final report

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Engineering Services to Develop Refrigeration Plant Efficiency Improvements

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Executive Summary

Minus40 was engaged by a Queensland based abattoir to conduct a Refrigeration Plant Energy Efficiency Study of their facility.

Site investigations and subsequent analysis have identified a range of energy saving opportunities. Capital costs are based on contractor budget pricing. A tender process is recommended to obtain project costs to a higher level of accuracy.

Based on site observations, data analysis and discussion with the abattoir, Minus40 recommends the following options to improve the abattoir's energy efficiency and performance:

1. Variable head pressure and condenser fan speed control
2. Compressor staging and capacity control
3. Condensate sub-cooling by screw compressor economiser.
4. Switching load from old Ammonia plant to new Ammonia plant

The overall outcome for implementation of the above recommended energy saving opportunities is summarised as follows:

Annual Electricity Savings [MWh]	Annual Maintenance Cost Savings [$]	Annual Energy Cost Savings1 [$]	Annual Total Cost Savings [$]	Total Capital Cost [$]	Annual GHG Savings2 [Tons of CO2]	Simple Payback [Years]	10 Years IRR/NPV3 [%] / [$]
1,650	190,000	148,500	338,500	1,846,731	1,650	5.46	13 / 58,812

[1] The indicated energy cost savings are based on current electricity unit costs paid by the abattoir for this site. Impending increase in costs have not been considered. [2] Greenhouse / electrical power emissions factor (full fuel cycle emission) for Queensland: 1.00 tCO2-e/MWh, published data by ***Department of Climate Change and Energy Efficiency***. [3] NPV is calculated at 12% discount rate.

The outcomes of the project were:

- Reduction in energy use and costs (expected to be significant in terms of electricity use).
- Reduced Scope 2 Greenhouse Gas emissions (expected to reduce CO_2 emissions by upwards of 3,000 tonnes per annum)
- Gaining of data to support similar projects at other plants.
- The information obtained will provide indications of potential energy reductions and emissions reductions able to be achieved for similar projects.

Site investigations and subsequent analysis have identified a range of energy saving opportunities. Capital costs are based on contractor budget pricing. A tender process is recommended to obtain project costs to a higher level of accuracy.

Contents

1 Background

1.1 Introduction

Industrial refrigeration plants are substantial users of energy. Often, the power consumed by the refrigeration systems constitutes the major portion of total site electrical use. Furthermore, many such systems were designed, built and/or otherwise extended with functionality and installation costs in mind, where little consideration was given to operating costs or environmental impact.

Minus40 has been commissioned by the abattoir to investigate potential energy efficiency opportunities on the refrigeration plant. This involves identifying applications for energy saving technologies and developing a business case for the implementation of these energy efficient industrial refrigeration technologies.

There are financing and funding options currently available to reduce capital costs for energy saving projects. To avail these, it is required that project costs be determined to a high level of accuracy which is possible by obtaining firm contractor pricing for the proposed projects.

1.2 Project Description

The inefficiency of the refrigeration system at the abattoir site arises in part due to the three separate refrigeration systems which are currently being operated. An old engine room consisting of dated technology supplies cooling to various chillers on site. This plant is currently taking much of the refrigeration load and accounts for most of the electrical energy usage on the site. A second modern engine room provides refrigeration to the coldstore facilities. This engine room, despite employing modern technology, is currently running below capacity to a point where it is also not operating efficiently.

A third (R22) refrigeration system is also operating on the site with this system supplying cooling to various part of the plant. R22 refrigerant is a potent greenhouse gas and is to be phased out. Under the current Government's timetable, R22 will be subject to tax according to its potency making this gas (which is only likely to be available by reclamation) extremely expensive. On this basis the R22 plant will not be viable in the long term and this project is likely to lead to the decommissioning of this cost inefficient and environmentally unsupported technology sooner rather than later.

Preliminary indications are that significant efficiencies could be gained by amalgamating the three separate systems into one modern refrigeration plant. This will allow the old inefficient plant to be decommissioned and for the elements of the single refrigeration plant to be better matched to the variable refrigeration loads across the processing plant. Under this scenario it would be expected that the refrigeration plant will be able to operate in a more efficient and stable manner.

In order for the abattoir to achieve the outcomes that it seeks and to maximise the efficiency gains and emission reductions, there is a need to further assess the current refrigeration plant loads and performance. This further assessment will allow preliminary design and costing of an improved refrigeration system.

1.3 Project Purpose

The purpose of the project is to demonstrate energy efficiency opportunities for the abattoir. The outcomes of this project will inform industry as to the cost benefit of various aspects of upgrading and modification of refrigeration plants.

1.4 Project deliverables

Upon completion of these services, Minus40 is to have delivered to site a Report, in which projects applicable to the site are presented, and completed Low Carbon Australia (LCA) and/or Clean Technology Innovation Program (CTIP) applications.

Recent Commonwealth government policy changes resulted in the closure of CITP, and integration of LCA into the Clean Energy Finance Corporation (CEFC). The CEFC is building on energy efficiency programs established by LCA to improve access to finance, so that organisations in all sectors can take advantage of the energy productivity gains and cost reductions available through implementing more efficient and cleaner technologies.

Applications derived from this project will be submitted to the CEFC. The report, delivered prior to preparation of CEFC applications will contain at least:

- **Description of proposed upgrade:** An overview of the projects, underlying energy saving principle(s), relevant site observations, scope for improvement, and applicability to site.
- **Energy Saving Opportunities:** The individual energy saving opportunities relating to the project.
- **Project Options:** Options for and representations of the project, where applicable.
- **Project Costing:** Projects selected during interim meeting will undergo scoping and coordination with contractors to establish firm budget costs.
- **Project Figures:** As follows:
    - **Electrical energy savings:** Electrical consumption savings are determined by the difference in calculated hourly electrical

consumption between the existing and proposed upgrade(s) of the business case.

  - **Electrical cost savings:** The site electricity tariff structure is included into the business case modelling. This includes peak, off peak and shoulder consumption (kWh) and demand (kVA) charges.
  - **GHG savings:** Annual greenhouse gas emission savings are based on electrical energy (consumption) savings as well as anticipated reduction in Freon refrigerant leakage (if applicable).
  - **Payback period:** The ratio of project costs to combined cost savings.
  - **IRR / NPV:** 10 year internal rate of return and net present value of a project.

The CEFC applications will contain the following additional technical material, in addition to other content and attachments required by CEFC:

- **Calculation methodology:** Detailed description of engineering calculations and modelling used to determine the energy and carbon savings achievable with each project.
- **Baseline determination:** Strategy for recording a representative energy baseline for the refrigeration plant for current operating/ambient conditions and production loads
- **Savings Verification strategy:** Methodology for quantifying achieved energy savings post-implementation even where ambient/climatic conditions and production loads have changed

2 Project Objectives

The objective of the engineering services is to prepare the requisite supporting technical and commercial project information, conduct project planning and to prepare applications for federal government support in implementing energy efficient upgrades and/or extensions at your site, under the following federal programs:

Australian Government

CLEAN ENERGY FINANCE CORPORATION

The Clean Energy Finance Corporation (CEFC), established by the Clean Energy Finance Corporation Act 2012, is dedicated to mobilising private sector and its own $10 billion capital into growing renewable energy, low-emission technology and energy efficiency projects and technologies in Australia.

The processes developed by Minus40 to:

- identify feasible energy savings projects,
- quantify annual energy and carbon savings for each project,
- establish a reference pre-project energy consumption baseline, and

- verify achieved savings post-project, even where production and climatic conditions have changed, and
- fully satisfy stringent CEFC requirements and ensure smooth passage of the application/s.

The desired outcomes of the project are:

- Reduction in energy use and costs (expected to be significant in terms of electricity use).
- Reduced Scope 2 Greenhouse Gas emissions (expected to reduce CO_2 emissions by upwards of 3,000 tonnes per annum)
- Gaining of data to support similar projects at other plants. The information obtained will provide indications of potential energy reductions and emissions reductions able to be achieved for similar projects.

3 Methodology

The scope of work was conducted in the following stages:

3.1 STAGE 1: REFRIGERATION PLANT INSPECTION

Inspection and observation of refrigeration plant in operation and identification of issues such as:

- piping and wiring layouts
- stock take of existing refrigeration plant components
- opportunities for improved plant energy efficiency
- mechanical installations which will limit or hinder plant efficiency or control upgrades
- condition of refrigeration plant equipment.

Coordinating with site staff and/or refrigeration contractor(s) to cover items including but not limited to the following:

- obtaining information on plant behaviour, maintenance issues and history
- acquisition of relevant plant and equipment documentation, such as manuals, maintenance records and electrical, site and refrigeration schematics
- planning the acquisition of operating plant data, such as slide valve positions, room temperatures, plant pressure and motor current data, for further analysis
- acquisition of energy bills, prior energy audit reports and production data.

3.2 STAGE 2: PLANT MONITORING AND DATA ACQUISITION

Plant operating data may be acquired using site based SCADA equipment, equipment provided by Minus40, or a combination of both. This is to be determined by Minus40 and site during site inspection period. Minus40 equipment will be installed during inspection period and will be removed and returned to Minus40 by client personnel (who will be briefed by Minus40 engineers).

We have made an allowance for external costs to extract SCADA data and for additional rental of monitoring equipment, as required. Actual costs as incurred will be charged to the client.

3.3 STAGE 3: DATA REVIEW, MODELLING, PRELIMINARY COSTING AND INTERIM CONSULTATION

Review of documentation and data obtained from site, which involves:
- checking validity of data obtained from site and sorting data
- determining the behaviour of the plant (basic functional description)
- identifying shortcomings in plant operation and control
- establishing upgrade concepts
- designation and/or elimination of potential mechanical and controls upgrades projects
- planning further analysis work of suitable upgrade concepts

Modelling tasks include:
- Derivation of compressor and refrigeration equipment analysis models using manufacturer software / literature
- Derivation of existing and proposed refrigeration plant analysis models
- Acquisition and sorting of local weather data
- Derivation of existing and proposed plant duty and operating profiles using plant data.
- Running and cross checking of analyses of existing plant and suitable upgrade concepts
- Calculation of energy consumption, electrical demand, energy saving and cost savings.

NB: The modelling techniques used determine baseline, i.e. observed refrigeration plant duty and energy consumption as well as predicted refrigeration plant duty and energy consumption for each proposed upgrade scenario. Proper consideration of these profiles is critical given that plant production and ambient weather conditions are continuously variable and “normalisation”, achieved by means of modelling, is needed to determine effective savings. An effective savings is the difference in energy consumption between whether a prospective project was conducted or not, which in turn justifies the implementation of the project.

Preliminary Costing and Interim Consultation, which involves:

- Internal costing based on estimates and previous quotes to establish approximate project costs
- Preparation of an interim presentation
- Communication with site and/or refrigeration contractor(s) to discuss modelling results and to determine the viability of proposed upgrade concepts.

3.4 STAGE 4: PROJECT COSTING AND SCOPING

Based on the outcomes of the Interim Meeting, worthwhile projects are to be scoped and costed, this involves:

i. preparation of Mechanical and Electrical Enquiry(ies); i.e. project work scope documents
ii. work scope documents to have sufficient detailed to be submitted to site contractor(s) for budget pricing
iii. communication with contractors to obtain and query relevant budget pricing
iv. for projects where it has been decided not to obtain contractor pricing, costing to be conducted by Minus40, with inclusion of quotations on lead items

3.5 STAGE 5: REPORT COMPLETION AND DIRECTIONS MEETING

All findings will be compiled into a report for submission to site. This involves:

- compilation of findings for input into Report
- revision of figures that use costs established at Stage 4
- review of Report to checking content, work scopes, costings and final figures
- submission of Report to site.

Final meeting to discuss:

- final selection of projects for implementation
- next steps toward applying for CEFC support - Stage 6.

Note: The formal report completed in this stage is an important and requisite attachment to the subsequent CEFC application/s.

3.6 CEFC APPLICATION PROCESSES

Prepare finance application and submit CEFC application. Prepare supporting engineering documentation, including

- Energy savings methodology description
- Energy baseline determination

- Post-implementation energy savings verification
- Collate supporting documentation for CEFC application, including
    - Financial reports
    - Company profile
    - Importance of project to company business
- Compile available information into CEFC application format.
- Respond to additional RFIs from CEFC post-submission as required.

4 Results

4.1 Description of Refrigeration Plant

The site consists of three independent refrigeration plants:

4.1.1 R22 Refrigeration Plant

This plant has 2 reciprocating compressors providing the cooling capacity for all boning and packaging areas. Heat rejection is achieved via 1 evaporative condenser. R22 in “direct expansion” mode is used to maintain the room temperature around 10^{o}C.

Considering the age of this plant, it has become unreliable and very expensive to maintain due to the carbon tax scheme. Besides, R22 is ozone depleting and has been scheduled for phase-out.

Figure 1: R22 Reciprocating Compressor.

Figure 2: R22 Evaporative Condenser.

4.1.2 Old Two Stage Ammonia Refrigeration Plant

This plant has five reciprocating compressors and four screw compressors providing the cooling capacity (-10°C for high stage and -40°C for low stage) for the freezer store, the blast chiller and the new hot beef chillers. Heat rejection is achieved via three evaporative condensers. Liquid ammonia is pump-circulated to the flooded type evaporators of various areas. Ammonia in “gravity flooded” mode is also used to cool the spray water which is in turn is used for hot carcass spraying.

This plant is running fully loaded most of the time and having difficulty meeting the requirement during hot days in summer. All the compressors and motors have dramatically degraded and become inefficient and unreliable, which poses a risk to the continuity of production.

Figure 3: Old Plant Reciprocating Compressors

Figure 4: Old Plant Evaporative Condensers.

4.1.3 New Two Stage Ammonia Refrigeration Plant

This plant has four screw compressors providing the cooling capacity (-8°C for high stage and -35°C for low stage) for the coldstore. Heat rejection is achieved via two evaporative condensers, which are variable speed driven. Liquid ammonia is pump-circulated to the flooded type evaporators.

This plant has only been in operation since 2008, and most of the time it only operates with very low refrigeration load, which is very energy inefficient.

Figure 5: New Plant Screw Compressors**.**

Figure 6: New Plant Evaporative Condensers**.**

4.2 Energy Consumption - Baseline

Minus40 has prepared an energy consumption analysis that covers the site's refrigeration and production plant. For the purpose of this analysis, Minus40 has obtained electricity invoices from site and 30-minute power consumption interval data from the site's energy management company.

Area	Annual Electricity Consumption MWh	Annual Electricity Costs $	Annual GHG t CO_2	Average Electricity Cost $/MWh
Old Plant - NMI: QB02649993 + New Plant – NMI:VV3120023671	**21,671**	**1,953,018**	**21,671**	**$90.12**
Refrigeration Plants[1]	**8,907**	**802,698[2]**	**8,907**	**$90.12**

Table 1: Energy baseline

Note: The refrigeration plant power consumption is recorded by the two national meter identifiers (NMIs) mentioned above, which also record power consumption of other users. From the analysis conducted, the refrigeration plant therefore represents approximately 41% of the power consumption recorded by the two NMIs

4.3 Energy consumption analysis

The 24 month period between June 2010 and May 2012 has been used for the purpose of this analysis.

4.3.1 24 Months Power Consumption Profile

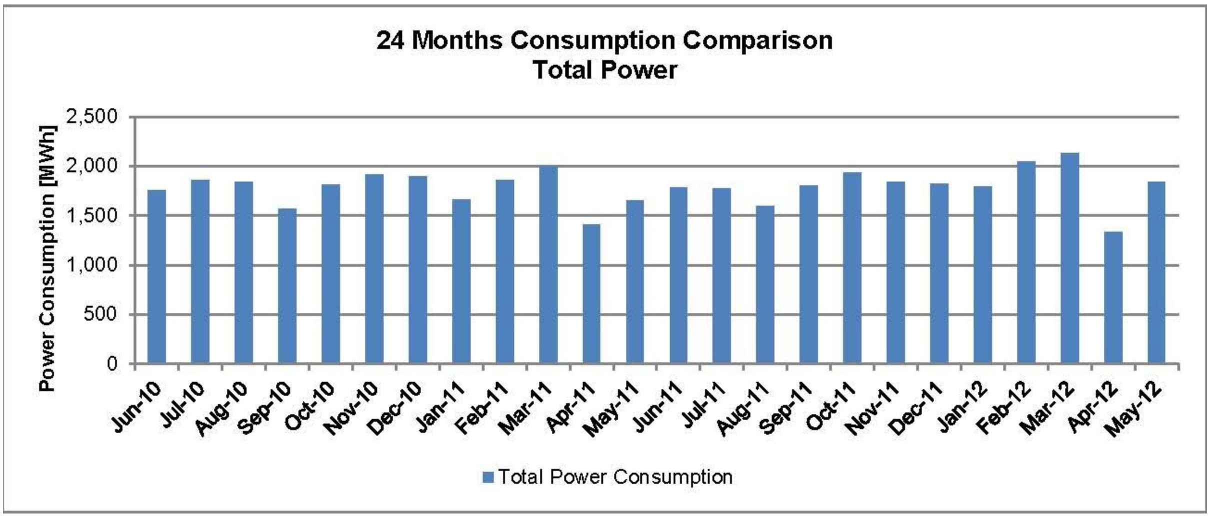

Figure 7: Total Power Consumption Comparison

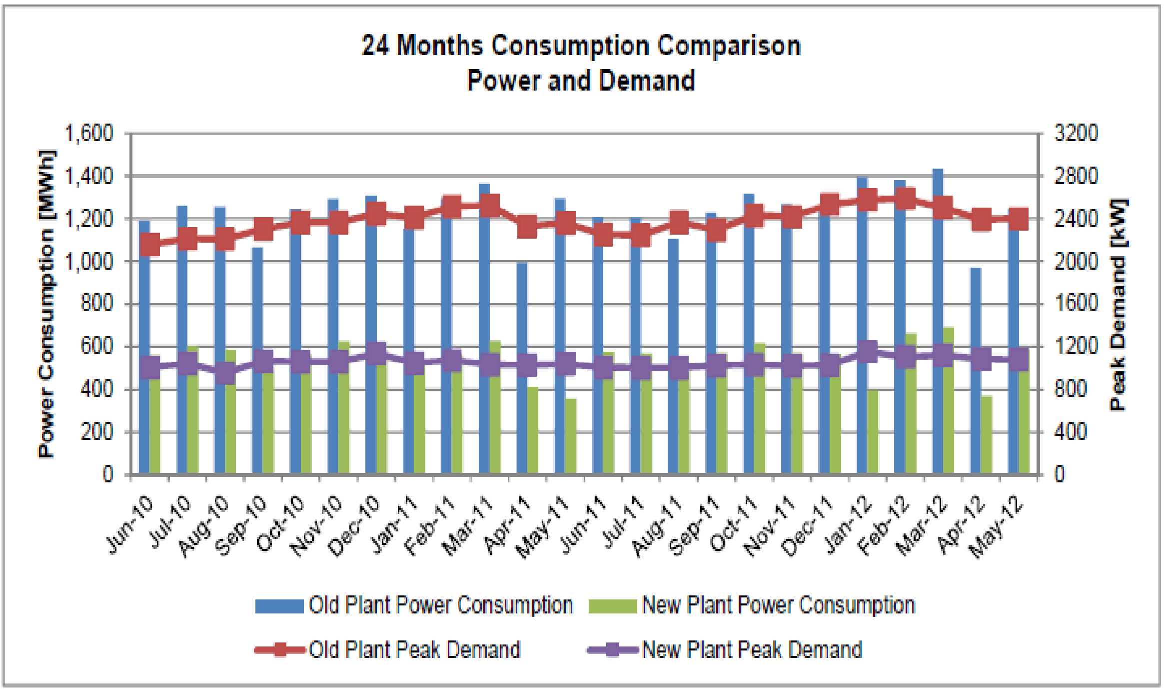

Figure 8: Power Consumption and Demand Comparison 24 Months

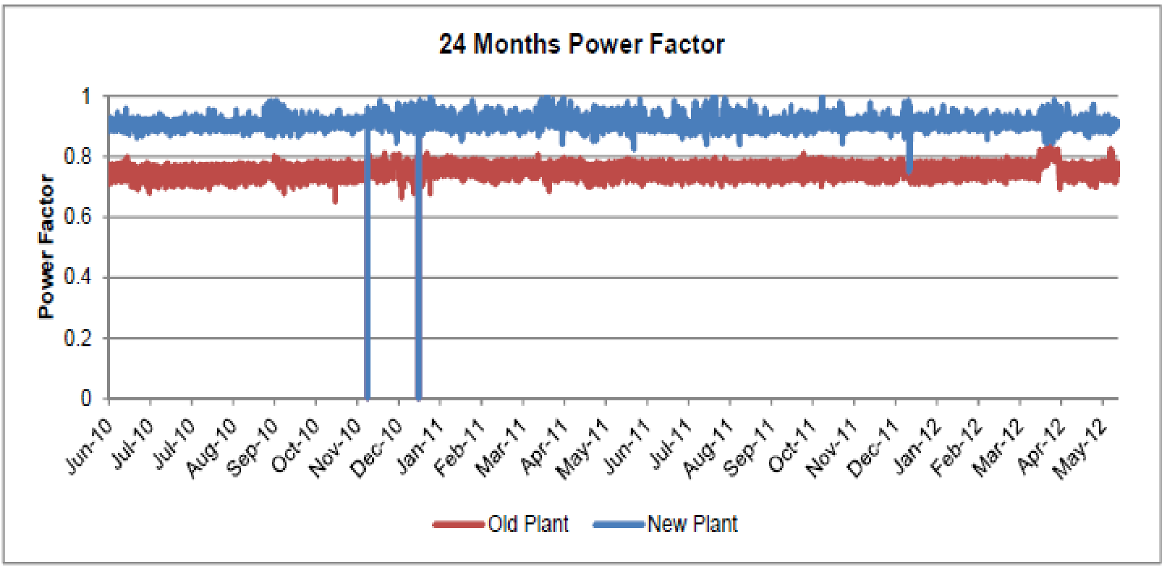

Figure 9: Power factors

4.3.2 *Weekly Comparison*

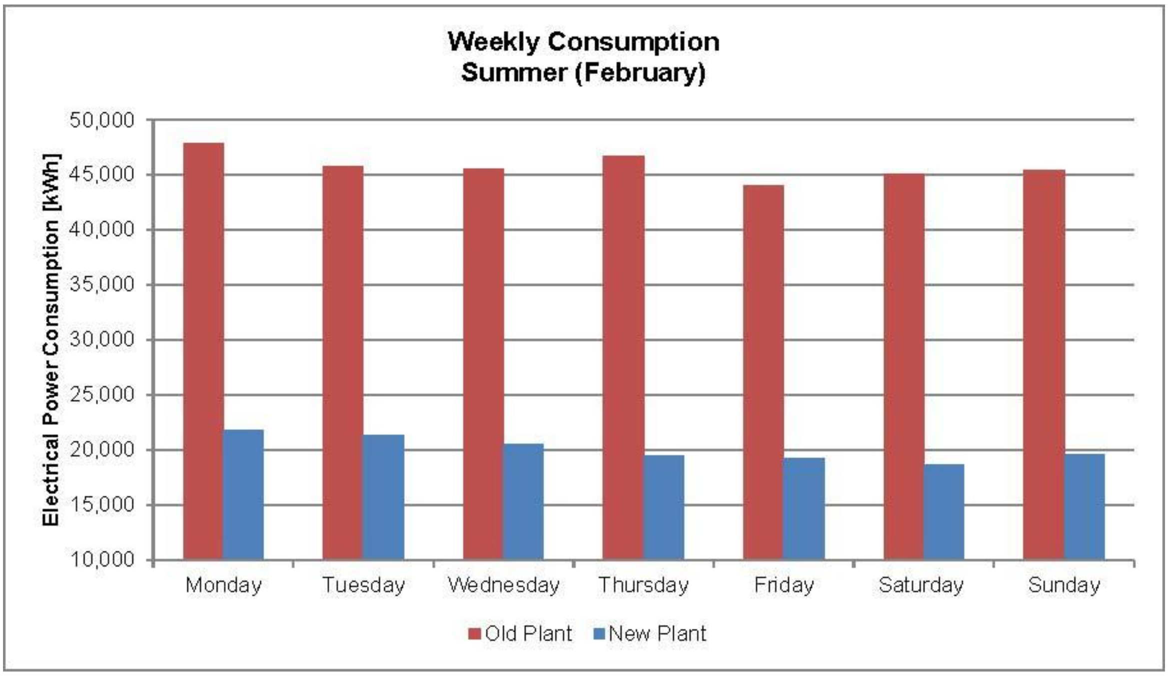

Figure 10: Weekly comparisons - Summer average

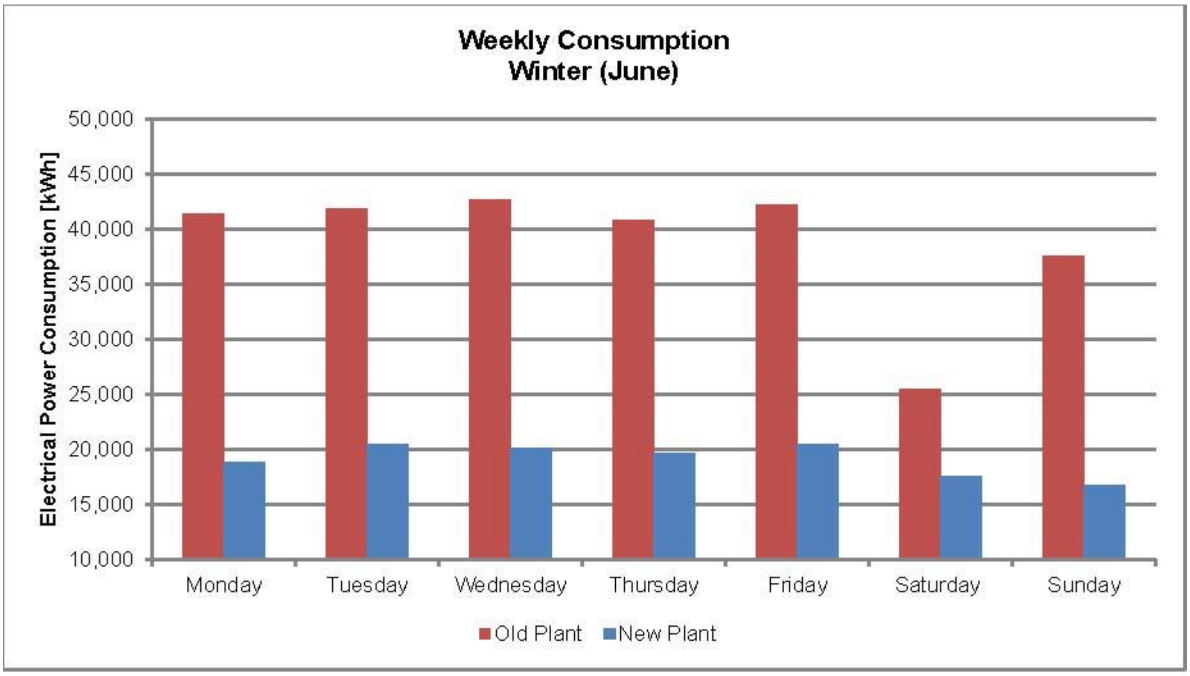

Figure 11: Weekly comparisons – Winter average

4.3.3 Daily Comparison

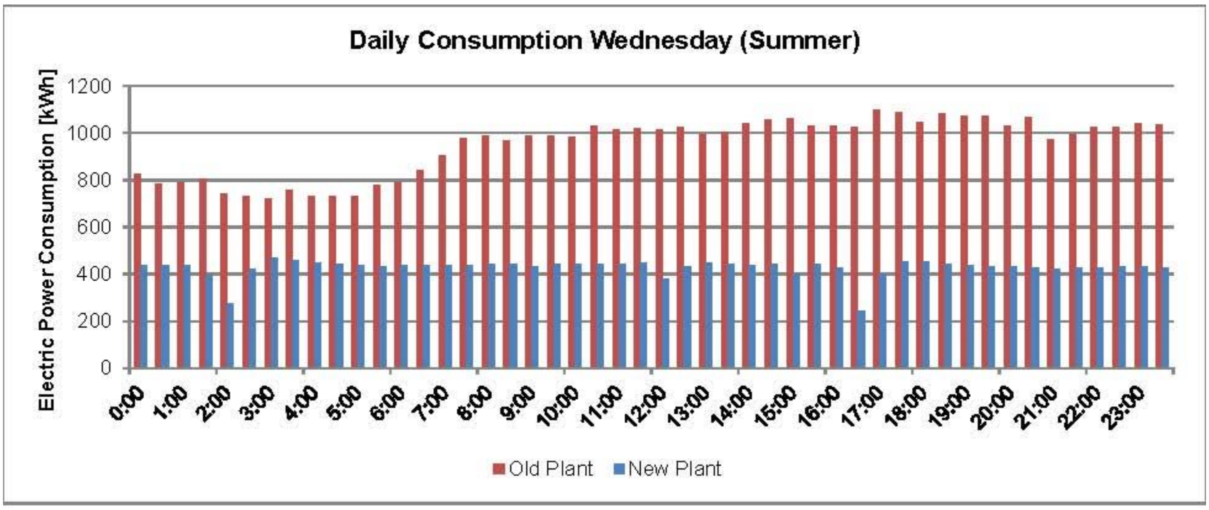

Figure 12: Daily Consumption – Summer Workday average

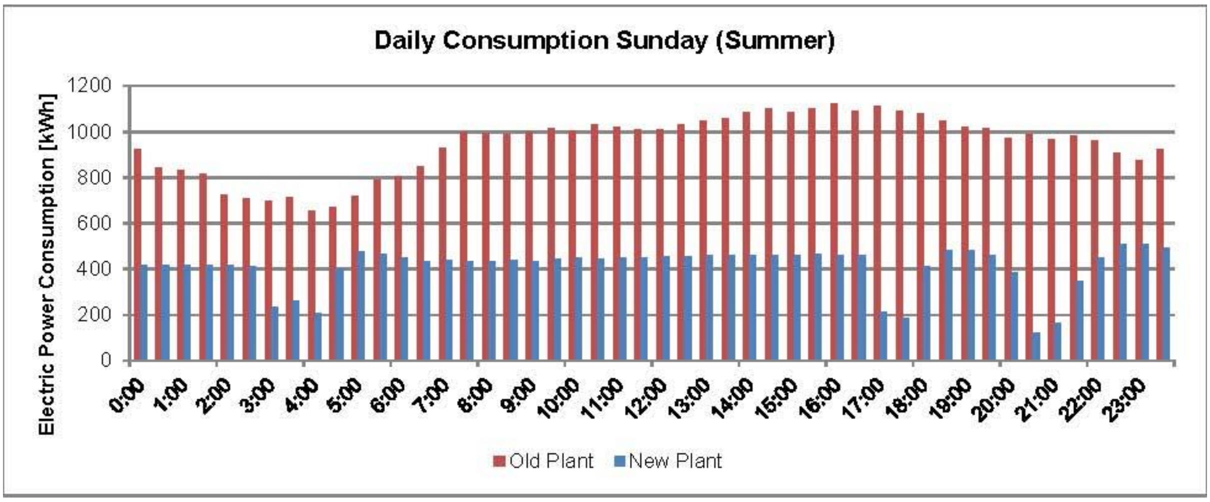

Figure 13: Daily Consumption – Summer Weekend average

4.3.4 Power consumption and demand ratio

Figure 14 shows that both old plant and new plant are more power consumption driven rather than demand driven, which means more attention should be paid to reduce the power consumption instead of demand.

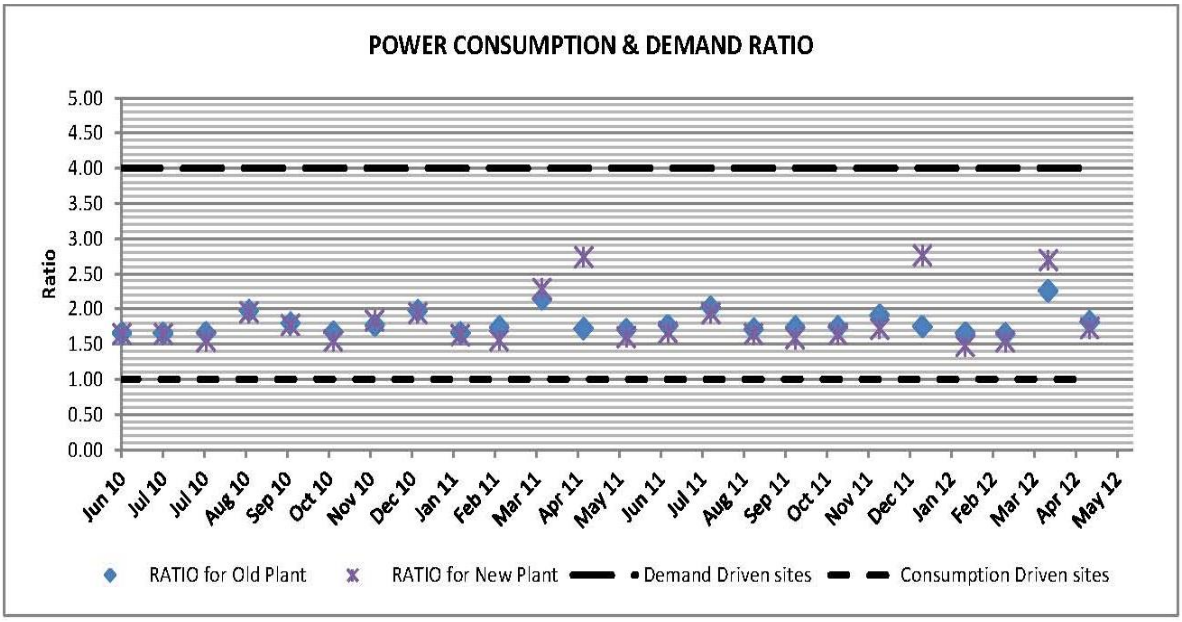

Figure 14: Power Consumption and Demand Ratio.

4.4 Key Performance Indicators

Table 2: Total energy consumption

Indicator	Electricity Consumption (kWh/kg)
Total Energy Consumption per Hot Standard Carcass Weight[1]	**0.26**
Refrigeration Energy Consumption per Hot Standard Carcass Weight[2]	**0.08**

1

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[1] This is calculated based on two weeks of refrigeration plants operation data analysis, which includes compressors, liquid pumps and condenser fans.

[2] Energy costs calculated based on $/MWh value determined for the two NMIs in consideration

5 Energy Savings Opportunities

5.1 Variable Pressure and Condenser Speed Controller

5.1.1 Principle of operation

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 variable speed drives (VSDs). 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.

The scope for improvement lies in implementing VHPC on the ammonia plant in conjunction with condenser fan speed control. 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) has to be implemented to realise maximum energy savings.

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.

5.1.2 Observations

Figure 15 shows the variation in new plant discharge pressures over two weeks. It is evident that discharge pressures are in the range of 875-1000 kPa during normal operation but as high as 1,200-1,400kPa for defrost. The control system has been set-up such that the all three fans turn on at 1,000 kPa and off at 875 kPa Therefore, the plant does not run at head pressures below 875 kPa. All fans are currently speed controlled by VSDs and energy savings potential exists, especially during cool weather.

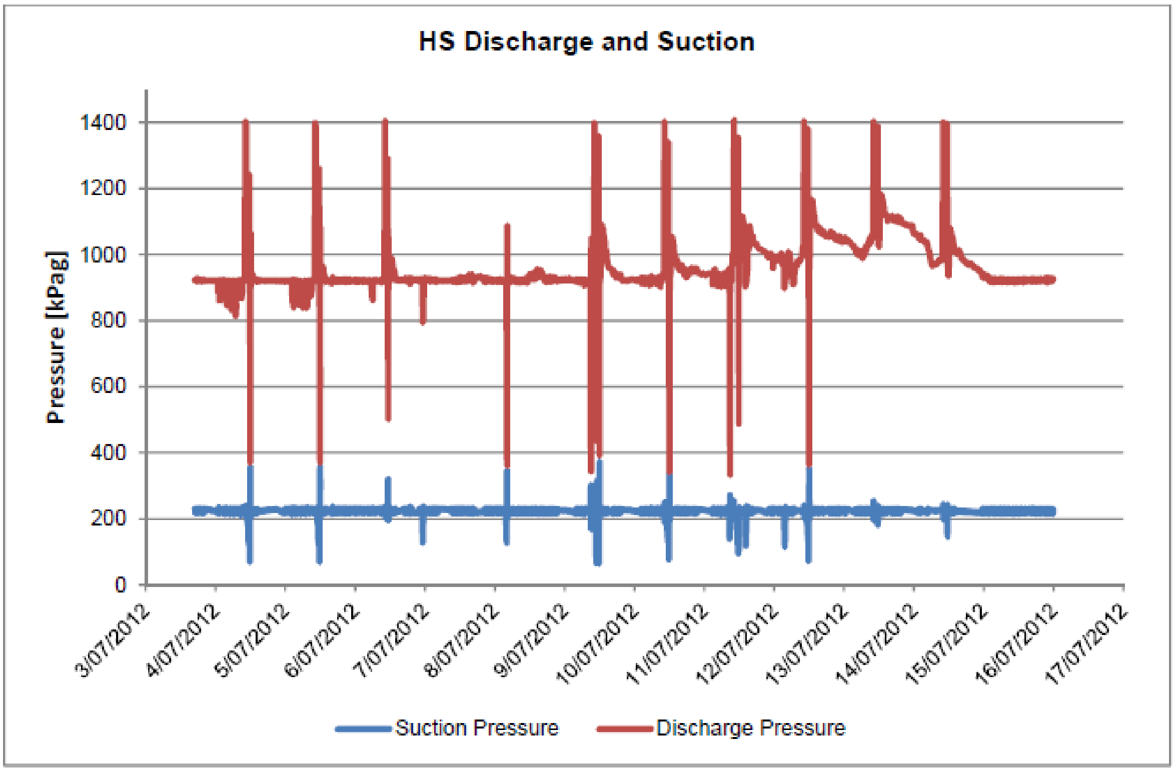

Figure 15: New Plant Discharge and Suction Pressure

5.1.3 Actions Required

The project involves:

- Installation of ambient dry bulb temperature and humidity sensor on site
- Installation of VSD for the new evaporative condenser described in Section 4.4, which will be added for the load switched from old plant room
- Implementation of variable head pressure and condenser fan speed control strategy

5.1.4 Project Costs

Major equipment including installation, commissioning cost has been obtained from a refrigeration contractor. Minor equipment pricing has been taken from list prices provided by suppliers. Mechanical/electrical/programming costs have been estimated. Cost breakdown is provided below (Table 3). Accuracy of estimation of capital costs is expected to be around ±20% due to the size and nature of the proposed project.

DETAILED COST BREAKDOWN			
Sl No	**Equipment**	**Cost (excl GST)**	**Comments**
Equipment			
1	Sensor	$2,000	Estimation, Ambient dry bulb and humidity sensor
2	Sensor Cable	$380	Olex multi core sensor cable - 100m in total
3	Evaporative Condenser Fan VSD	$8,000	1 x 22kW VSD for the new evaporative condenser
4	PLC hardware upgrade	$2,000	Estimation for additional I/O cards
5	Wiring Consumables	$500	Estimation
	Equipment sub-total	**$12,880**	
	Miscellaneous and unforeseen items	**$1,932**	Estimation, Equipment delivery costs and other costs, approx. 15% of Capital Equipment
	Total: Equipment	**$14,812**	
Labour			
Electrical contractor			
1	Design - Update of the single line diagrams	$720	Estimation, $90p/h * 1d
2	Sensor wiring	$1,080	Estimation, $90p/h * 1.5d
3	PLC & SCADA programming: head pressure and variable fan speed control logic	$6,000	Estimation, $150p/h * 5d
4	VSD drive configuration	$600	Estimation, $150p/h * 0.5d
5	Other works	$1,260	Estimation, 15% of all previous works
6	Travel Expenses & Stay Away Cost	$2,986	Estimation, Local contractor will be used for wiring and a PLC programmer from Sydney
	Electrical contractor sub-total	**$12,646**	
Engineering and Project Management			
1	Functional Description of the control logic	$5,760	Estimation, $180p/h * 4d
2	Project management and supervision	$2,880	Estimation, $180p/h * 2d,
3	Verification and optimisation of controls	$1,440	Estimation, $180p/h * 1d
4	Travel Expenses & Stay Away Cost	$1,372	Estimation, 1 day at site by 1 engineer
	Engineering sub-total	**$11,452**	
	Sub-Total: Labour	**$24,098**	
TOTAL		***$38,910***	

Table 3: Detailed cost breakdown (Variable Pressure and Condenser Speed Controller)

5.2 Compressor Staging and Capacity Control

5.2.1 Principle of operation

Considerable energy savings can be achieved on an industrial refrigeration plant by variable speed control of screw compressors, especially during part load conditions.

Conventionally industrial screw compressors unload via the slide valve and thus consume considerable amounts of energy at part load conditions. Screw compressors running unloaded for considerable amounts of time lead to substantial and unnecessary energy consumption. This is explained as follows:

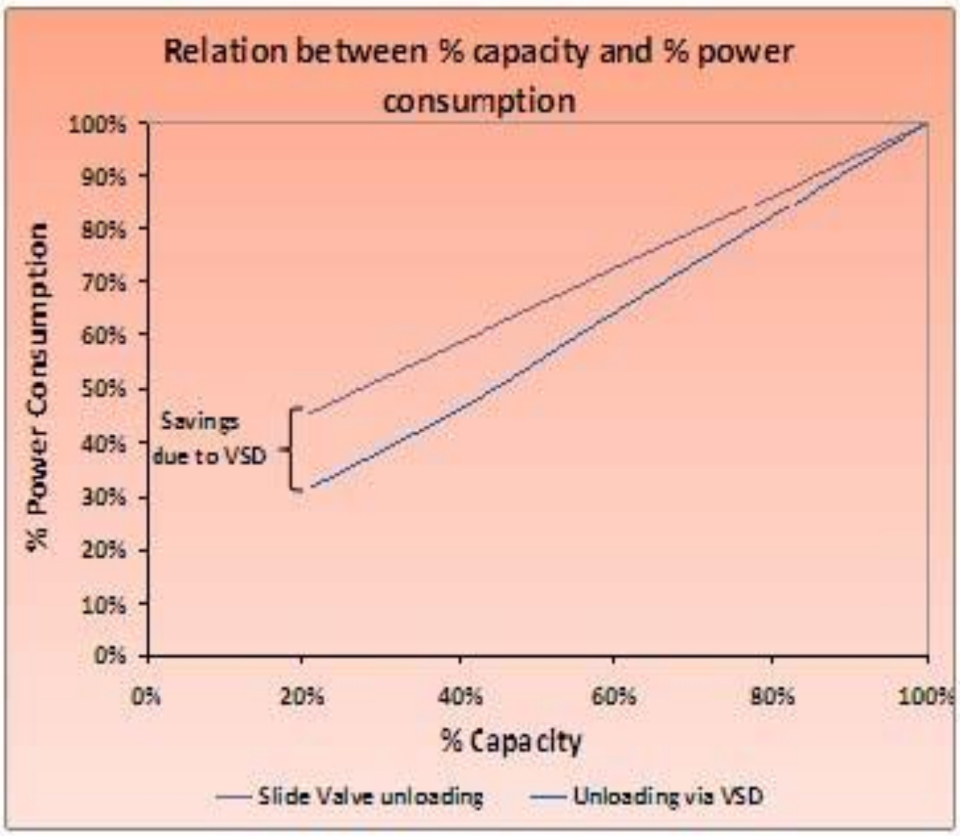

Figure 16: Slide Valve Modulating vs VSD Modulating

Most industrial screw compressors unload via their slide valve and correspondingly their cooling capacity reduces. With slide control, the reduction in refrigeration capacity of a screw compressor relative to power consumption is disproportionate. For example, at 30% slide position, the refrigeration capacity of a screw compressor is approximately 40% whereas the power consumption is excessive at approximately 60%. The alternative to slide valve control is to use a VSD to modulate the capacity of a compressor. As indicated in Figure 16, the reduction in refrigeration capacity relative to power consumption is essentially equal, particularly between 40% and 100% refrigeration capacity.

On a multiple compressor plant, steps must be taken to stage compressors such that they run in their efficient range to the extent possible.

5.2.2 Observations

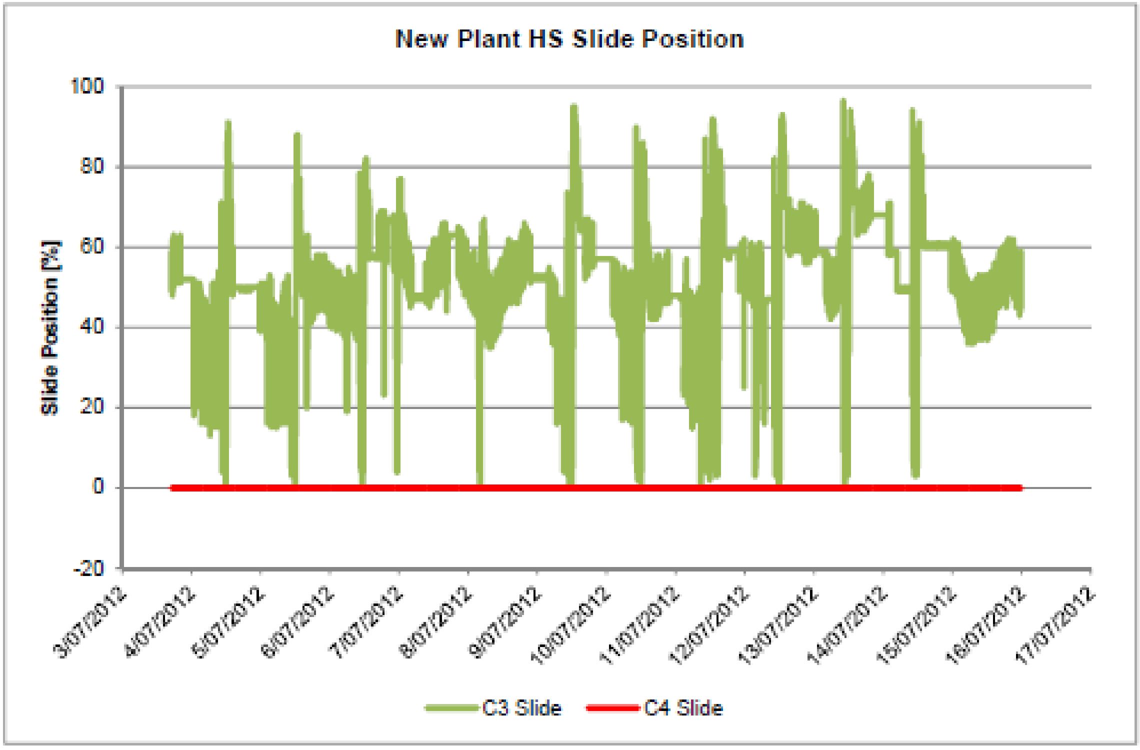

Figure 17: New Plant High Stage Compressor Slide Position

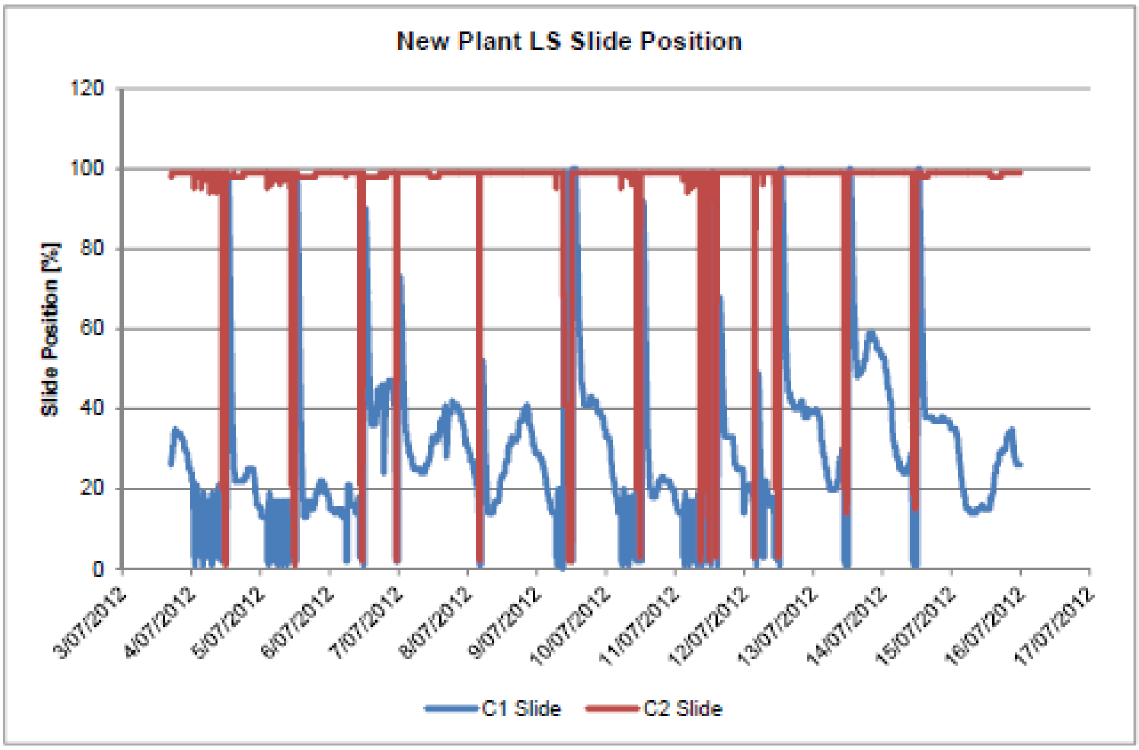

Figure 18: New Plant Low Stage Compressor Slide Position

Two Mycom screw compressors (C3, C4) are running as high stage compressors, C3 operates as lead compressor and C4 operates when the plant capacity requirement exceeds C3's capability. And two Mycom screw compressors (C1, C2) are running as low stage compressors, with the same setup as high stage compressors, all screw compressors are capacity modulated via slide valve. Figure 17 shows the high stage compressor slide position variation over two weeks. C3 unloads very often, during 95% of the monitoring period, slide position below 70%, with average of 48%. C4 did not run during the monitoring period. Figure 18 shows the low stage compressor slide position variation over two weeks, C1 operation is even worse, during 90% of the monitoring period, C1 slide position below 50%, with average of 25%. C2 was always at full slide position. Potentially significant energy savings exist on both high stage and low stage screw compressors, hence the purpose of this project is to set the compressors to operate at maximum possible efficiency, therefore save energy.

5.2.3 Actions Required

The project involves the following:

- Installation of a VSD on high stage compressor C3
- Implementation of compressor staging and capacity control logic minimising slide valve unloading to the extent possible for both high stage and low stage compressors including the new high stage and low stage compressors described in Section 4.4, which will be added for the load switched over from the old plant.

5.2.4 Detailed Costs Breakdown

Major equipment including installation, commissioning cost has been obtained from refrigeration contactor. Minor equipment pricing has been taken from list prices provided by suppliers. Mechanical/electrical/programming costs have been estimated. Cost breakdown is tabled below (Table 4). Accuracy of estimation of capital costs is expected to be around ±20% due to the size and nature of the proposed project.

Table 4: Detailed breakdown costs (Compressor staging and capacity control).

DETAILED BREAKDOWN			
Sl No	**Equipment**	**Cost (excl GST)**	**Comments**
Electrical and control equipment			
1	MT compressor VSD	$120,000	Estimation, 465kW, 415V, IP54, plant room mounted
2	VSD filters	$0	Additional filters to remove harmonics distortion not included
3	Additional VSD communication cards	$500	Estimation
4	Additional switch and safety gear	$5,000	Estimation, additional switch gear
5	Shielded Power Cable - Between compressor motor and VSD	$8,500	Olex - 10m, It is estimated that existing power cable can be reused between power

			board and VSD
6	Control and Instrumentation cable	$684	Estimation, 50m instrumentation and 50m data cable
7	Upgrade of motor bearings and brushes	$3,000	Estimation
8	LT compressor VSD - Mycom320VM	$50,315	Estimation, 225kW, 415V, IP54, plant room mounted
9	VSD filters	$0	Additional filters to remove harmonics distortion not included
10	Additional VSD communication cards	$500	Estimation
11	Additional switch and safety gear	$5,000	Estimation, additional switch gear
12	Shielded Power Cable - Between compressor motor and VSD	$1,300	Olex - 10m, It is estimated that existing power cable can be reused between power board and VSD
13	Control and Instrumentation cable	$684	Estimation, 50m instrumentation and 50m data cable
14	Upgrade of motor bearings and brushes	$2,500	Estimation
15	Wiring Consumables	$2,000	Estimation, cable trays and other installation materials as required
16	Lifting equipment hire	$3,000	Estimation
17	PLC upgrade	$10,000	Estimation for additional I/O cards, SW upgrade
	Electrical Equipment sub-total	**$212,983**	
	Miscellaneous and unforeseen items	**$31,947**	Estimation, Equipment delivery costs and other costs, approx. 15% of Capital Equipment
	Total: Equipment	**$244,930**	
Labour			
Electrical contractor			
1	Design - Update of the single line diagrams with VSDs and field wiring	$2,160	Estimation, $90p/h * 3d
2	Installation and Wiring - VSD's	$5,760	Estimation, $90p/h * 4d * 2men
3	Upgrade of existing electric motors - bearings and brushes	$10,080	Estimation, $90p/h * 7d * 2men
4	PLC & SCADA programming and configuration: compressor speed and capacity control	$12,000	Estimation, $150p/h * 10d
5	VSD drive configuration	$1,800	Estimation, $150p/h * 1.5d
6	System Commissioning	$1,440	Estimation, $90p/h * 2d
7	Verification and optimisation of controls	$1,080	Estimation, $90p/h * 1.5d
8	Other works	$5,148	Estimation, 15% of all previous works
9	Travel Expenses & Stay Away Cost	$6,048	Estimation, Local contractor will be used for wiring and a PLC programmer from Sydney
	Electrical contractor sub-total	**$45,516**	
Engineering and Project Management			
1	Implementation Scope	$5,760	Estimation, $180p/h * 4d
2	Functional Description of the control logic	$5,760	Estimation, $180p/h * 4d
3	Project management and Supervision	$4,320	Estimation, $180p/h * 3d
4	Travel Expenses & Stay Away Cost	$1,372	Estimation, 1 day at site by 1 engineer
	Engineering sub-total	**$17,212**	
	Sub-Total: Labour	**$62,728**	
TOTAL		***$307,658***	

5.3 Condensate Subcooling via Screw Compressor Economiser

5.3.1 Principle of operation

On any ammonia plant containing screw compressors, condensate can be subcooled by the refrigerating effect derived by utilizing the economiser port of these compressors. The economiser port provides a suction pressure intermediate between that of main suction pressure of the compressor, and the discharge pressure (system condensing pressure in this case).

By expanding some of the high pressure liquid refrigerant from the liquid receiver to this intermediate suction pressure, the cooling effect of the evaporating refrigerant at this pressure can be utilised to subcool the remaining high pressure liquid refrigerant to a lower temperature before it is then expanded into the surge vessels, thus reducing the amount of flash gas developed in these vessels. Typically this cooling effect is utilised in several different ways:

1) Open flash economiser vessel, in which all refrigerant is first expanded into the economiser, and then expanded further into the surge vessels.
2) Economiser vessel with flooded subcooler coil, in which the remaining high pressure refrigerant is subcooled by immersion within the evaporating refrigerant at intercooler pressure
3) Subcooler plate heat exchanger (PHE), in which the remaining high pressure refrigerant is subcooled by evaporating refrigerant within the heat exchanger. Several different arrangements are possible.

5.3.2 Actions Required

It is important to note that *this project is only feasible if high stage Compressor Staging and Capacity Control described in Section 4.2 is implemented*. On slide valve controlled compressors, the economiser capacity is only available if the slide valve position of the compressor is above 60%. However, with speed control, some economiser capacity is still available at 50% speed and 100% slide valve position. In the current scenario, implementation of condensate sub-cooling would not provide any effect as it is evident that these compressors run below 60% slide position for considerable periods of time. The project involves the following:

- Installing an economiser vessel complete with a signal column, level transmitter, high level float switch, dual safety relief valve, isolation and oil drain valves
- Installing a flooded plate heat exchanger underneath the above economiser vessel in the liquid feed line from the liquid receiver to the intercoolers such that the refrigerant flows in a thermo-syphon loop
- Interconnecting ammonia piping from economiser vessel to the economiser

ports of all high stage compressors, between economiser vessel and the plate heat exchanger, from liquid receiver to economiser vessel and from the plate heat exchanger to intercoolers

- Installing economiser vessel, plate heat exchanger and pipe insulation for all relevant sections
- Installing appropriate bypass arrangements on high pressure liquid line so that the system can be reverted to original operation if required.

5.3.3 Detailed Costs Breakdown

Major equipment including installation, commissioning cost has been obtained from the refrigeration contactor. Minor equipment pricing has been taken from list prices provided by suppliers. Mechanical/electrical/programming costs have been estimated. Cost breakdown is detailed in Table 5. Accuracy of estimation of capital costs is expected to be around ±20% due to the size and nature of the proposed project and variances in contractor pricing.

Table 5: Project breakdown (Condensate supercooling)

DETAILED BREAKDOWN			
Sl No	**Equipment**	**Cost (excl GST)**	**Comments**
Mechanical equipment			
1	Flooded PHE for economising	$150,000	Estimation, Capacity approx. 400kW with 5K approach to economizer suction conditions, Tc=+35C, Heat exchanger stand.
2	Economiser accumulator vessel		Estimation, horizontal vessel, insulated and sheet metal clad
3	Associated pipe works, stop and control valves		Estimation, isolation valves, capped, angle type
4	Liquid line bypass arrangement		Estimation
5	Instrumentation		Estimation
6	PLC hardware upgrade	$5,000	Estimation for additional I/O cards
7	Electrical equipment and wiring consumables	$1,500	Estimation, additional electrical hardware, cables, etc.
	Mechanical Equipment sub-total	**$156,500**	
	Miscellaneous and unforeseen items	**$23,475**	Estimation, Equipment delivery costs and other costs, approx. 15% of Capital Equipment
	Total: Equipment	**$179,975**	
Labour			
Refrigeration contractor			
1	Design - schematics and documentation	$1,440	Estimation, $90p/h, 2d
2	Pumpdown of the system, evacuation of pipework	$1,440	Estimation, $90p/h, 1d * 2men
3	Installation of new pipework for condenser and for compressors	$0	Included in the equipment cost estimation
4	Testing, charging and commissioning	$0	Included in the equipment cost estimation
5	Miscellaneous & travel costs	$8,000	Estimation
6	**Refrigeration contractor sub-total**	**$10,880**	

Electrical contractor			
1	Electrical design and documentation	$2,880	Estimation, $90p/h, 4d
2	Site wiring	$1,800	Estimation, $90p/h, 2.5d
3 3	PLC & SCADA programming and configuration: condensate subcooling arrangement + compr. economizing + new sensor and safety inputs	$8,400	Estimation, $150p/h * 7d
4 4	Testing and commissioning	$1,440	Estimation, $90p/h, 2d
5 5	Other works	$2,178	Estimation, 15% of all previous works
6 6	Travel Expenses & Stay Away Cost	$4,200	Estimation
	Electrical contractor sub-total	**$20,898**	
Engineering and Project Management			
1 1	Implementation Scope	$8,640	Estimation, $180p/h, 6d
2 2	Functional Description of the control logic	$5,760	Estimation, $180p/h * 4d
3 3	Project management and Supervision	$7,200	Estimation, $180p/h, 5d
4 4	Verification and optimisation of controls	$1,200	Estimation, $150p/h * 1d
5 5	Travel Expenses & Stay Away Cost	$1,372	Estimation, 1 day at site by 1 engineer
	Engineering sub-total	**$24,172**	
	Sub-Total: Labour	**$55,950**	
TOTAL		***$235,925***	
TOTAL **With additional high stage Compressor Staging & Capacity Control costs (table 4)**		***$543,583***	

5.4 Switching Load from Old Ammonia Plant to New Ammonia Plant

5.4.1 Principle of operation

The old two stage Ammonia plant built in late 1980s consists of five reciprocating compressors of various models and four screw compressors also of various models, with high stage saturated suction temperature of -10oC and low stage saturated suction pressure of -40oC. Heat rejection is achieved via three evaporative condensers and another dedicated cooling tower is used to provide the cooling capacity for oil cooling for all compressors. All reciprocating compressors and two of the screw compressors were designed as swing machines to be able to operate either on high stage or on low stage.

The plant setup operates at a fixed condensing pressure with all condenser fans staged and cycled on/off. All reciprocating compressors are capacity modulated via cylinder unloaders and all screw compressors are capacity modulated via slide valve.

Figure 19 shows the variation in old plant discharge pressures over two weeks. It is evident that discharge pressures are in the range of 875-1000 kPa. The control system has been set-up such that the all fans turn on at 1,000 kPa and off at 875 kPa Therefore, the plant does NOT run at head pressures below 875 kPa.

Figure 20 shows the high stage compressor slide position variation over two weeks, RS1 unloads very often, during 30% of the monitoring period, slide position below 80%, with average of 85%.

Figure 21 shows the low stage compressor slide position variation over two weeks, during 50% of the monitoring period, RS2 unloads with slide position below 80%, with average of 70%; during 70% of the monitoring period. RS4 unloads with slide position below 80%, with average of 65%.

Figure 22 shows the high stage reciprocating compressor load percentage variation over two weeks, however, reciprocating compressor efficiency only drops slightly if the compressor unloads via unloaders.

Considering the age of the plant, most of the equipment is old and unreliable, and the technologies used are out of date. Some of the old types of motors have already been rewound and some of the compressors have been refurbished. Most time of the year, the plant operates fully loaded. Failure of any of the refrigeration plant components is likely to have an immediate effect on production. The site is now experiencing high maintenance and service costs.

Furthermore, due to the existing setup and degradation of the major equipment, such as compressors, motors and evaporative condensers, the old Ammonia plant is running inefficiently, therefore consuming considerable amounts of power which could be much reduced if suitable upgrades could be implemented. However, due to the fact that most of the equipment of this plant is approaching the end of the life, it’s not commercially astute to invest any money into it.

Besides, there is a new Ammonia plant on site which was built in 2008. Considering the cooling capacity that the new plant can provide and the refrigeration load that the new plant is serving, the new plant has never been fully utilised since its operation, which means all screw compressors, especially high stage compressor C3 and low stage compressor C1 always operate partially loaded (as shown in Figure 17 and Figure 18). The efficiency of the screw compressor is known to be very poor if it is capacity modulated with slide valve position below 80%.

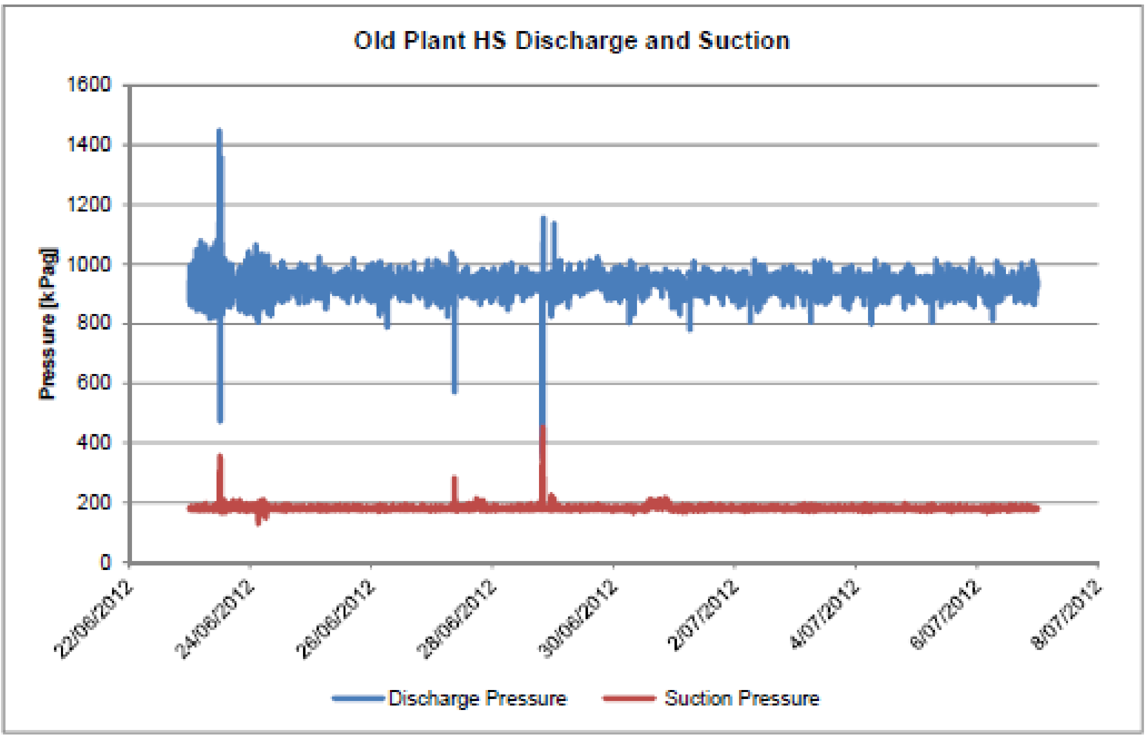

Figure 19: Old Plant Discharge and Suction Pressure

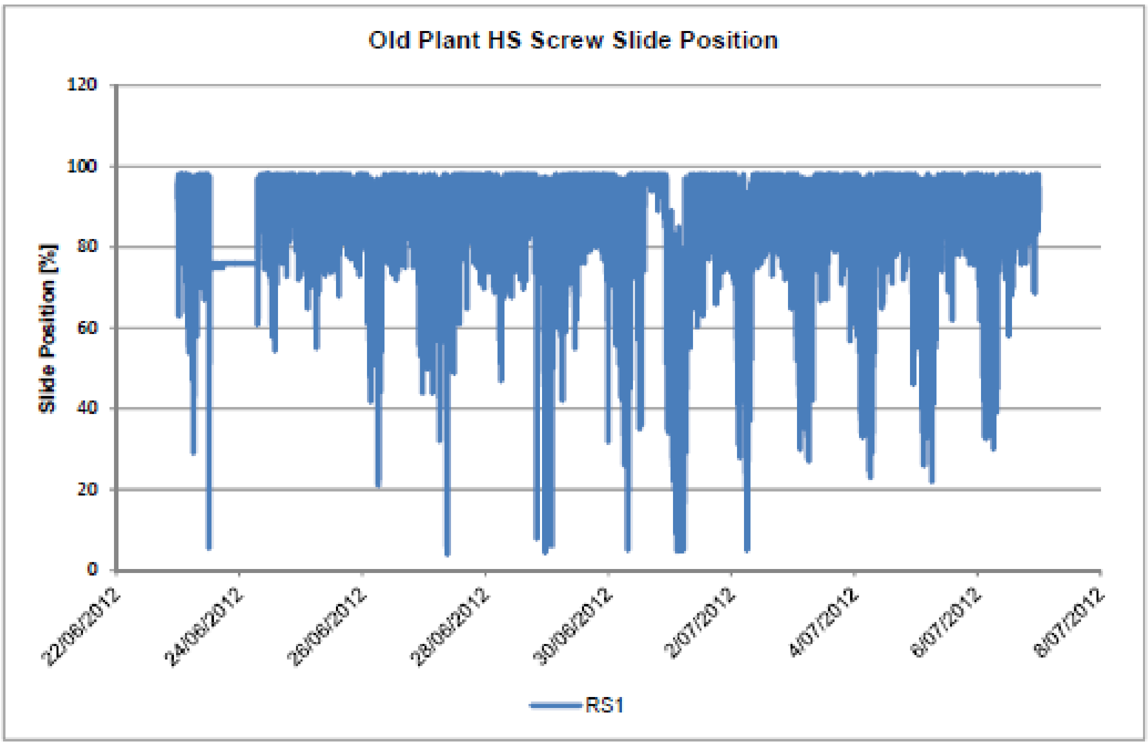

Figure 20: Old Plant High Stage Screw Compressor Slide Position

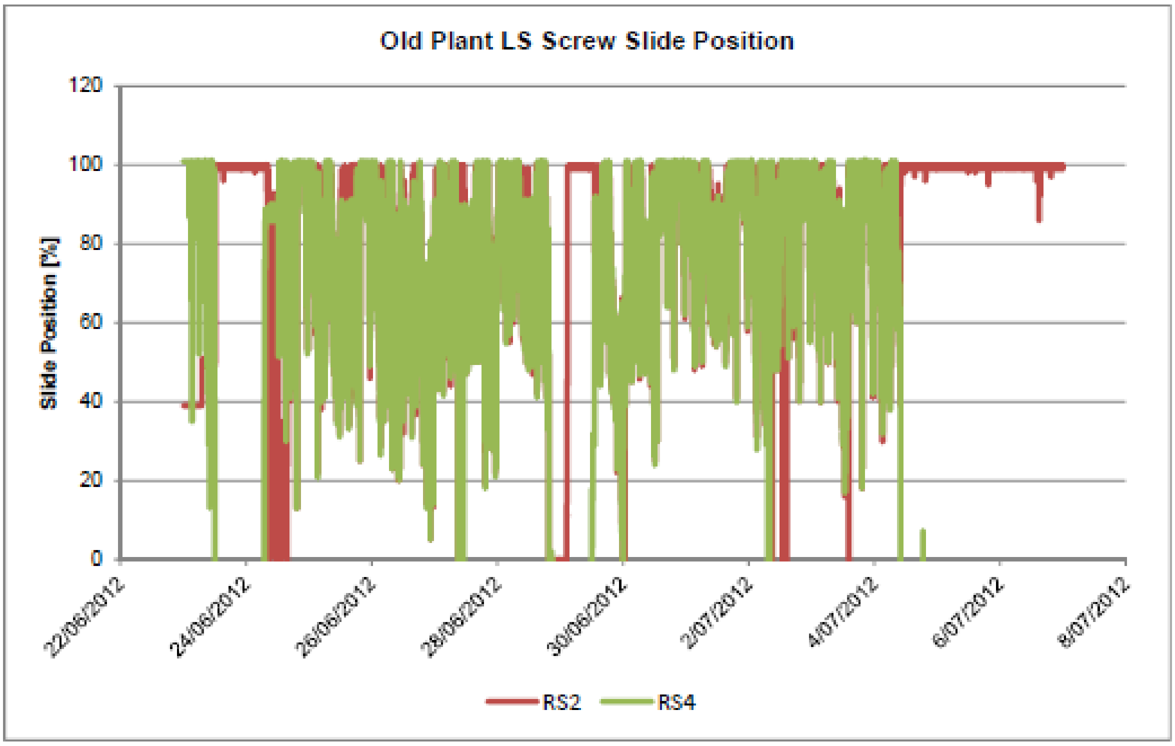

Figure 21: Old Plant Low Stage Screw Compressor Slide Position

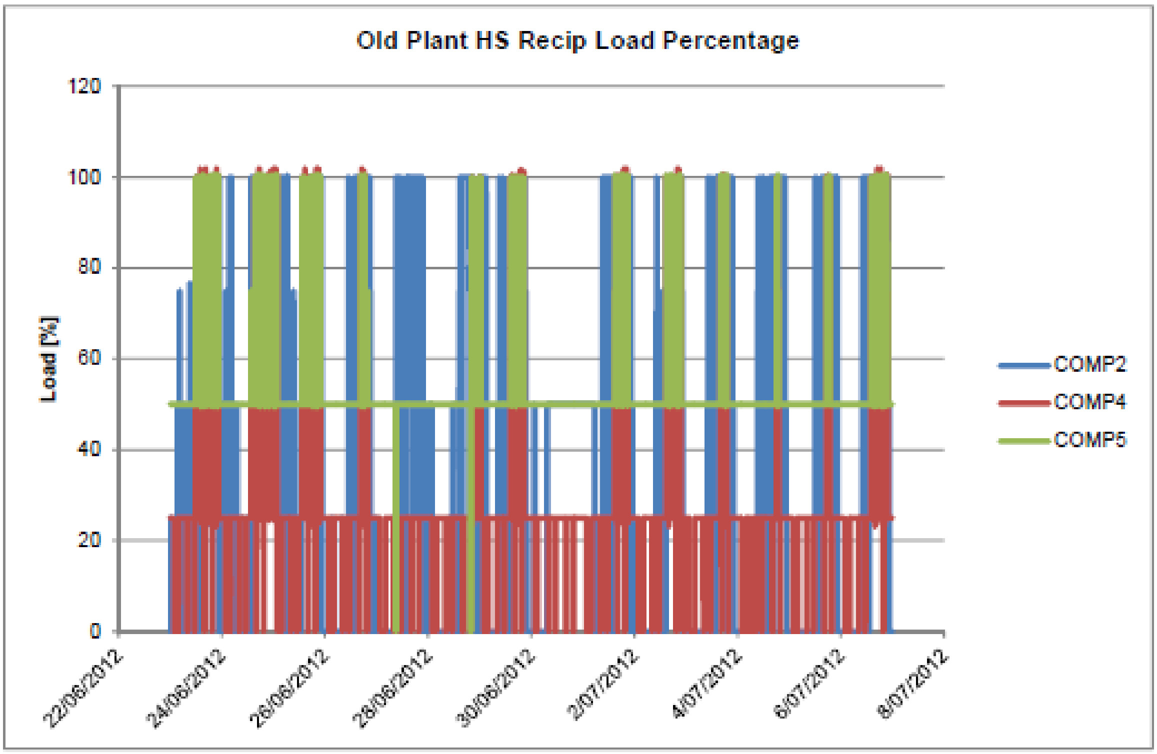

Figure 22: Old Plant High Stage Reciprocating Compressor Load Percentage

5.4.2 Actions Required

Based on the above background and observations, the concept of switching the load served by the old Ammonia plant to the new Ammonia plant has been developed and the project involves:

- Installation of a new high stage screw compressor package, a new low stage screw compressor package and a new evaporative condenser at the new Ammonia plant
- Interconnecting the Ammonia high pressure liquid piping between the existing common liquid header, which feeds the liquid to the existing intercooler vessels and the chilled spray water vessel, and the economiser plate heat exchanger of the new plant, which was described in **Section 4.3**
- Interconnecting the dry suction return piping between the existing common dry suction header of the existing intercooler vessels and the chilled spray water vessel and the high stage common suction header of the new plant room
- Interconnecting the dry suction return piping between the low stage accumulator vessel of the old plant room and the low stage common suction header of the new plant room
- Interconnecting the common hot gas piping between the old plant and the new plant
- Installation of proper isolation/bypass valves so that the old plant can still operate as a backup of the new plant in case of new plant room compressor failure

5.4.3 Detailed Costs Breakdown

Major equipment including installation and commissioning cost has been obtained from refrigeration contractor. Minor equipment pricing has been taken from list prices provided by suppliers. Mechanical/electrical/programming costs have been estimated. Cost breakdown is provided in Table 6. Accuracy of estimation of capital costs is expected to be around ±20% due to the size and nature of the proposed project.

Table 6: Project breakdown *(*Switching Load from Old Ammonia Plant to New Ammonia Plant)

DETAILED BREAKDOWN			
Sl No	**Equipment**	**Cost (excl GST)**	**Comments**
	Equipment		
1	New high stage Mycom 250VS package	$157,200	End user price from Mycom
2	New low stage Mycom 320VS package	$221,538	End user price from Mycom
3	Extension of engine room and condenser platform	$100,000	estimated
4	New evaporative condenser	$125,750	End user price from BAC, RCC1015-10R,22kW fan

5	Pipeline bridge and related civil works - Section 1	$20,000	Cost estimation received from the site. Verification of the cost estimation has not been carried out
6	Pipeline bridge material and civil works - Section 2 (existing)	$0	No allowance for the pipe bridge upgrade has been used. It is estimated that the existing pipe bridge can be reused
7	Pipeline - Hot gas defrost line	$12,000	Estimation, 40NB, 150m
8	Pipeline - High pressure liquid line	$36,750	Estimation, 100NB, PUR insulated in galvanized spiral casing, 150m
9	Pipeline - Dry suction line for LT vessel	$69,000	Estimation, 125NB, PUR insulated in galvanized spiral casing, 150m
10	Pipeline - Dry suction line for LT vessel	$69,000	Estimation, 150NB, PUR insulated in galvanized spiral casing, 150m
11	Pipe fittings and bends	$46,688	Estimation
12	Welding consumables	$56,025	Estimation
13	Other equipment required for pipeline installation like supports, brackets etc.	$23,344	Estimation
14	Drain pots and vent lines for hot gas defrost line	$3,000	Estimation
15	Line components	$10,000	Estimation, stop and check valves, etc.
16	Ammonia circulation pumps	$0	No allowance. Existing NH3 pumps to be reused
17	Additional ammonia	$0	Estimation, existing refrigerant will be reused
18	Additional oil	$750	Estimation, 50L additional oil
19	PLC upgrade	$10,000	Estimation for additional I/O cards, SW upgrade
20	Crane and other lifting equipment hire	$4,000	Estimation
	Sub-Total: Equipment	$965,044	
	Miscellaneous and unforeseen items	$144,757	Estimation, Equipment delivery costs and other costs, approx. 15% of Capital Equipment
	Total: Equipment	$1,109,801	
	Labour		
	Refrigeration contractor		
1	Design - schematics and documentation	$3,600	Estimation, $90p/h * 5d
2	Evacuation of system and preparations for pipework modifications	$2,880	Estimation, $90p/h * 4d
3	Installation of pipework and line components	$46,080	Estimation, $90p/h * 16d * 4men
4	Pipework fittings and line components insulation	$17,280	Estimation, $90p/h * 6d * 4men
5	System testing and commissioning	$7,200	Estimation, $90p/h * 5d * 2men
6	Other works	$15,408	Estimation, 20% of all previous works
7	Travel Expenses & Stay Away Cost	$19,154	Estimation
	Refrigeration contractor sub-total	**$111,602**	
	Electrical contractor		
1	Design & documentation - Controls	$2,880	Estimation, $90p/h * 4d
2	Setup of the controls in PLC	$12,000	Estimation, $150p/h * 10d
3	System Commissioning	$2,160	Estimation, $90p/h * 3d
4	Other works	$2,556	Estimation, 15% of all previous works
5	Travel Expenses & Stay Away Cost	$4,236	Estimation, Local contractor will be used for wiring and a PLC programmer from Sydney
	Electrical contractor sub-total	**$23,832**	

Engineering and Project Management			
1	Implementation Scope	$11,520	Estimation, $180p/h * 8d
2	Project management and Supervision	$5,760	Estimation, $180p/h * 4d
3	Travel Expenses & Stay Away Cost	$1,722	Estimation, 2 days at site by 1 engineer
	Engineering sub-total	**$19,002**	
	Sub-Total: Labour	**$154,436**	
TOTAL		***$1,264,237***	

6 Energy Savings Verifications Options

With varying thermal load and varying temperature requirements that are dictated by seasonal constraints and production demands, the efficiency of the refrigeration system will vary substantially by virtue of compressor part loading efficiency, ambient conditions and the fundamentals of thermodynamics. The extent to which these factors influence performance is in turn dependent on the design and operation of the system itself. Therefore, a direct measurement of the reduced energy consumption of the refrigeration plants following the upgrades is not possible.

Hence, to derive the energy saving due to implementation of all opportunities described in Section 4, it is necessary to make a comparison of the current and future energy use and determine the difference as follows:

Energy Savings = Pre-implementation Energy Usage - Post-implementation Energy Usage

The following plan could be used as a guideline for post-implementation energy use measurement:

a) Monitor the new plant operation for a period of 2-3 weeks including weekend operation after implementation of all opportunities. This includes monitoring of compressor motor amps, slide valve positions, speeds of the two VSD driven screw compressors, plant pressures, condenser fan speeds and on/off status
b) Analyse monitored data.
c) Obtain production data and weather data for the period of data logging, compare with data obtained during the logging conducted as a part of this study and scale the values appropriately.
d) For more accurate results, steps (a) and (b) could be repeated during different seasons of the year.

The difference between the power consumption before and after the upgrades, with appropriate scaling for production variations and ambient conditions, gives the energy savings due to implementation of this project.

With the introduction of carbon pricing mechanisms in Australia and increasing energy costs across the board, red meat processing operations are looking for opportunities to reduce costs, energy use and carbon emissions. Refrigeration, being the single largest user of electricity at many red meat processing plants, is the logical starting point when looking at the potential for electrical energy savings at such plants. It is envisaged that the data collected during this project will be relevant to many other plants where similar efficiency gains may be possible by upgrading and/or modifying refrigeration plant.

Preliminary estimates put the potential energy savings available from this project in the order of 3 to 4 Giga Watt hours which will mean a significant reduction in scope 2 emissions and a significant reduction in electricity usage and costs. This represents a 15 to 20% reduction in overall electricity consumption for the abattoir. Based on historical electricity usage patterns and quoted tariffs for 2012/2013 these reductions will result in an annual cost saving of between $176,000 and $235,000.

7 Conclusion & Recommendations

Minus40 has inspected the refrigeration plants, obtained plant operating data, analysed and investigated various energy saving technologies applicable to the plants. The following are the conclusions and recommendations of the investigations:

7.1 Conclusions

(a) Both the old and new ammonia plants appear to operate at a fixed head pressure set-point. Due to this, the compressors run at elevated head pressures even during cold winter conditions.

(b) All screw compressors of both the old and new ammonia plants are capacity modulated via slide valve. For considerable periods of time all screw compressors operate unloaded, especially the compressors of the new ammonia plant, and therefore the plant operates inefficiently.

(c) The high pressure refrigerant liquid is currently not sub-cooled and is expanded (flashed) into the surge vessels, causing the plant to run at reduced efficiency.

(d) The old ammonia plant has been in operation for over 40 years though some of the major components have been refurbished and/or repaired. Most of the major components are old and unreliable. Failure of any of the refrigeration plant components is likely to have an immediate effect on production.

7.2 Recommendations

(a) Install a new high stage Mycom 250VSD package, a new low stage Mycom 320VMD package fitted with VSD and a new BAC RCC1015-10R evaporative condenser with VSD driven fan at the new ammonia plant

(b) Switch all the load served by the old plant to the new plant by reconnecting the liquid line, hot gas line, intercooler and low temperature vessel dry suction line to the new ammonia plant, but install proper isolation/bypass valves so that the old plant can still operate as a backup in case of the new plant compressor failure.

(c) Install ambient temperature and humidity sensor and implement variable head pressure and fan speed control logic for the new ammonia plant.

(d) Install a VSD for the high stage compressor C4 and implement compressor staging and capacity control logic for both high stage and low stage compressors at the new plant.

(e) Install a flooded plate type economiser in between the liquid receiver and the intercooler at the new plant to sub-cool the high pressure ammonia liquid from the liquid receiver, hence the plant will operate at better efficiency and provide more capacity for the site future extension.

Future energy cost increases will improve the financial return on all projects, however no projections have been considered in this report.

The outcomes of this project will inform industry as to the cost benefit of various aspects of upgrading and modification of refrigeration plants.

7.3 Abattoir Insights – A commercial perspective

With the completion of the survey it has come to light that there are other future possibilities for further savings within the refrigeration designs.

The nature of compressors and the mechanical action of compressing the gas which generates heat as a by-product that has to be removed to allow the gas to condensate into a pressurised liquid. This heat is normally removed by a cooling tower or evaporative condenser and discharged to the atmosphere. However this is a lost opportunity for the abattoir as this energy may be put to use elsewhere in the plant. As a result of this project, the abattoir would now like to review the options and cost-effectiveness to use this low grade heat; for example, in underfloor heating to prevent frost heave or as a pre-heating pathways to a hot water system. For some of these proposed options, the abattoir would need to investigate rainwater harvesting for the cooling towers and defrosting on demand rather than via a timer.

Defrosting on demand uses a system to measure the amount of frost build up on the cooler face and when it reaches the pre-set level it triggers a defrost cycle. The proposed system would expect to have problems and more development work may be required to evaluate and optimise the air quality from plant to plant. Once these issues are rectified, it may be possible to run for long periods without requiring defrosting. A defrost basically injects heat into the room that is targeted for cooling, and it is therefore considered that the fewer the defrost cycles required the better. Traditionally most defrosts are done on a time basis and will defrost on a given time and day needed. Utilisation of low grade heat in such an application is expected to have substantial benefits and therefore warrants further investigation.

8 APPENDIX 1 – Major Refrigeration Equipment Details

8.1 Old Ammonia Plant

Refrigerant	R717 (Ammonia)					
Compressors	**System No.**	**Brand**	**Compressor Model and type**	**El. Motor Size [kW] / Efficiency [%]**	**Power Supply**	**Comments**
	COMP1	Budge	8 Cylinders - Recip	93/NA	380420V / 3PH / 50Hz	High Stage
	COMP2	Budge	8 Cylinders - Recip	93/NA		High Stage
	COMP3	Viter	6 Cylinders - Recip	75/NA		High Stage
	COMP4	Budge	8 Cylinders - Recip	93/NA		High Stage
	COMP5	Viter	16 Cylinders - Recip	150/NA		High Stage
	RS1	Mycom	200LG-MX – Screw	265/NA		High Stage Swing
	RS2	Stal	SVA65	367/NA		High Stage Swing
	RS3	Stal	SVA67	187/NA		Low Stage
	RS4	Stal	SVA65	110/NA		Low Stage
Condensers	**System No.**	**Brand**	**Model**	**Fan/Pump motor size (kW)**	**Power Supply**	
	No.2	Budge	KB1205	2 X 7.5 / 3	380420V / 3PH / 50Hz	
	No.3	BAC	VXCS265	18.5 / 3		
	No.4	BAC	VXCS680	2 x 22 / 3		

8.2 New Ammonia Plant

Refrigerant	R717 (Ammonia)					
Compressors	**System No.**	**Brand**	**Compressor Model and type**	**El. Motor Size [kW] / Efficiency [%]**	**Power Supply**	**Comments**
	No.1	Mycom	250VLD – Screw	150 / NA	380420V / 3PH / 50Hz	Low Stage
	No.2	Mycom	250VLD – Screw	150 / NA		Low Stage
	No.3	Mycom	250VLD – Screw	465 / NA		High Stage
	No.4	Mycom	250VLD – Screw	465 / NA		High Stage
Condensers	**System No.**	**Brand**	**Model**	**Fan/Pump motor size (kW)**	**Power Supply**	
	No.1	BAC	RCC1015-10R	22 / 4	380420V / 3PH / 50Hz	
	No.2	BAC	RCC1015-10R	22 / 4		

9 APPENDIX 2 – Supporting Calculations

9.1 OVERALL INPUT DATA

- Average cost of electricity: 9.00 [c/kWh]
- Greenhouse emission / electrical power emissions factor: 1.00 [ton CO_2 equivalent/MWh]

9.2 MODELLING PLANT PERFORMANCE

The behaviour and performance of both existing and future upgraded plants are simulated on an hourly basis for 1 year. This is done to incorporate ambient weather variations and the refrigeration load profiles of the plants.

Mathematical models were developed through a combination of manufacturer's specifications and energy balances.

These models are solved via the software package EES (Engineering Equation Solver - Professional V8.652-3D).

- Weather data has been obtained from the Bureau of Meteorology (closest station to the abattoir) at 1 hour intervals.
- Screw compressor performance is based on literature values obtained using the Mycom – MycomW 2012ep software by Mayekawa Manufacturing Co. Japan.
- Reciprocating compressor performance is based on Vilter specifications (Vilter VMC Series).
- In order to establish the load profiles of each of the plants, the following parameters were obtained at 1 minute intervals:
- Working pressures
- Slide valve position / compressor speed / cylinder unloading status
- Motor amps
- Condenser fan status and speed

The simulations provide annual power consumption on an hourly basis of the refrigeration system.

Electrical savings [MWh p.a.] & [$ p.a.]:

- The electrical consumption is calculated per hour for the existing and proposed system
- The difference in power consumption is calculated per hour
- The difference in power consumption [MWh p.a.] calculated per hour is summed over the year, giving the annual electrical consumption saving
- The annual electrical consumption saving is multiplied by the average electricity tariff to obtain total annual cost savings. This average electricity tariff includes both consumption and demand costs.

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 and demand.
- Maintenance 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.

10 year IRR [%]:
Determined using the “IRR” function in MS Excel:

- Total annual cost savings are used as savings for years 1 to 10 (positive numbers)
- Project costs used as expenses for year 0 (negative number)
- The effects of equipment degradation and changes in energy prices are not considered.

10 year NPV [$]:
Determined using the “NPV” function in MS Excel:

- Total annual cost savings are used as savings for years 1 to 10 (positive numbers)
- Project costs used as expenses for year 0 (negative number)
- The discount rate specified above is used.
- The effects of equipment degradation and changes in energy prices are not considered1.