final report

Project code: P.PIP. 0386

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Date published: 16 Mar 2015

PUBLISHED BY
Meat and Livestock Australia Limited
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Commercial to industrial refrigeration upgrade, feasibility and implementation study
Ryan Meat Company

This is an MLA Donor Company funded project.

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

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ABSTRACT

Small/Medium red meat processors traditionally use commercial refrigeration solutions using Freon refrigerants for their cooling needs, in carcase chillers, process areas and freezers. Preliminary investigations have shown that energy savings can be found if the processors switch from commercial type refrigeration equipment to a centralized industrial system. This type of an upgrade would reduce the overall carbon footprint, reduce site power consumption per unit of production, improve finished product quality and provide means to protect the business against rising environmental and energy costs.

At Ryan Meat Company, the proposed industrial approach entails the replacement of existing air cooled refrigeration condensing units operated with synthetic refrigerants such as R22, R134A and R404A with a central small two-stage Ammonia plant. The medium temperature loads (carcase chillers) would be served by reticulated ammonia from the high stage, whilst the freezer load would be served by reticulated ammonia from the low stage.

The applicability of this technology to a small/medium size Australian red meat processing site can be investigated and quantified through a feasibility and implementation study that considers system performance, the achievable energy savings and practical aspects of the project such as availability and cost of the capital equipment.

The study outcomes will provide guidance to the red meat industry on the effectiveness, practicality and commercial feasibility of small ammonia systems to the small/medium meat processors as modern alternative to traditional Freon refrigeration systems.

EXECUTIVE SUMMARY

Minus40 has been commissioned by Meat and Livestock Australia (MLA) to investigate commercial to industrial refrigeration upgrade opportunities at Ryan Meat Company. Ryan Meat Company is a medium-sized abattoir in northern Victoria, specialising in red meat processing and sales to local meat wholesalers and butcher shops. The acquisition of an export license, as well as the rise in power cost was a push to replace their multiple commercial refrigeration units by a centralised two-stage ammonia plant.

The study showed that implementing alternatives to existing Freon plants reduces electrical energy consumption, gas consumption and also brings associated savings due to the use of a natural refrigerant.

The benefits of an industrial ammonia system were compared to the previous commercial refrigeration system type that Ryan Meat Company owned. The results are summarised in the following table:

Commercial Freon units	Industrial ammonia system	Advantages of the ammonia system	Disadvantages of the ammonia system
Multiple units	Centralised system	(1) Lower maintenance cost, (2) lower energy consumption	(1) No redundancy on the low stage system currently, hence a compressor failure could mean loss of low stage capacity; However a dedicated low stage compressor is planned to be implemented.
Air cooled units	Water Cooled system	(1) Lower energy consumption (2) Increased plant stability	(1) Water treatment and pumping cost
Direct expansion	Liquid recirculation	(1) Lower energy consumption	
Synthetic refrigerants	Ammonia refrigerant	(1) Environmentally benign refrigerant, (2) no greenhouse release from ammonia (3) Carbon trading system or refrigerant phase-out risk alleviation	(1) Ammonia is a toxic refrigerant that requires proper safety and risk management measures
Commercial refrigeration	Industrial refrigeration	(1) Longer span life (double!)	(1) Higher capital costs
Basic Controls	Smart controls	(1) Lower energy consumption (2) Increased plant stability	
Freezer Electric defrost	Freezer Hot-gas defrost	(1) Lower energy consumption	

The energy savings achieved by the upgrade of a commercial refrigeration system to an industrial refrigeration system are significant. In the case of Ryan Meat Company, a total of 37.5% energy savings of total site consumption was achieved.

Scenario description	Annual Energy Savings	Annual Gas Savings	% savings in total site energy consumption	Annual Energy Cost Savings (excl GST)	Other cost savings (excl GST)	Total Capital Cost (excl GST)	Annual GHG Savings	Simple Payback
	[MWh]	[GJ]	[%]	[$]	[$]	[$]	[Tons of CO_2]	[Years]
Actual	163	447	37.5%	$34,694	$17,000	$850,000	194	16.4
With CTIP Funding[*]	163	447	37.5%	$34,694	$17,000	$625,000	194	12

It should be noted that the above simple payback and capital cost figures are based on total capital cost for the ammonia plant, and not on the incremental cost above a like-for-like replacement of the Freon plant. This results in a much higher cost/payback than would otherwise have been the case.

As indicated in the above table, ammonia refrigeration systems usually require higher capital costs than commercial refrigeration systems and payback can appear to be relatively long. However, the benefits of industrial refrigeration systems make them a future proof investment as :

- Electricity and gas prices are likely to increase, reducing the overall payback time.
- Ammonia systems will not be affected by any potential emission trading schemes and synthetic refrigerant phase-out programs. Therefore, the additional savings due to the use of a natural refrigerant compared to synthetic refrigerants would increase over time as the price of synthetic refrigerant is likely to considerably increase.
- Production losses due to equipment failure is less likely to happen as industrial refrigeration equipment are more reliable and better monitored than commercial refrigeration
- Further energy savings can be achieved by optimising the controls.
- The implementation of a properly designed industrial refrigeration system will always result in energy savings compared to a commercial refrigeration system. Therefore, implementing such systems can attract government funding such as the late CTIP that Ryan Meat Company received or preferential financing options.

In the case of Ryan Meat Company, the replacement of their multiple commercial refrigeration units by a centralised two-stage ammonia plant was a success, resulting in electricity and gas savings but also allowing the business to comply with the export refrigeration requirements.

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[*] The Clean Technology Investment Program (CTIP), now closed for new applications, is a merit-based grants program to support Australian manufacturers to maintain competitiveness in a carbon constrained economy. For more information, visit http://www.business.gov.au/grants-and-assistance/closed-programs/CleanTechnology/CleanTechnologyInvestment/Pages/default.aspx

1. INTRODUCTION

Ryan Meat Company is a medium-sized abattoir in northern Victoria, specialising in red meat processing and sales to local meat wholesalers and butcher shops. The business has been in operation for 60 years, but following growth in the business, a desire to export, and rising power costs, there was a push to improve energy efficiency.

The refrigeration system is responsible for a large part of the company's energy costs, so it was an obvious target for efficiency improvements. The system used a variety of air-cooled commercial refrigeration units running on synthetic refrigerants (including R22, R134a, R404a and R408a) posing a financial risk for Ryan Meat Company due to the phase-out of R22 and R408a by 2016.

Minus40 has been commissioned by Meat & Livestock Australia (MLA) to investigate a commercial to industrial refrigeration upgrade at Ryan Meat Company. Upon completion of this project (completion of commissioning and energy savings verification), the following key outcomes will be achieved:

- The achieved energy savings for small ammonia systems relative to Freon systems will be quantified, under different operating conditions.
- The overall commercial performance of small ammonia systems for small/medium meat processors will be demonstrated, and any cost items requiring improvement or development will be identified.
- A fact sheet on the use of small ammonia systems including guidelines on their applicability and associated cost savings opportunities will be prepared.
- A case study document on the Ryan Meat Company project will be prepared.

2. BACKGROUND

In 2012, an energy study at Ryan Meat Company undertaken by Minus40, recommended replacing the entire refrigeration plant, providing greater capacity, improved efficiency, eliminating environmentally harmful synthetic refrigerants and alleviating financial risks. The study suggested the implementation of an ammonia chiller with a CO_2 cascade system for the freezer. Shortly after the completion of the study, the processing facility had experienced a considerable increase in production which is expected to continue and increase further due to the granting of an Export Licence. The processor was therefore planning an upgrade of the refrigeration plant to build additional carcase chiller rooms and blast freezer rooms in the next 2-3 years, thus implying additional low temperature and medium temperature refrigeration load. A two-stage Ammonia plant was best suited for this kind of extension, rather than the original concept of a combination of Ammonia-glycol chillers and multiple low temperature CO_2 refrigeration units.

The Export Licence was granted in 2013 and includes stringent refrigeration requirements regarding chilling and freezing temperatures and times, which can be more efficiently met by an ammonia refrigeration system for the expected level of production. The previously determined heat load and plant operational requirements were better suited to a less expensive Ammonia chiller system. As the heat load was estimated to increase considerably, an Ammonia-only system made more financial sense in the long term due to the superior energy efficiency.

The implementation of the new refrigeration system was partially funded by the Clean Technology Investment Program (CTIP) covering around 25% of the total capital cost – and in June 2014, the multiple commercial refrigeration units were replaced by an efficient two-stage ammonia plant. The scope of works included supply, assembly, installation, testing and commissioning of mechanical, electrical and associated control equipment in relation to the cooling and hot water systems to meet Ryan Meat Company’s current and future requirements. This included: chiller rooms, a new blast freezer room, and a new plant room. Minus40 provided operator training on new equipment, running procedures, and safety procedures. The client was also given engineering design and documentation, including wiring diagrams.

Special consideration was given to the location of Ryan Meat Company at Nathalia, being that it is located on a flood plain and there could be associated risks such as damage to equipment and subsequent spoilage of products. The recommended solution was to build the new refrigeration plant room on an elevated steel frame, at the same level as buildings already on-site. Similarly, the electrical switchboards were also elevated.

3. PRE-IMPLEMENTATION SYSTEM

3.1. Refrigeration systems

The main refrigeration equipment operated on site consisted of three carcase storage chillers (big lamb chiller, small lamb chiller and beef chiller), a small runners chiller and a refrigerated shipping container also known as reefer that was used as a storage freezer. All refrigeration was provided by several commercial refrigeration units, whereby refrigerant is compressed in the reciprocating compressor to a high pressure, condensed in the air cooled condenser, expanded to lower pressure in a thermostatic expansion valve, then evaporated at low temperature in a finned-coil heat exchanger (evaporator) with air forced across it by means of fans, and then drawn into the compressor again.

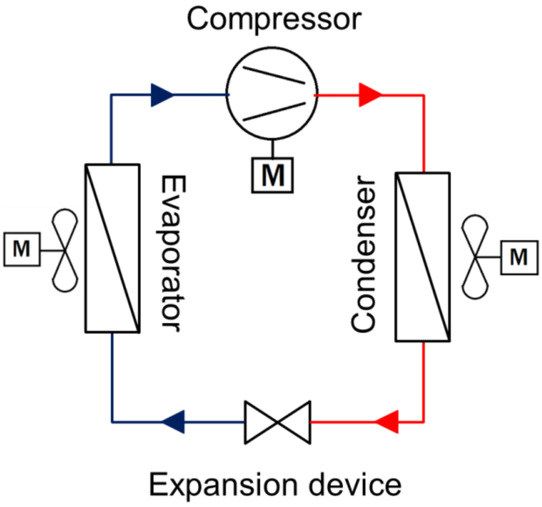

Figure 1 - Vapour Compression refrigeration principle

The condensing units for the carcase chillers were located underneath the floor of the processing facility. Whereas this location provided shade from direct sunlight, access to fresh air was limited resulting in higher condensing temperatures due to the recirculating warm air, causing excess power consumption and peak demand.

The runners chiller configuration was similar to the carcase chillers with the air cooled condensing unit mounted underneath the runners room.
The refrigerated shipping container was located east of the main processing facility with an on-board refrigeration unit used to freeze and store the chilled runners.
The defrost was achieved by air defrost for the chillers ’evaporators, while the reefer’s evaporator was defrosted electrically.

All the refrigeration units were running on synthetic refrigerant; R22, R408a, R404a and R134a. It is worth noting that R22 and R408a are ozone depleting refrigerants which are currently being phased out under the Montreal Protocol. The import quota into Australia has been reduced progressively over the last several years and it is due for final phase-down by 2016 after which only 0.5% of base levels will be commercially available. Increasingly limited availability of R22 and R408a would have implied considerable risk and cost exposure to Ryan Meat Company in the event of a major leak or simple system recharge requirements if the refrigeration system would have continued operation.

Closer analysis of the refrigeration system by Minus40 found that:

- The condensing units were relatively clean, oil and refrigerant leak free
- The majority of the condensing units compressors were near the end of their expected life cycle
- Most of the air cooled evaporators were degraded to a level where equipment asset replacement was the only option
- Big Lamb chiller, Small Lamb chiller and Beef chiller units experienced a high amount of recirculating air that had a direct effect on the refrigerant condensing temperature and equipment power consumption and demand
- The controls were limited with :
  - All carcase chillers operating on room temperature controllers and low pressure switches
  - Shipping container operating on room temperature (on-board controller)
  - Multiple pressure switches used to provide elementary condenser fan staging control.

Figure 2 - Refrigerated shipping container

Figure 3 - Condensing unit for Load out Chiller, installed underneath the chiller

Figure 4 - Oil leaks at the compressor - often a sign for refrigerant leakage

Figure 5 - Degraded Evaporator in Big Lamb Chiller

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<td>
Figure 6- Uninsulated Suction Gas and Liquid Lines to Load Out Chiller</td>
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Figure 7 - Old condenser Coils with Minimal Fan Staging Control</td>
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3.2. Heating system

The hot water necessary for sterilisation and wash down was generated by 35 heat pumps running with R134a refrigerant and a LPG heater to boost the temperature from 60°C to 82°C. The hot water was stored in an 11kL tank. Hot water at 82°C is mainly used for sterilisation, while wash-down is obtained by mixing hot water and cold water.

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<td>
Figure 8 - R134a Heat Pumps</td>
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Figure 9 - LPG Booster</td>
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4. NEW REFRIGERATION SYSTEM

4.1. Refrigeration System

4.1.1. Description

The new refrigeration system consists of a water cooled industrial liquid recirculation two-stage ammonia refrigeration system. The carcase chillers are served by medium-temperature ammonia while the new blast freezer is served by low temperature ammonia. The runners chiller has currently been removed, but a new chiller may be installed in future. The required cooling is now achieved by two reciprocating compressors, with the low stage (swing) compressor providing the cooling capacity for the new blast freezer and the high stage compressor supplying the carcase chillers whilst also catering to the heat rejection from the low stage system. The system is water cooled by an evaporative condenser. All the evaporators have been replaced and the medium temperature evaporators are still being air defrosted, while the freezer's evaporator is now defrosted with hot gas. A new PLC and SCADA system have also been implemented in order to control the plant appropriately. Numerous smart controls, described in section 3.2, have also been implemented.

The diagram shown below, shows the concept design of the new refrigeration plant.

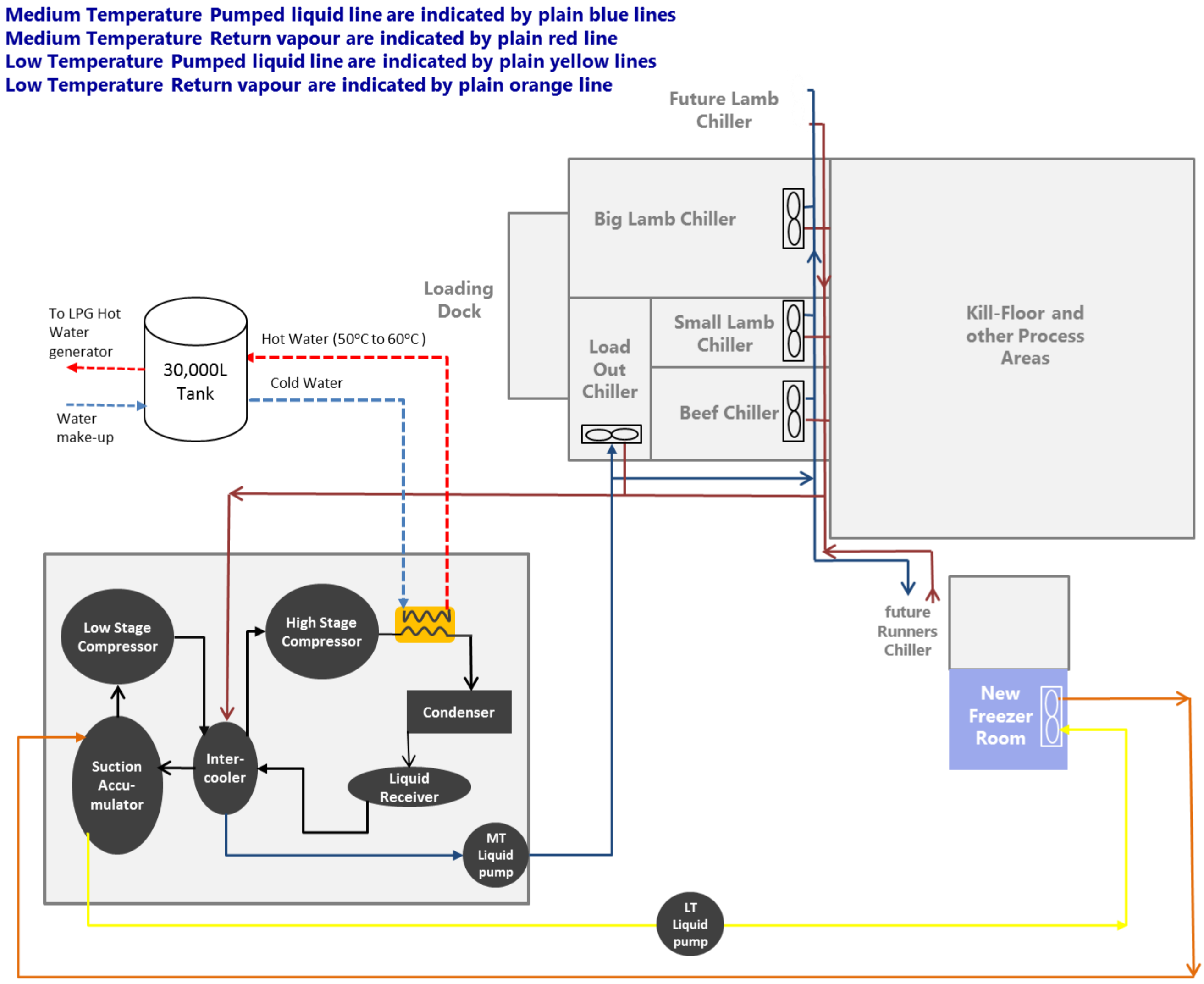

Figure 10 - Liquid Ammonia Recirculation two-stage Ammonia System Working Principle

The low temperature liquid pumps draw low temperature saturated liquid ammonia (showed in plain yellow lines) from the low temperature suction accumulator. When the blast freezer room calls for cooling, the liquid feed solenoid valve is opened to allow the liquid ammonia to flow into the evaporator. While flowing through the evaporator coil, part of the ammonia evaporates due to the absorbed heat while the rest stays liquid, creating a mixture of saturated liquid and saturated vapour (showed in plain orange lines).

The mixture from the blast freezer flows into the suction accumulator where saturated vapour and saturated liquid are separated. The saturated vapour then flows to the compressor where it is compressed to higher pressure and then condenses into the inter-cooler.

The medium temperature liquid pumps draw medium temperature saturated liquid ammonia (showed in plain blue lines) from the intercooler. When a chiller room calls for cooling, the liquid feed solenoid valve is opened to allow the liquid ammonia to flow into the evaporator. While flowing through the evaporator coil, part of the ammonia evaporates due to the absorbed heat while the rest stays liquid, creating a mixture of saturated liquid and saturated vapour (showed in plain red lines).

The mixture from the chillers flows into the intercooler where saturated vapour and saturated liquid are separated.

The vapour leaving the inter-cooler is saturated and flows to the high stage compressor where it is compressed at a high pressure.

The superheated high pressure vapour then flows into the de-superheater in which the vapour is de-superheated by transferring the heat to the water in the heat exchanger. The saturated high pressure vapour then flows into the condenser where it condenses and becomes a saturated liquid. The saturated liquid is then collected in a liquid receiver which is then fed into the inter-cooler. The cycle then repeats.

Figure 11 - High and Low Stage Reciprocating Compressors

Figure 12 - Evaporative Condenser, plate heat exchanger for Heat recovery and Liquid Receiver

Figure 13 - Inter-Cooler

Figure 14 - VSD for evaporator fans

4.1.2. Smart controls

The upgrade also included implementing multiple smart controls, achieved through proper PLC programming, to improve the efficiency of the plant:

i. Variable Head Pressure Control, by which the system's control logic varies the cooling tower fan speeds with wet and dry bulb temperatures so that the head pressure is consistently kept as low as possible, in order to ensure maximum efficiency and minimum operation costs.
ii. Fan Speed Control, which reduces the speed of the fans when the plant is not at peak load, and hence maximum refrigeration duty is not required. This technique saves the energy associated with unnecessarily running the fans at full speed for 100% of the time.

These techniques are describes in detail in the following paragraphs.

Variable head pressure control

The head pressure of a refrigeration plant is the pressure at which the compressors discharge and the refrigerant condenses. In a conventional plant, head pressure is fixed and the plant control system attempts to maintain that fixed value. Variable Head Pressure Control (VHPC) aims to optimise the head pressure of a refrigeration plant at any given time while taking into account operational factors such as minimum compression ratios and oil separation as well as variables such as ambient conditions and plant load.

Condenser fans on refrigeration plants run to maintain a certain refrigeration discharge pressure. For any mode of operation with actual plant heat rejection being less than the Theoretical Heat Rejection (THR) of the condensers and/or operation at lower than the design ambient wet bulb temperature, the full condenser fan capacity is not required. By convention, condenser fans are staged, such that fan power consumption is linearly proportional to fan requirement. The energy efficient alternative to staging condenser fan(s) on or off is to speed control them with VSD(s). Power consumption of variable speed controlled fans follows the fan affinity laws which state that the ratio of fan power consumption is proportional to the cube of the ratio of fan speeds. For example, if the heat rejection requirement is 50% of maximum, fan power consumption with conventional staging is also 50%, but is 12.5% with speed control.

Ambient wet bulb temperature is generally stable for long periods of the day and tends to fluctuate only with a change of weather. As VHPC depends on wet bulb temperature and plant load, well defined VHPC logic would dampen head pressure fluctuations, if implemented in conjunction with condenser fan speed control. On the other hand, head pressure on an otherwise conventional setup tends to fluctuate with plant load. Therefore, VHPC, in addition to reducing head pressure also stabilises the head pressure of the plant, resulting in more efficient and steadier plant operation over the year.

It should be noted that if head pressures are simply reduced to minimum without considering fan speeds, it could lead to an energy penalty as additional fans need to turn on to maintain the reduced head pressure set-point. Hence a logic which considers optimum total power consumption (compressor + condenser fans) was implemented to realise maximum energy savings. Figure 15 illustrates the relationship between compressor power consumption and head pressure set point

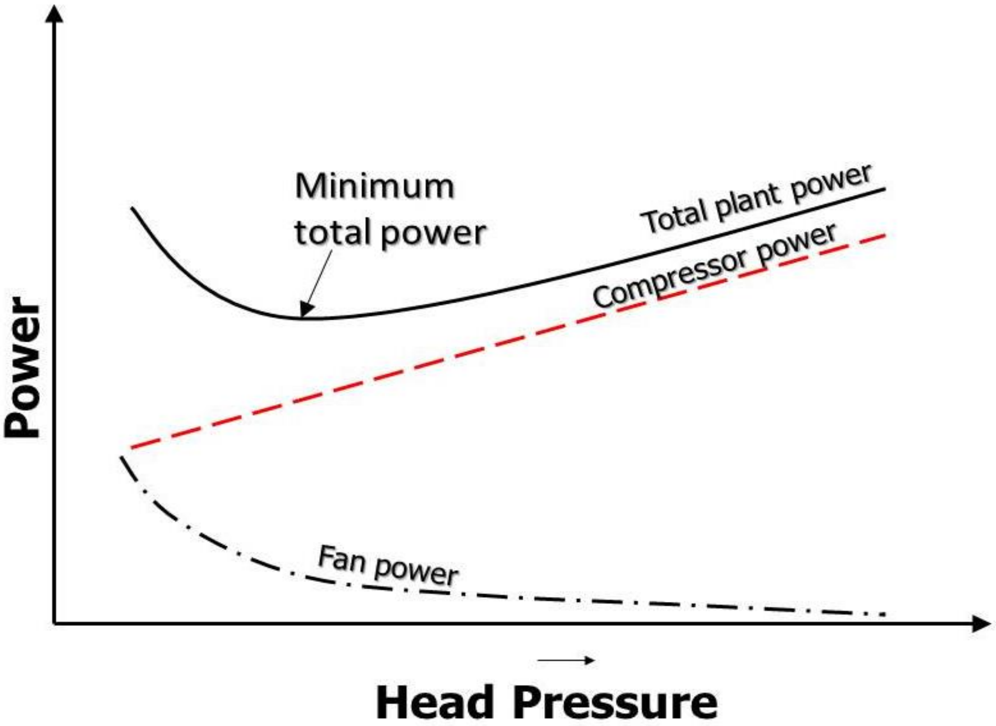

Figure 15 - Relationship between compressor power consumption and pressure set point

The VHPC logic and condenser fan speed control takes into account the ambient conditions and the plant load. The plant load is obtained by the compressor capacity (slide valve position and compressor speed) which is made available on the plant PLC. A certain approach is calculated between the calculated wet bulb temperature and the condensing temperature of the plant based on the plant load. This defines the instantaneous head pressure set-point of the plant and required condenser fan speed.

Evaporator Fan Speed control

Fan speed control reduces the speed of the fans when the plant is not at peak load, and hence maximum refrigeration duty is not required. This technique saves the energy associated with unnecessarily running the fans at full speed for 100% of the time.

By varying the fan speeds to suit load, energy savings are possible because lower fan speed translates to less heat being introduced to the refrigerated spaces, therefore less load on the refrigeration system.

Reduction in fan speed is directly proportional to evaporator capacity. However, as detailed previously, power consumption of variable speed controlled fans follows the fan affinity laws which state that the ratio of fan power consumption is proportional to the cube of the ratio of fan speeds.

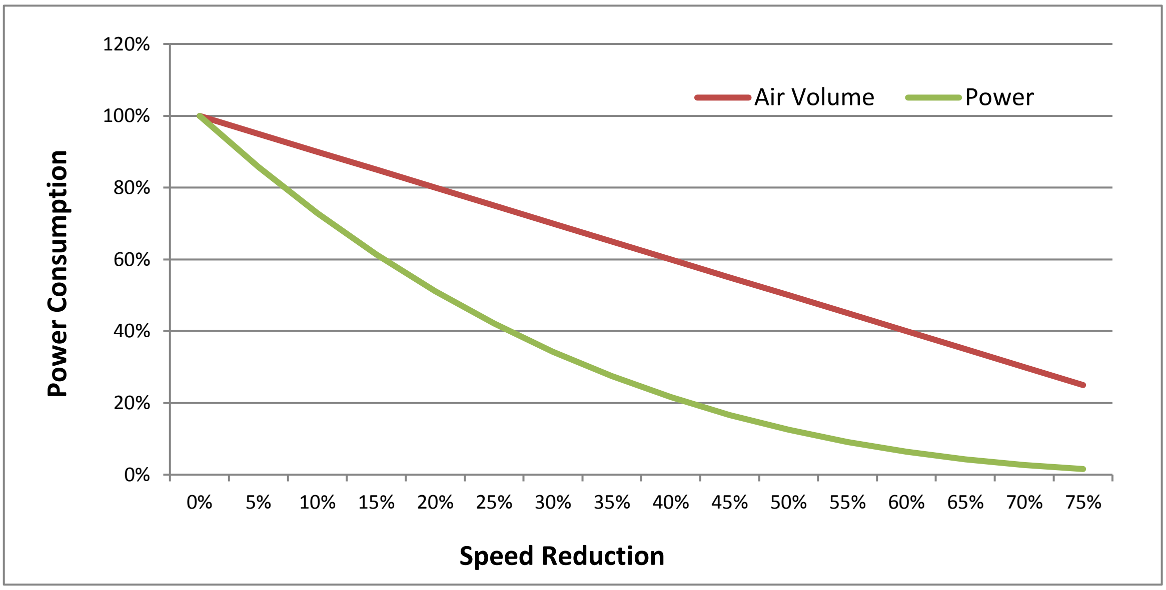

Figure 16 - Relationship in Between Fan Speed, Fan Power Consumption and Air Volume

As it can be observed on figure 16, reducing the fan speed by 20% results in power saving of around 40% and a reduction of air flow of around 20%.

The fan speed control logic implemented for the carcase chillers at Ryan Meat Company is a ‘recipe based’ logic which allows the plant operator to set the fan speeds during loading, pull-down and holding. Typically, the fan speeds are 60% during loading, 90% during pull-down and 50 %during holding. Apart from reducing energy consumption as detailed above, this logic assists in minimising product weight loss during the holding period.

4.2. Heating system – Heat recovery

The hot water previously generated by the 35 heat pumps is now generated by the rejected heat from the refrigeration plant.

The heat recovery system makes use of the heat rejected by the plant, to pre-heat the incoming town water, which will then be used as hot water on site for purposes such as sterilisation, wash-down and boot-wash. The hot water generated is usually between 50°C and 60°C – therefore the water necessary for sterilisation needs to be heated up to 82°C in the existing LPG fired hot water generator.
Heat recovery was achieved by installing a plate heat exchanger onto the discharge line of the high stage compressor, an insulated hot water tank and the necessary pipework and pumps.

It has been observed at Ryan Meat Company that a larger amount of hot water is being generated during hot days. This is due to the fact that the amount of heat available varies in accordance with the refrigeration plant operation. The reason is that the higher the ambient temperature and the cooling load, the higher the condensing pressure of the plant, and hence the greater the amount of heat that can be recovered. Therefore, this means that more heat is available for recovery in summer than in winter.

Figure 17 - Hot Water Tank

Figure 18 - Heat Recovery Plate Heat Exchanger

5. PRE AND POST IMPLEMENTATION SYSTEMS COMPARISON

5.1. Overall Comparison

The implemented two-stage Ammonia refrigeration system presents several benefits compared to the previous refrigeration units used at Ryan Meat Company. Table 1 provides an overview of the advantage and disadvantages of the new system compared to the previous commercial refrigeration system.

Table 1- Comparison of Direct Ammonia System compared to Commercial Freon Refrigeration System

Commercial Freon units	Industrial ammonia system	Advantages of the ammonia system	Disadvantages of the ammonia system
Multiple units	Centralised system	(1) Lower maintenance cost, (2) lower energy consumption	(1) No redundancy on the low stage system currently, hence a compressor failure could mean loss of low stage capacity; however a dedicated low stage compressor is planned to be implemented.
Air cooled units	Water Cooled system	(1) Lower energy consumption (2) Increased plant stability	(1) Water treatment and pumping cost
Direct expansion	Liquid recirculation	(1) Lower energy consumption	
Synthetic refrigerants	Ammonia refrigerant	(1) Environmentally benign refrigerant, (2) no greenhouse release from ammonia (3) Carbon trading system or refrigerant phase-out risk alleviation	(1) Ammonia is a toxic refrigerant that requires proper safety and risk management measures
Commercial refrigeration	Industrial refrigeration	(1) Longer span life (double!)	(1) Higher capital costs
Basic Controls	Smart controls	(1) Lower energy consumption (2) Increased plant stability	
Freezer Electric defrost	Freezer Hot-gas defrost	(1) Lower energy consumption	

5.2. Centralised system vs. Multiple units

The pre-implementation refrigeration system consisted of several commercial refrigeration units while the new ammonia refrigeration system consists of a central plant with low and high stage compressors which supply all the carcase chillers and the blast freezer room.
By centralising the refrigeration plant, the number of equipment to maintain is reduced, hence reducing maintenance costs and the risk of leakage.

Centralised system also tends to be more efficient than several individual units as losses (thermal, mechanical, electrical) are minimised.

5.3. Water cooled vs. Air cooled

The several Freon units were air-cooled and high condensing temperatures were observed. The ammonia refrigeration system is an evaporative cooled system and condensing temperature are much lower due to the fact that "wet bulb" temperature of the ambient air is generally lower than "dry bulb" of the ambient air. In addition, during the day, the air temperatures tend to rise faster than the ambient humidity, so that the "wet-bulb" temperatures tend to vary less than the dry (or sensible) air temperature. This is illustrated in the example of ambient dry and wet bulb temperature variation shown below.

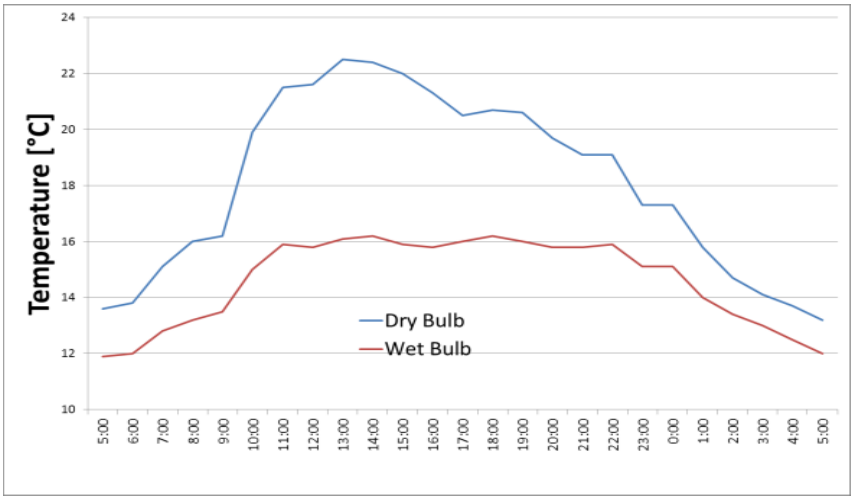

Figure 19 - Variation of Wet Bulb and Dry Bulb temperature throughout a Typical Day

This means that during the heat of the day, air-cooled condensers using dry air for their cooling cannot achieve as low condensing temperatures as those operating against the wet-bulb temperature (e.g. evaporative condensers). This is the reason why water-cooled or evaporative cooled refrigeration systems are less susceptible to hot summer conditions and use less energy than air-cooled systems, in the majority of cases.

5.4. Ammonia refrigerant vs. Synthetic refrigerant

All refrigerants can be divided into two classes: the natural refrigerants, which are naturally occurring substances within our environment, and the synthetic refrigerants, which are chemically produced. Ammonia, currently used as sole refrigerant at Ryan Meat Company, belongs to the natural refrigerant category while R134a, R404a, R408a and R22, previously used at Ryan Meat Company, are synthetic refrigerants which are harmful for the environment.

An overview, along with their typical GWP's and ODP's can be seen in table 2.

Class	Environmental Properties		Regulatory Status
	GWP	ODP	
Synthetic Refrigerants			
CFC's - ChloroFluoroCarbons (for ex. R11, R12, R502, R13)	Very high	Very high	Have been phased out since 1995
HCFC's - HydroChloroFluoroCarbons (for ex. R22, R408a)	High	Low	phased out by 2016
HFC's - HydroFluoroCarbons (for ex. R134A, R404A, R410A)	High	Zero	Prices were heavily affected by Carbon Tax China and USA have signed their phase-out by 2030
HFO's - HydroFluoro-Olefins (for ex. HFO-1234yf)	Very Low	Zero	-
Natural Refrigerants			
R717 - Ammonia - NH_3	Zero	Zero	-
R744 - Carbon Dioxide - CO_2	1	Zero	-
HC's - HydroCarbons	Very Low	Zero	-

Table 2 - Refrigerant Environmental Properties

HCFC's, including R22 and R408a, are ozone depleting refrigerants. Consequently, they are being phased out under the Montreal Protocol. Import quota into Australia has been reduced progressively over the last several years and will be increasingly limited over the coming years. It is due for final phase-down by 2016 after which only 0.5% of base levels will be commercially available. It is expected that that the actual price and availability of HCFC's will be high and rare respectively.
If there is no change in the use of HFCs, they could contribute as much as 20% to human-induced climate change by 2050[†]. Consequently, The USA and China have signed off for a phase-out of HFCs, including R404a and R134a, by 2030. The phase down of these gases starts in 2020. It is expected that Australia will also fall into line in the coming years.

Ammonia was one of the first, most efficient industrial refrigerants and is an environmentally benign refrigerant (GWP=0; ODP=0) which has no negative environmental impact when released into the atmosphere. Consequently, any current or future phase outs / phase down

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[†] Source: Dr. Gus Velders et al, 24 FEBRUARY 922 2012 VOL 335 SCIENCE

will not affect ammonia refrigerant prices and availability. Due to its toxicity, operational precautions associated with ammonia are required such as:

- Ammonia alarm system (not required if the plant room is not enclosed, and the pipe-work and valves are installed such that any leaks are released to atmosphere
- Labelling and location of critical valves to be isolated in the event of emergency
- eye-wash and shower
- Personal protective equipment.

5.5. Industrial equipment vs. Commercial equipment

The previous refrigeration equipment at Ryan Meat Company consisted of multiple Freon refrigeration units which are commercial type refrigeration equipment. On the other hand the new ammonia refrigeration plant is built with industrial type refrigeration equipment.

Commercial type refrigeration equipment is built primarily with cost in mind and therefore their usable and efficient life expectancy is relatively short, usually between 8 and 12 years depending on the exact unit and its application. On the other hand, industrial equipment is usually well built and designed and has a life expectancy which can exceed 20 years. Ammonia refrigeration plants built in the 60s are still running in Australia and despite being more than 50 years old, those refrigeration plants are still operating efficiently.

Industrial Ammonia refrigeration systems consist of steel pipework, while commercial refrigeration systems usually consist of copper pipework. Due to the nature of installation, the copper pipe-work systems tend to result in leaks whereas the welded steel systems are generally leak resistant.

5.6. Basic Controls vs. Smart Controls

Commercial refrigeration systems, used previously at Ryan Meat Company, are built with minimal controls to keep the system capital costs low. In the case of Ryan Meat Company, the controls consisted of low pressure switches and temperature controllers. On the other hand, the new ammonia system is controlled by “smart” controls. For example the variable speed drives installed on the motors are controlled based on a specific logic programmed in the PLC ensuring that the plant is running at its most efficient. The smart controls implemented at Ryan Meat Company are described in section 4.1.2.

The energy savings in modern refrigeration systems when compared to older type of systems are achieved through significantly more efficient equipment and through the addition of “smart controls” that optimise the operation of the system.

Maximum system efficiency is not achieved due to the limitations on the controls side.

Several control techniques can be applied to improve the operation and save energy. These techniques require the plant to be equipped with a PLC or SCADA system.

5.7. Direct Expansion vs Pumped Recirculation Systems

The refrigeration units previously used at Ryan Meat Company were direct expansion systems using a thermostatic expansion valve as throttling device. The new ammonia refrigeration system is a recirculated refrigeration system using a regulating valve. Contrary to the previous thermostatic expansion valves, the regulating valves are operating at minimal differential pressure resulting in energy savings from the compressors.

With few exceptions, most small commercial refrigeration systems use Thermostatic Expansion Valves as throttling devices, as shown in the figure below. Commonly referred to as “TX” valves, these valves require that the pressure of the liquid condensate act against a mechanical spring to open an orifice. If the liquid pressure is insufficient, then insufficient liquid could pass through the TX valve, causing the evaporator to starve of liquid, and the cooling capacity of the system then drops. Therefore, all direct expansion systems (those systems using dry expansion control devices such as TX valves) are required to operate at a sufficiently high condensing pressure in order to maintain sufficient cooling capacity at the evaporator.

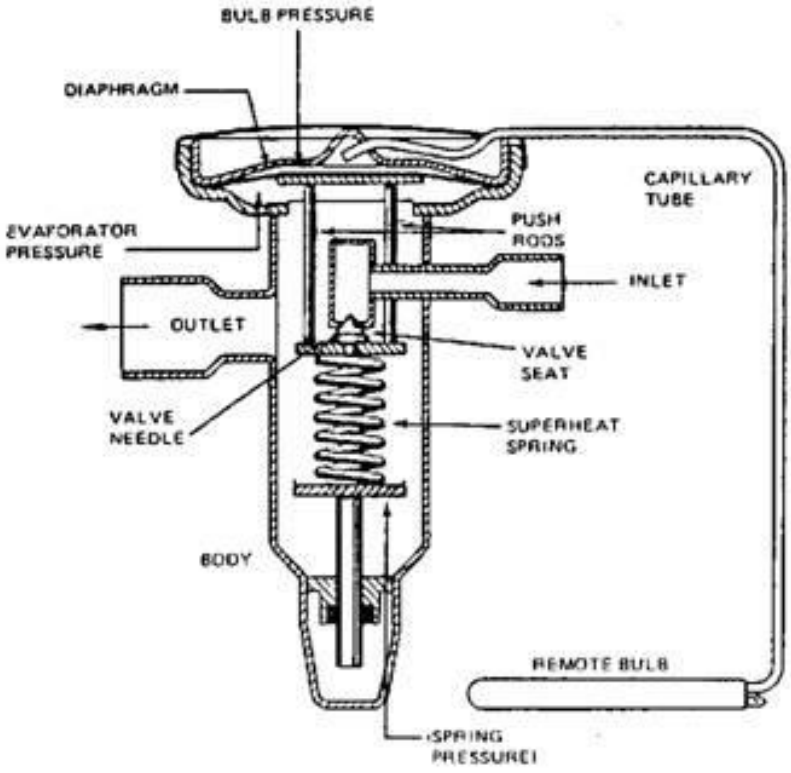

Figure 20 – Thermostatic Expansion (TX) valve – source: Ozchill

With recirculation systems, on the other hand, the throttling device can operate at minimal differential pressure, and this requirement for a high liquid pressure generally does not exist. The energy consumption of the compressor depends on the pressure differential between the evaporation and condensing temperatures. Where this pressure cannot be reduced, such as on DX systems, the energy consumption of the compressor cannot be reduced to the extent possible with recirculation systems.

Also, recirculated liquid ammonia evaporators can achieve much higher room humidity than direct expansion synthetic refrigerant alternatives, thereby minimizing weight loss from the product. This is one of the main reasons why recirculated refrigeration systems are often substantially more energy efficient than DX systems.

5.8. Electric Defrost vs. Hot Gas Defrost

The reefer’s evaporator, used to freeze the meat, was defrosted by electricity. With the new ammonia refrigeration system, the evaporator of the blast freezer is defrosted by hot gas.
The electric defrost was achieved by operating several electric heaters located within the evaporator whilst turning the evaporator fans off. While it is a simple and convenient method, it presents several disadvantages:

1. Electric heater elements often fail and require replacement, resulting in maintenance costs.

2. Electric power is the most expensive form of heat, and electric defrost heaters can con tribute very significantly to the total refrigeration system’s power consumption.
3. Electric defrost adds additional heat into the room, and causes the evaporator itself to heat up. After completion of defrost, the refrigeration system needs to remove this added heat in addition to any heat load in the room or cabinet.

A more efficient alternative to electric defrost is hot gas defrost. This is achieved by utilising ammonia plant discharge gas for defrosting the evaporator. While this method of defrosting adds capital cost to the system, considerable savings in energy consumption and maintenance costs can be achieved, as detailed above.

In both the pre-implementation system and post-implementation system, the chillers’ evaporators are air-defrosted.

6. NEW SYSTEM OBSERVATION

6.1. Operational issues

As for any implementation, issues are encountered. In the case of Ryan Meat Company, little issues were encountered after the commissioning of the plant which were:

- The variable head pressure control was not effective and causing issues with liquid feed into the intercooler vessel. A change in the expansion valve size fixed the issue.
- The heat recovery is not providing sufficiently high water temperatures. The system cannot keep up with the demand for the hot water. This is possibly because of the way the site is operated. It was estimated that the system would run over night so that water could be heated overnight and used in the morning. However, the plant currently operates at very low loads during the night as all chilled carcases are loaded out by evening. It was observed that higher water temperature was achieved during summer days due to higher condensing temperatures and more load in the system.
- Measurement and verification activities (see section 7) indicated that the variable head pressure control could be optimised in order to achieve maximum energy savings.

6.2. Site Challenges

Contrary to commercial refrigeration systems, ammonia refrigeration systems require a proper safety and emergency management plan. It is then important to ensure that staff are properly trained to run the plant and understand the safety aspects of ammonia. As a result, this can result in additional administration requirements, and a proper follow up to ensure that the equipment and procedure are up to date.

7. ACHIEVED ENERGY SAVINGS

Minus40 conducted measurement and verification activities in relation to the refrigeration system upgrade project that was implemented at Ryan Meat Company. All equipment was installed and commissioned by June 2014. This following outlines the energy savings due to implementation of the project. The energy savings analysis is based on electricity interval data of the transformer serving the entire site, weekly production data provided by Ryan Meat Company and ambient dry bulb temperature from the Bureau of Meteorology for Shepparton Airport.

7.1. Methodology

7.1.1. Electricity

A regression approach based on measured site power consumption has been applied to verify the energy savings, which involves:

- Analysing various variables that impact on the refrigeration system power consumption
- Constructing a multiple variable regression model for the pre-implementation system and checking the model against actual consumption
- Using the obtained model to predict plant power consumption for the period of post-implementation and comparing with the actual power consumption to identify the actual energy savings.

This method does not consider operating status of individual equipment, but on overall site energy consumption, which is described by a regression model.

As the site under consideration is a meat processing facility, the refrigeration load and power consumption is significantly influenced by the production activity on site. Additionally, the ambient dry bulb temperature also plays a role, which results in a higher refrigeration load in summer and lower in winter. Apart from this, since the pre-implementation refrigeration plant was air-cooled, ambient dry bulb temperature also affects the condensing temperatures and hence the COP of the compressors. Due to the above reasons, the following two key variables have been selected to build a regression model:

- Production rate, kg of Hot Standard Carcase Weight (HSCW)
- The ambient dry bulb temperature, Tdb

A weekly-based model has been applied due to the weekly cycle of production activities on site (no production during the weekend). Additionally, the site staff has notified that they have started to process only lamb since around April 2013, as compared to both lamb and beef previously, which affects the KPI (Key Performance Indicator - Power consumption per kg HSCW) figures considerably. Therefore, the regression model has been developed based on data after this variation to production profile.

The following approach has been used:

- 30 minute electricity interval data for the site was obtained before the implementation of the project during the period from 6th May 2013 to 27th April 2014 (52 weeks) and after the implementation during the period from 6th October 2014 to 2nd November 2014 (4 weeks). Weekly power consumption data was thus obtained.

- Hourly ambient dry bulb temperature for the same period as electricity interval data was obtained from Bureau of Meteorology for Shepparton Airport, which is sufficiently close to the site location. This data was then averaged to obtain weekly-averaged ambient dry bulb temperature.
- Weekly production data (total kg of HSCW) for the same period as electricity interval data was provided by site.
- A multiple variable Polynomial regression model was constructed based on the above weekly data during the period from 6th May 2013 to 27th April 2014 using Microsoft Excel, where the polynomial order of 2 was selected with cross-terms included. The regression model includes:
- Dependent variable: weekly total site power consumption
- Independent variables: weekly production (kg of HSCW) and averaged dry bulb temperature (°C)

The suitability of the obtained regression model was verified by comparing predicted power consumption with actual power consumption during the period of 6th May 2013 to 27th April 2014. If considerable disagreement occurs, the possible factors which affect the power consumption are to be re-evaluated and a revised regression model would be required. In this report, the current regression model was found to provide a good estimation of the plant power consumption with the averaged deviation between predicted and actual values within 6% and an R2 (coefficient of determination) above 0.75.

The current regression model was used to calculate power consumption from 6th October 2014 to 2nd November 2014 which gives the power consumption of the site if the project was not implemented (called the “adjusted baseline” in M&V terms), this is compared with the actual power consumption for the post-implementation plant during the same period (called the “reporting period” in M&V terms). The difference in power consumption between the two scenarios gives the energy savings due to implementation of the project.

The calculated savings were converted to MWh per tonne and multiplied by the baseline annual production to obtain total annual energy savings.

7.1.2. LPG

The LPG consumption is influenced by the factors such as numbers of knife sterilised, washing area surface, wash time, number of employees. Whereas sterilisation gas consumption is highly linked the production, the wash-down gas consumption is not. Therefore, Contrary to refrigeration LPG consumption is not directly linked to production. As the only data available were LPG bills and production data, only direct energy savings have been taking into account.

7.2. Observations and Energy Savings

7.2.1. Electricity

The following graphs demonstrate the power consumption for the site pre and post project. Significant energy savings can be observed due to the project.

Figure 21 shows the power consumption per kg of HSCW for four weeks in October 2013 (Pre-project) and October 2014 (post project). The data for 2014 shows significantly lower values compared with those for 2013, indicating a roughly 30% less power consumption than the previous year.

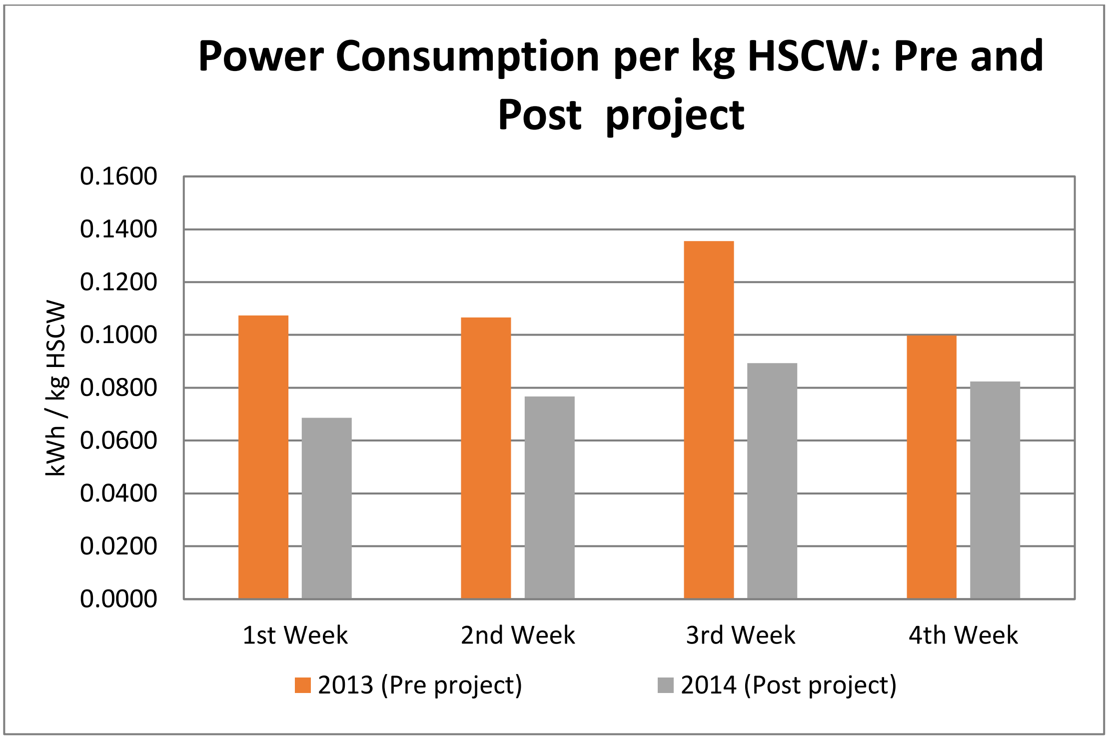

Figure 21- Power consumption per kg HSCW for pre and post project period

The following figure, Figure 22, shows the weekly power consumption for pre and post project, indicating for each workday the post project power consumption is lower than pre-project with the power consumption per day dropping from around 2,500 to 2,100 kWh. It should be noted that the production has increased by around 15% in the post project period, so the power consumption per day is expected to have a further drop if similar product rate to the pre project period took place. During the weekend, there is no production and therefore, pre and post project data become relatively comparative.

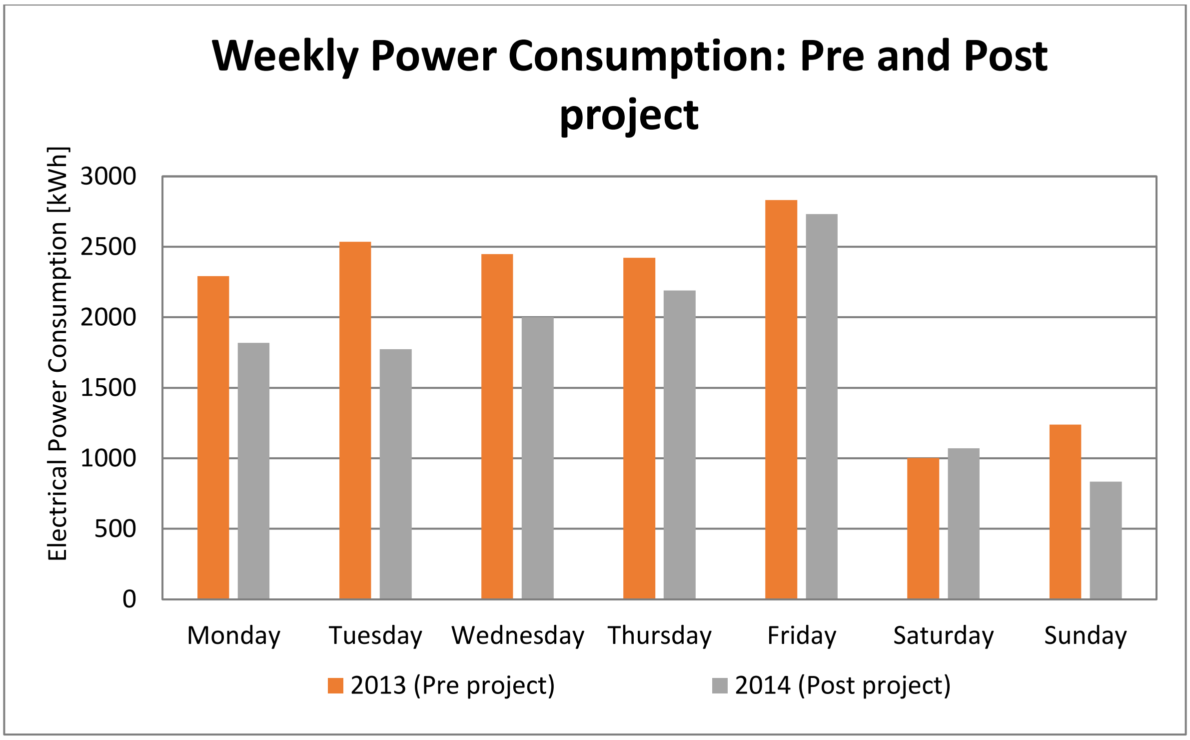

Figure 22 - Weekly power consumption for pre and post project period

Figures 23 and 24 show the daily power consumption for pre and post project. It can be seen that during the pre-project period, the power consumption peaks between 5 AM and 5 PM, whilst that during the post project period is only between 5 AM and 2 PM. During the night period, e.g. from 6 PM to 5 AM, the post project power consumption has also dropped significantly.

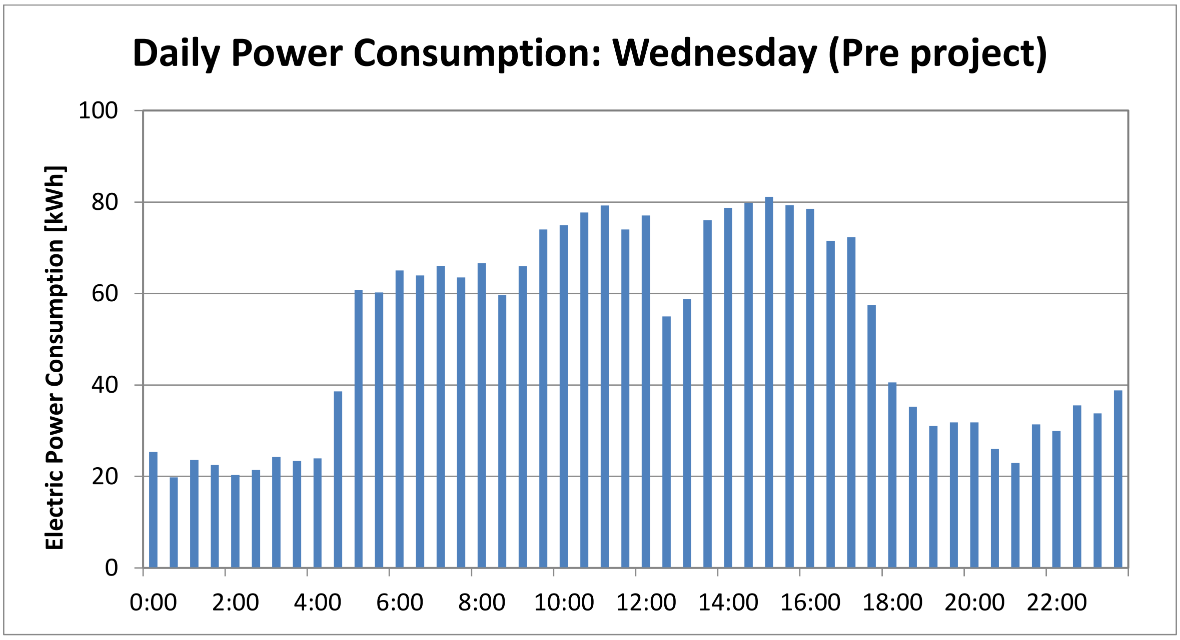

Figure 23 - Daily power consumption profile for pre project period

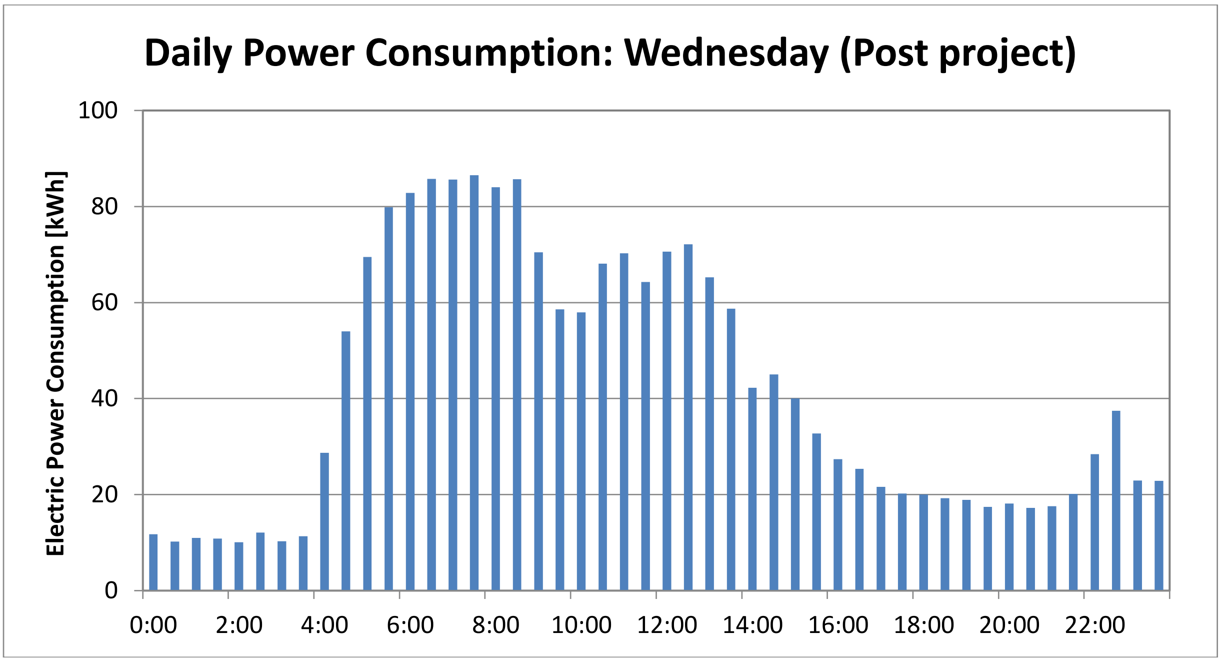

Figure 24 - Daily power consumption profile for post project period

Figure 25 shows the overall site power consumption profile along with production starting from August 2011 to present.

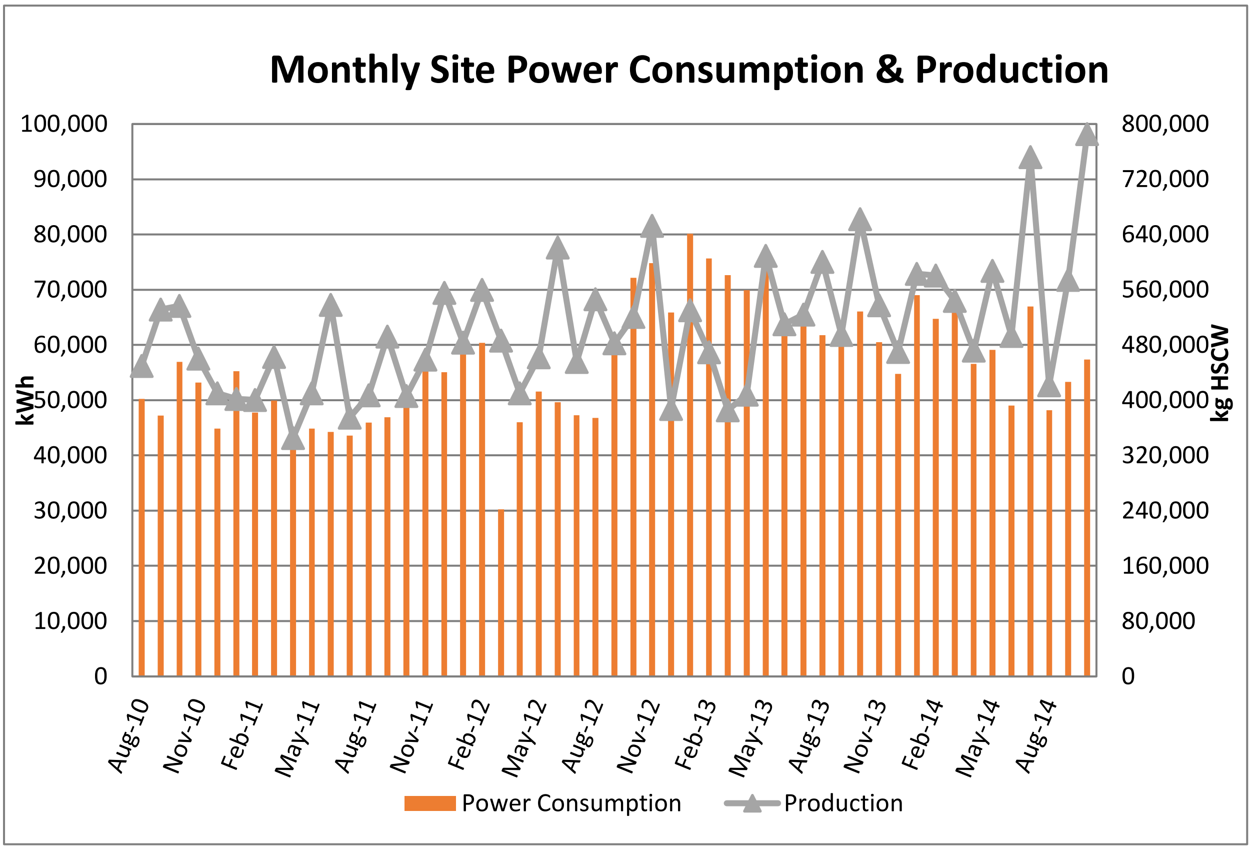

Figure 25 - Overall site power consumption and production profiles

Table 3 - Electricity savings per ton of HSCW processed - Based on total site power metering data

	Site electricity consumption	Tonnes of HSCW processed	MWh/tonne of HSCW processed	% Reduction in energy consumption per tonne
	[MWh]	**[tonnes]**	**[MWh/tonne]**	**[%]**
Four weeks in October 2013	58	525	0.1105	**28.8%**
Four weeks in October 2014	50	635	0.0787	

Note: Table 3 is a direct comparison of power consumption vs production during October 2013 and 2014 and is not calculated using the regression model. Although not a true representation of the energy savings, the results are still indicative because the production activity is one of the most critical factors influencing power consumption.

The above results indicate significant electricity savings due to the implementation of the project. Electricity savings were measured on one month. Further measurement on a longer period would be required to achieve greater accuracy on the electricity savings.

7.2.2. LPG

The LPG consumption savings has been analysed over 4 months from October 2014 to January 2015. During those 4 months, a reduction of 10% in LPG consumption was observed. It has been assumed that the trend remain the same for the rest of the year.

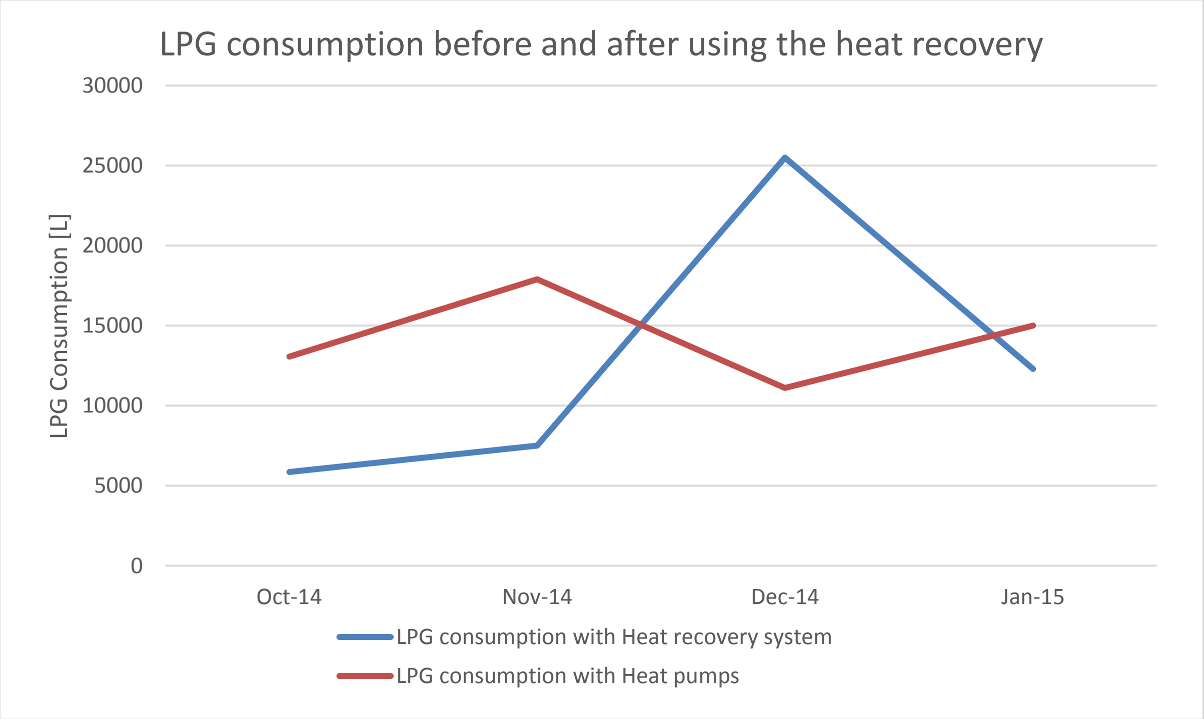

Figure 26 - LPG consumption savings

An analysis of the LPG consumption for the remaining of the year would accrue the accuracy of the calculated savings.

Table 4 - LPG savings per ton of HSCW processed - Based on total LPG Consumption Bills

	Site LPG consumption	Site LPG consumption	% Reduction in energy consumption per tonne
	[L]	**[GJ]**	**[%]**
October 13- September 14	57,068	1,484	**10.4%**
October 15 – September 15	51,141	1,330	

7.3. Project Costs and ROI

Table 5 - Energy savings, project cost and ROI

Scenario description	Annual Energy Savings	Annual Gas Savings	% savings in total site energy consumption	Annual Energy Cost Savings (excl GST)	Other cost savings (excl GST)	Total Capital Cost (excl GST)	Annual GHG Savings	Simple Payback
	[MWh]	[GJ]	[%]	[$]	[$]	[$]	[Tons of CO_2]	[Years]
Actual	163	447	37.5%	$34,694	$17,000	$850,000	194	16.4
With CTIP Funding	163	447	37.5%	$34,694	$17,000	$625,000	194	12

Although the paybacks appear to be very long, investing into a two-stage ammonia refrigeration system is a future proof investment for Ryan Meat Company as:

- Electricity price is likely to increase, reducing the overall payback time.
- Ammonia will not be affected by a carbon emission trading scheme and the refrigerant phased-out. Therefore, the additional savings due to the use of a natural refrigerant compared to synthetic refrigerants would increase over time as the price of synthetic refrigerant is likely to increase considerably.
- Production losses due to equipment failure is less likely to happen as industrial refrigeration equipment is more reliable and better monitored than commercial refrigeration
- Further energy savings can be achieved by optimising the controls.

8. CONCLUSION

Implementing alternatives to existing Freon refrigeration plants can reduce electrical energy consumption, gas consumption (if heat recovery is implemented) and also bring associated savings due to the use of natural refrigerant.

Direct ammonia refrigeration systems usually require high capital cost as well as proper design, however the benefits associated are important and can contribute to alleviate financial risk for small to medium sized meat processor such as:

- Energy cost
- Equipment breakdown and production loss
- Exposure to any carbon or emission trade scheme

In the case of Ryan Meat Company, the replacement of their multiple commercial refrigeration units by a centralised two-stage ammonia plant was a success, resulting in energy savings of 37.5% of the total site consumption. The new system also allowed Ryan Meat Company to comply with the export refrigeration requirements.

9. APPENDIX: SUPPORTING CALCULATIONS

OVERALL INPUT DATA

- Greenhouse emission / electrical power emissions factor: 1.19 [ton CO_2/MWh]

ASSUMPTIONS

- There is no major change in the refrigeration plant arrangement during the considered pre-implementation period (6th May 2013 to 27th April 2014), which allows a consistent plant performance during this period.
- The product processed each week has the same properties (i.e specific heat etc), which implies the refrigeration load only depends on mass of product and ambient conditions. This is the main reason why the pre-implementation period for developing the regression model considered the time after the site stopped processing beef.
- Energy savings per kg HSCW during other periods of the year is the same as the considered post-implementation measurement period of 6th October 2014 to 2nd November 2014 .

MULTIPLE VARIABLE REGRESSION MODEL

In this report, the actual annual energy savings were obtained based on a multiple variable regression model which was developed using Microsoft Excel. The formula of the regression model is shown below:

$$\begin{aligned} Power\ (kWh) = 3151.68 &+ 0.0000926337 Product(kg\ HSCW) \times Tdb(℃)^2 \\ &- 0.00307492 Product(kg\ HSCW) \times Tdb(℃) + 0.113034 Product(kg\ HSCW) \end{aligned}$$

Where Tdb = Ambient dry bulb temperature

HSCW = Hot Standard Carcase Weight

Electrical savings [MWh p.a.]

- Detailed in earlier sections of this report

Total annual cost savings [$ p.a.]:

For this site, the total annual cost savings are considered to be:

- Annual cost savings due to reduced energy consumption
- Maintenance/Other cost savings.

Project costs [$]:

- As per project costing

Payback period [years]:

- Ratio of Project costs to total annual cost savings

GHG Savings [ton CO_2 p.a.]:

For this site, the total greenhouse gas savings are considered to be:

- Annual electrical consumption savings multiplied by emissions factor specified above.