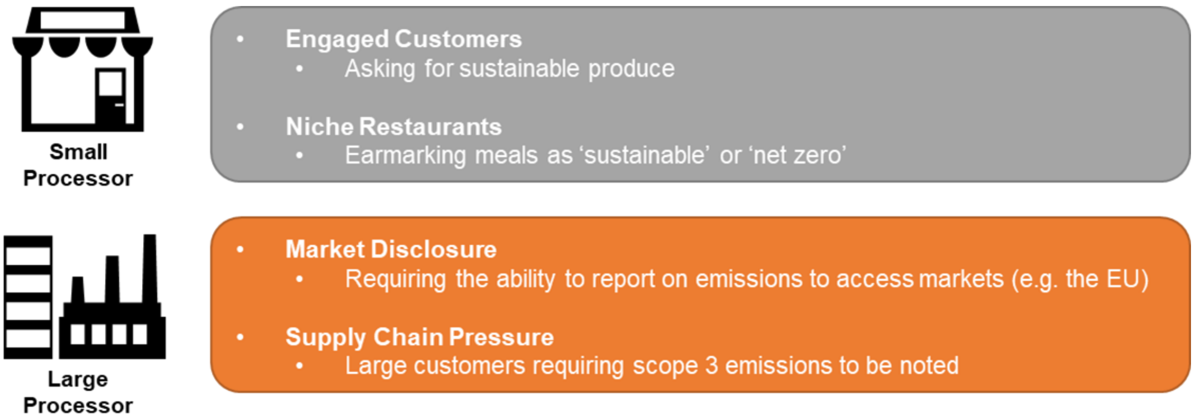


Figure 11 - Market forces driving the need for Net Zero, depending on size of processor

While the red meat industry commitment to net zero is an important step, realising these emissions reductions can only be achieved if the processors themselves are working towards the same goals. One opportunity to encourage businesses to invest in the net zero transition is to fully assess the economic, social, and environmental impacts of the changing energy landscape on the Australian red meat processor sector. Quantifying the true cost and potential benefit of action on GHG emissions, in the context of facilities' everyday decisions and practices, could help build support for net zero action and accelerate decarbonisation project implementation in line with what it needs to be to achieve industry targets.

The net zero impact assessment investigation could take the form of a business case, calculation tool and/or informational report that can be disseminated at all levels within the industry.

The scope for assessment should include the following key points at a minimum:

- Background on what net zero is, and the national and international socio-political context
- Modelling/forecasting of energy market changes, particularly cost of electricity, natural gas, LPG, and coal. This should consider impacts of future tariffs on purchase of non-renewable energy, and/or on products produced in facilities using fossil fuels.
- Energy and carbon offset cost and supply forecast
- Sensitivity analysis of emissions reduction options to changes in natural gas and grid electricity prices
- Projected impacts to the red meat processor market and individual businesses of changing national and international GHG emissions legislation and regulation. Focus on export markets.
- Magnitude and consequences of supply chain pressure by large retailers to certify net zero.
- Potential benefits to offering a net zero product, including changes to operational costs due to energy cost fluctuation and whether consumers would pay more for net zero products.
- Trends in ESG policies of financial institutions, and potential impact on the plant's ability to secure funding under different net zero scenarios.
- Engage with key market stakeholders and retailers to understand the materiality of decarbonisation meat products.
- Engage with red meat processor businesses to understand their current stance on net zero, key business drivers, concerns, and barriers to committing to a net zero transition.
- Risk analysis of non-action on net zero red meat processing plants to medium and long-term business viability, resilience, and profitability.

7.3 Metering and monitoring – Harnessing the Power of Data

It is understood that AMPC already has a metering and monitoring support program underway to support the plants installing sensors on sub-process streams. It is recommended that this program be augmented to also focus on data collection, monitoring, and analysis as this was identified as a common area of weakness among the participating sites, as discussed in Section 5.3 of this report. Metering projects should not be eligible for grant support unless they include installation of a smart data collection and monitoring system, accompanied by planning for all associated training and business process updates. Similarly, the project should not be considered complete until all sensors have been commissioned, calibrated, verified, and connected to the monitoring system.

For a metering system to drive action on energy and carbon reduction, the data it generates must be collected, monitored, and analysed. The value in metering energy use is significantly reduced if not monitored regularly. To do this, the sites would need an energy monitoring system which connects with all existing and new meters to consolidate, store, and visualise data. Energy monitoring can either be set up within the existing site operation and control system, or a new energy management software could be procured and then integrated with the existing system. Once the metering and monitoring systems are established and have operated for a suitable time period, the compiled data should be analysed.

In this case, it is recommended that at least 2 consecutive months of time-series data is collected at the nominated metering points before proceeding with analysis and further renewable energy investigation. It is important that the data is collected for the same 2 months for every variable, so that relationships between variables over time may be identified.

It is recommended that the following key points be considered during the development and/or assessment of the monitoring and analysis aspects of a site's metering and monitoring plan.

Selecting and running an energy monitoring system:

- Allocate responsibility for monitoring performance to someone in-house or engage an external party to monitor and analyse the collected data.
- When submetering across systems, focus on consolidating and standardising data in one place or platform.
- Ensure data is collected and stored in a way that is accessible, easily shareable, and useable. This means that data is formatted for ease of identification, extraction, and transformation. The data monitoring platform and interface should also be easy to access and user friendly, and staff should be trained to use it properly.

Energy data analysis for process optimisation:

- Look for abnormalities in the energy data.
- Compare the data to your baseline and business activity. Use this comparison to identify if equipment is running when it does not need to be.
- Regularly monitor the data for unexpected spikes. These spikes can indicate when equipment needs repairing or maintaining.
- Set alarms for non-typical performance, which notifies the responsible person. This helps to reduce ongoing energy losses by quickly identifying operational faults, valves left on, leaks etc.
- Tune existing processes – boiler operation for improved efficiency, hot water temperature set-points, water pressure at outlets etc.

Lastly, it is worth highlighting that the process of metering and monitoring should underpin a continuous improvement program. The systems are less 'set and forget' and more 'key indicators' to drive performance improvement over time. There should be an appropriate program of system reviews and checks to ensure the data is continuing to provide insights and uplifts to site operations.

7.4 Net Zero Strategy Program

It is important for each red meat processor business to develop their own Net Zero plan.

Supporting businesses to develop Net Zero Plans could help accelerate Industry adoption of renewable energy for process heating. A key barrier to accelerating decarbonisation within the red meat processor sector was found to be uncertainty around what net-zero really looks like on the ground, the risks and benefits of net-zero transition on the business specifically, as well as lack of clear direction on how to proceed. A clear, strategic pathway will set the course for businesses to continuously reduce their emissions into the future. A net-zero strategy should be founded in understanding of the business's direction and the energy market to develop a comprehensive plan and pathway looking at short-, medium- and longer-term actions and targets to achieve net zero for Scope 1,2 and 3 emissions.

Development of a site and/or overarching business net zero strategy can be undertaken internally by a sustainability manager within the red meat processor organisation. This approach has the benefit of intimate understanding and familiarity with the business's operational practices, strategic direction, and priorities. Alternatively, if the facility does not have a sustainability professional on staff and is not inclined to engage one, external energy and sustainability consultants can be engaged to work with the business in developing the net zero plan. Smaller meat processing businesses may struggle to support this function within their payroll but may be able to access smaller government grants for assistance, which is a contrast to larger corporations who may have begun to develop detailed action programs, beginning with metering actions. Corporate commitment to net zero targets and an emissions reduction plan will also require on-going performance monitoring and reporting, which needs to be planned out as part of the net zero plan.

Note that sites would need to have installed the sub-metering and data monitoring system outlined in this report before a net zero strategy could be completed.

7.5 Conclusion

In conclusion, a key opportunity to support industry net zero change is to further the understanding and awareness of the potential impacts of a net zero transition for red meat processor businesses. Lack of support from an executive level is currently a key barrier to facilities optimising their energy productivity and moving to decarbonise their thermal energy supply system. Urgency is needed in addressing the materialising reality that market disclosure and access could be upturned over the next 5-10 years as the market landscape pushes on through this period of change.

Sites could also benefit from assistance in developing their own net zero strategies, as there is currently minimal formalised planning or commitment to corporate decarbonisation. These measures could build executive support for net zero transition within red meat processor businesses, so that the required internal resources are mobilised to implement change. Only once businesses can demonstrate a satisfactory plan to transition to renewable energy would implementation grant assistance be offered.

The major 'shovel ready' opportunities identified for meat processing facilities to reduce GHG emissions:

- Optimisation of the on-site passive heat recovery system. Key applications include economisers, desuperheaters and rendering plant.
- Solar PV to meet site electrical baseload, optimised for self-consumption.
- Combustion of biogas generated through on-site anaerobic digestion of wastewater, for steam production or cogeneration.

Industry innovators should keep an eye on large-scale solar thermal, large-scale battery storage and biogas to biomethane technologies, which have potential for application to Australian meat processing facilities.

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9.0 Appendices

9.1 Appendix 1: Standard metering and monitoring plan

Equipment or sub-process being metered	Variable being measured	Units	Interval	Physical location
Boiler steam production	Steam flow rate	L/hr	Minute	Boiler steam outlet
	Steam temperature	°C	Minute	
	Biogas to boiler flow rate	L/hr or GJ/hr or m^3/hr	Minute	Boiler fuel inflow to Boiler #2
	Natural gas flow rate		Minute	Boiler fuel inflow for each boiler
Steam consumption by sub-process	Steam flow rate	L/hr	Minute	At inlet point to each steam user (blood furnace, render plant, HW tank, warm water tank, boiler feedwater, other plant etc.) To capture transmission losses, steam through each outlet of the steam header.
	Steam pressure	kPa	Minute	
	Steam temperature	°C	Minute	
Main refrigeration evaporative condensers	Refrigerant temperature	°C	Minute	At refrigerant inlet and outlet on the cooling towers
	Refrigerant flow rate	L/hr	Minute	
Refrigeration electricity consumption	Electricity consumption	kWh	0.5hr	Electricity sub-meter on each compressor, condensers, and evaporators (electricity to each chiller/cooled area also works).
Hot water at each end supply point	Temperature	°C	Minute	At supply point for each end use (Kill Floor, Bone Room, Offal, and Plant)
	Water flow rate	L/hr	Minute	

Condensate return to feedwater tank	Temperature	°C	Minute	Inflow of condensate return to feedwater tank
	Water flow rate	L/hr	Minute	
Hot water recovery to hot water/feedwater tank	Temperature	°C	Minute	Inflow of hot water return to HW/feedwater tank
	Water flow rate	L/hr	Minute	
Wastewater discharge	Effluent temperature	°C	Minute	At effluent discharge point from plant, or inflow point to water treatment ponds
	Effluent flow rate	L/hr	Minute	
Town water at each supply point	Temperature	°C	Minute	Town water inlet point to HW tank, warm water tank, boiler feedwater makeup, condenser cooling water makeup
	Water flow rate	L/hr	Minute	
Warm water at each end supply point	Temperature	°C	Minute	At supply point for each end use
	Water flow rate	L/hr	Minute	
Thermosyphon oil cooling	Temperature	°C	Minute	Oil inflow and outflow to thermosyphon oil coolers
	Oil flow rate	L/hr	Minute	

9.2 Appendix 2: Project Snapshot

To be completed after review and approval of final report by AMPC, and with input from AMPC regarding most useful project takeaways.