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Renewable energy for process heat – Opportunity study phase 2

Final project knowledge sharing report

By Jarrod Leak | Australian Alliance for Energy Productivity

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ABOUT THIS REPORT

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ABOUT A2EP

A2EP is an independent, not-for-profit coalition of business and research leaders helping Australian businesses pursue a cleaner and more successful future by producing more with less energy.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

When considering renewable options for low temperature heating applications (<90 ˚C): Electrify where you can or switch to renewable fuels where you must.

Decarbonising industrial process heat is a major challenge for Australia. It accounts for more than 40% of fossil fuel use in industry.

While a number of renewable energy options have been identified as suitable for decarbonising industrial process heat, historically they have been unable to compete on financial terms. This continued perception has contributed to low take-up of such options, particularly industrial heat pumps which are being used increasingly outside of Australia but local awareness and capacity remains low.

As part of its Advancing Renewables Program, the Australian Renewable Energy Agency (ARENA) engaged the Australian Alliance for Energy Productivity (A2EP) to conduct the Renewable energy for process heat - opportunity study to accelerate the adoption of renewable energy in industrial and commercial process heating. Twenty pre-feasibility studies and seven feasibility studies were completed over two phases of the program across a wide range of food, beverage and industrial processes to consider the suitability of renewable energy options for these applications, with a particular consideration of industrial heat pumps.

The pre-feasibility and feasibility studies demonstrated that industrial heat pumps are economically and technically feasible for low temperature (<90 ˚C) heating applications and can be superior to other renewable heating solutions (such as solar thermal or biogas from anaerobic digestion) where conditions are favourable, that is, suitable temperatures, high-capacity factors and good opportunity to integrate heating and cooling.

In Europe, Japan and New Zealand, heat pumps are used in a large range of processes, with well-established supply chains for equipment supply, installation and service. The Australian market is not yet so mature. A higher capital cost per thermal kilowatt (compared to traditional boilers) to install a heat pump has been a key impediment.

However, the pre-feasibility and feasibility studies showed that a higher than necessary capacity heat pump was often being considered, with the assumed need to have a one-for-one swap with a boiler in terms of capacity to accommodate peak loads. The studies have shown that with better information (from energy data and heat mapping), the utilisation of waste heat and process integration, along with the inclusion of a thermal battery, a heat pump with a comparatively lower capacity can be used, delivering lower capital costs, lower operating costs, lower emissions and a number of non-energy benefits, including the potential to generate revenue from demand response opportunities.

PROJECT OUTCOMES / KEY FINDINGS

Heat pumps are commercially viable for many applications requiring <90 ˚C

See page 8

Obstacles to industrial heat pump use

- Lack of awareness of options, benefits and applicability
- Lack of knowledge and capacity to pursue
- Perceived high cost compared to conventional boilers or other renewable alternatives.

See page 10

Why are heat pumps considered not economically viable?

- Oversizing of capacity
- Insufficient energy & heat data
- A like-for-like approach

See page 11

To tackle obstacles, A2EP produced:

- A fossil-free heat selection flowchart
- A knowledge-sharing website
- A heat pump selection tool

See page 10

The importance of capacity factor on economic feasibility

See page 12

Non-energy benefits of heat pumps must be factored into assessments

See page 12

LESSONS LEARNT

Installing a heat pump doesn't need to be a one-for-one swap in terms of capacity

- Collect heat and energy data to understand peak and baseline requirements
- Study heat flows and consider process integration to optimise heat recovery

See page 13

Other challenges and opportunities:

- Need for electrical upgrades
- Space limitations impacting installation of thermal batteries
- Optimising demand flexibility

See page 16

Is a heat pump right for me?

Temperature demand less than 90 °C

Plant operating hours >2,000 hours/year (>4,000 hours/year is preferable)

Space for the heat pump and thermal battery

GLOSSARY

Air-sourced heat pump	The heat pump uses air as the heat source.
Capacity factor	Measures the utilisation of the heat pump. Total heat delivered divided by the maximum heat that can be delivered by the heat pump. This is a function of the operating hours and the heat output from the heat pump.
CapEx	Capital expenditure.
COP	Coefficient of Performance – the thermal output divided by electrical input for the heat pump.
Demand flexibility	The ability to adjust your electricity demand profile either by shifting to a cheaper tariff, shedding to demand to provide a demand response revenue, shimmy to support grid stability or shaping to adjust long term demand profiles.
Heat source	The 'waste heat' used to evaporate the refrigerant in the heat pump
Heat sink	The process fluid which you want to heat up by condensing the refrigerant in the heat pump
LCOH	Levelised Cost of Heating being the cost of heating per gigajoule after allowing for CapEx and OpEx.
OpEx	Operational expenditure.
Thermal battery / Thermal storage	Storage device for heat (or coolth) typically being an insulated tank of hot water but can also be a phase change material (PCM), thermal oil, molten salt (e.g., KNO_3 mixture), concrete, etc. Typically used for smoothing out intra-day peak demand.
Temperature lift	The difference between the heat sink temperature and the heat source temperature which directly correlates to the COP.
Peak demand	The maximum instantaneous heat demand from the process, typically measured in kilowatts over a time period, e.g., 750 kW peak demand for 30 minutes.
Pinch analysis	A method used to minimise energy consumption by modelling heating and cooling demands within a process to maximise heat recovery.
PPA	Power Purchase Agreement – taken up with an electricity retailer to provide 100% renewable electricity.
Water-sourced heat pump	The heat pump uses water as the heat source.

INTRODUCTION

Decarbonising process heat is not only essential for businesses, industries and governments to achieve net zero targets, it will be key to maintaining competitiveness in a low carbon world. Industry is responsible for around 44% of Australia's final energy consumption, with 52% of that being used for process heat (ITP Thermal 2019). Given 70% of that is sourced from fossil fuels, the decarbonisation of industrial process heat presents both a major challenge and opportunity

Renewable energy options for process heat are both commercial and available. They include:

- renewable fuels for boilers and generators, such as using waste biomass or biogas from anaerobic digestion
- solar thermal heat for industrial applications and electricity generation
- industrial heat pumps powered by renewable electricity.

While a number of renewable energy options have been identified as suitable for decarbonising industrial process heat, historically they have been unable to compete on financial terms. This continued perception has contributed to low take-up of such options, particularly industrial heat pumps which are being used increasingly outside of Australia but local awareness and capacity remains low.

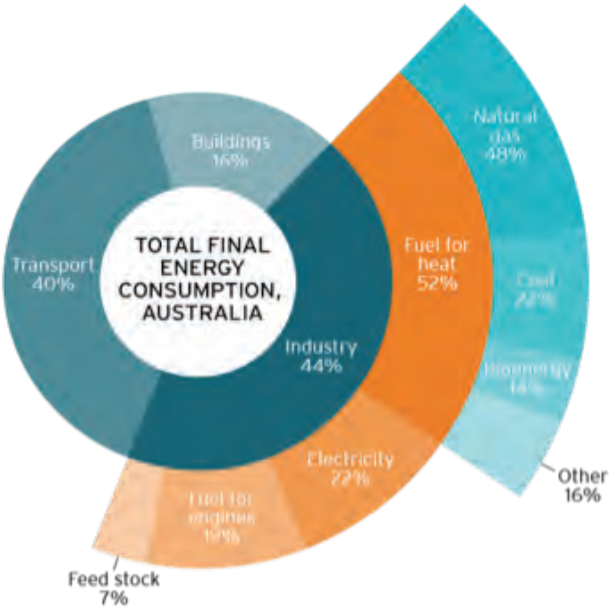


Figure 1: Industrial process heat use as part of total final energy consumption in Australia. Source: Renewable energy options for process heat*, ITP Thermal, 2019.*

The project for ARENA

To investigate and help address the obstacles to renewable heat technologies in Australia, the Australian Renewable Energy Agency (ARENA) engaged the Australian Alliance for Energy Productivity (A2EP) to conduct the 'Renewable energy for process heat - opportunity study' project, as part of ARENA's Advancing Renewables Program.

A2EP managed the project with advisory assistance from ARENA, Climate-KIC Australia, Sustainability Victoria and NSW Department of Planning, Industry and Environment. The project included two phases of studies undertaken by independent expert energy engineering consultancies: 20 pre-feasibility studies and seven feasibility studies. Renewable process heat options were investigated for a range of industries (including food and beverage manufacturing, meat processing, vegetable processing and steel manufacturing) across a range of heating demands from 300 GJ up to more than 50,000 GJ per year (see Appendix A for case studies).

PROJECT RESULTS AND OUTCOMES

Heat pumps are technically and commercially viable for many applications requiring heat <90 ˚C

A range of renewable process heating alternatives were considered such as biogas from on-site anaerobic digestion (AD), solar thermal, syngas from pyrolysis and heat pumps. All sites had existing manufacturing operations and each study investigating replacement or augmentation of the existing, fossil fuel-based heating technology. Each process heating alternative was assessed on financial performance based on the simple payback and internal rate of return of installing and operating the renewable fuel alternative.

The studies did not investigate optimising process efficiency optimisation (e.g. malt-drying efficiency) but did investigate heat recovery opportunities which were deemed necessary to complete at two sites. For heat demands below 90 ˚C, heat pumps were determined to be technically feasible, provided that the right site-specific factors were in place, such as sufficient space for the heat pump and thermal battery and sufficient electrical capacity at the site. A wide range of economic performance was observed across the various renewable fuel technologies with heat pumps being the recommended technology in 90% of the studies.

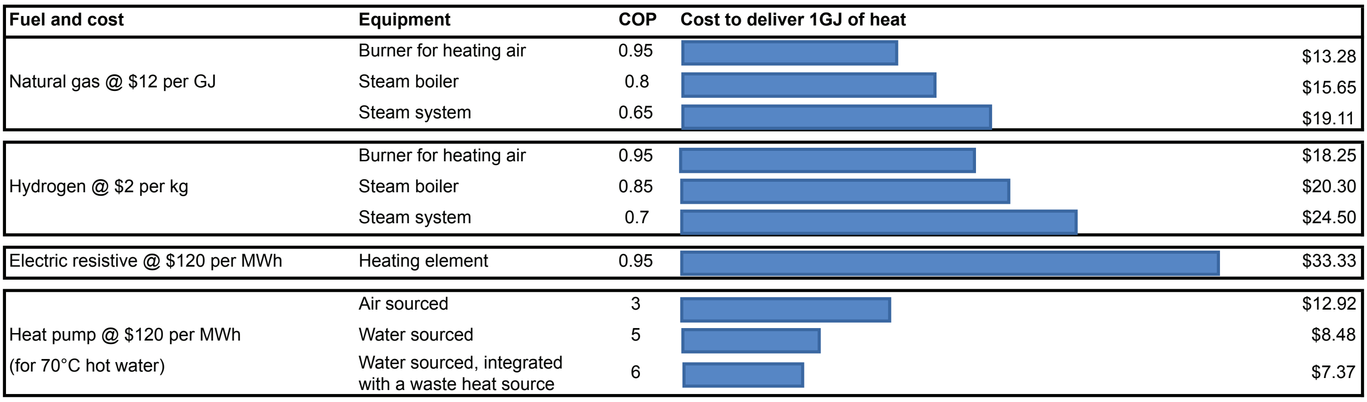
Application & region	Existing heating technology	Selected technology for heating <90 ˚C				
		Anaerobic digestion + biogas	Bio-mass	Heat recovery	Solar thermal	Heat pump
Brewery - VIC	Electric Resistance					X
Brewery - NSW	Natural gas steam boiler					X
Beverage - NSW	Natural gas steam boiler					X
Malting - QLD	Natural gas burner					X
Meat processing - VIC	Natural gas steam boiler			X		X
Hops - TAS	Natural gas burner		X			X
Petfood - VIC	Natural gas steam boiler				X	
Confectionary - VIC	Natural gas steam boiler					X
Meat processing - NSW	Natural gas steam boiler			X		X
Malting - NSW	Natural gas burner				X	X
Food - TAS	Natural gas steam boiler					X
Brewery - SA	Natural gas steam boiler					X
Food - VIC	Natural gas steam boiler					X
Food - NSW	Natural gas steam boiler	X				
Beverage - NSW	Natural gas steam boiler					X
Confectionary - VIC	Natural gas steam boiler					X
Petfood - NSW	Natural gas steam boiler					X
Winery - NSW	Natural gas steam boiler					X
Food - NSW	Natural gas steam boiler					X
Steel - NSW	Cogen steam boiler			X		X

Table 1: Appropriate/selected technology for each pre-feasibility study

This table shows that heat pumps were by far the dominant technology. Some sites considered a combination of technology as shown with multiple X's per site.

Using the heat pump costings from the pre-feasibility studies and industry knowledge for boiler and resistance heating costs, it was possible to use simple engineering calculations to find the Levelised Cost of Heating (LCOH) for different fuel options, as summarised in Figure 2.

For equipment with a 1MW nameplate capacity



Fuel and cost	Equipment	COP	Cost to deliver 1GJ of heat
Natural gas @ $12 per GJ	Burner for heating air	0.95	$13.28
	Steam boiler	0.8	$15.65
	Steam system	0.65	$19.11
Hydrogen @ $2 per kg	Burner for heating air	0.95	$18.25
	Steam boiler	0.85	$20.30
	Steam system	0.7	$24.50
Electric resistive @ $120 per MWh	Heating element	0.95	$33.33
Heat pump @ $120 per MWh (for 70°C hot water)	Air sourced	3	$12.92
	Water sourced	5	$8.48
	Water sourced, integrated with a waste heat source	6	$7.37

Figure 2: Levelised Cost of Heating (LCOH) comparison for different fuels.

The above estimates compare equipment cost only, not the fully installed cost which varies greatly depending on site requirements. Using hydrogen as a fuel to displace natural gas was not part of the study framework but has been included for comparison.

The Coefficient of Performance (COP) for the equipment is indicative only and will vary according to the site conditions and technology chosen. For example, air-sourced CO_2 heat pumps can achieve COP greater than six under certain circumstances.

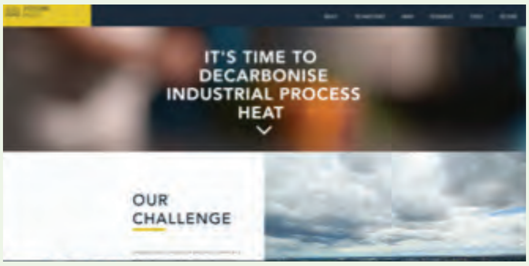
Overcoming obstacles to use of industrial heat pumps

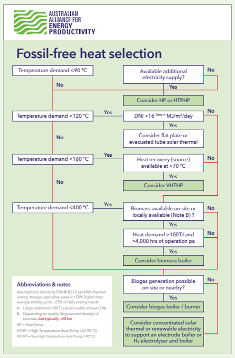
During the course of the studies, A2EP and the energy consultants determined there were three main obstacles to using of heat pumps which arose a number of times:

- Lack of awareness of heat pump options, benefits and applicability
- Lack of knowledge and capacity to pursue and size appropriate options
- Perceived high cost of heat pumps compared to conventional boilers or other renewable alternatives.

A2EP has developed tools and resources in response to these obstacles:

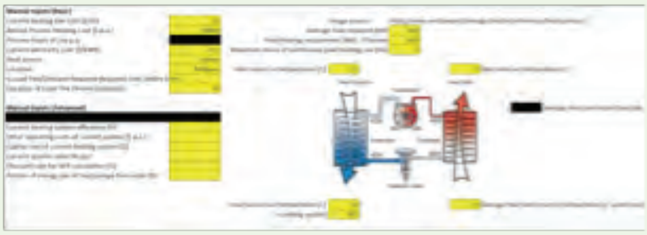
One resource for general awareness raising of process heat alternatives for decarbonisation is a website called www.FutureHeat.info. The website includes information about a range of heat pump options and also thermal battery options and how they can be used in different industry sectors, as well as case studies of implemented solutions and webinars from Australian and international experts.





To aid energy managers and decision-makers in determining whether heat pumps and other options are worth considering for a particular application, A2EP has created a simple flow chart. Taking into consideration factors such as temperature demand required, space and availability of waste heat and biomass, the chart can point to which renewable process heat technologies to consider. The chart provides a general guidance only and should not replace a proper site study from a reputable energy consultant.

View the full-size flow chart in Appendix B.



Using the results from the pre-feasibility and feasibility studies, A2EP, pitt&sherry and SmartConsult developed a heat pump diagnostic and selection tool to allow a further quick assessment on the applicability of a heat pump to displace fossil fuel heating and basic assessment of the capacity required. Note this tool only provided a like-for-like comparison with a boiler which often results in CapEx and OpEx higher than possible compared to an integrated approach using heat mapping and pinch analysis. Implementing some of the recommendations in the 'Lessons learnt' section of this report will assist in lowering both the CapEx and OpEx.

View the full tool in Appendix C.

Improving the COP

Literature often describes the ratio of electricity to gas prices as a key determinant in the economic performance for a heat pump (Arpagaus 2020). Analysis of the study results has shown that the impact of this ratio can be reduced by optimal integration of the heat pump with waste heat recovery which gives improved COP for the heat pump operation. It was observed that using a method to map heat flows and then maximise heat recovery, such as pinch analysis, provided a reliable method to increase the heat source temperature for the heat pump to use, delivering a 2.5% performance improvement for every 1 °C increase in the source temperature. The higher source temperature improves the heat pump COP and therefore reduces the impact of the electricity to gas price ratio.

Once this was achieved, it was observed that several other factors needed to be considered to deliver favourable economics for heat pumps such as: capacity factor, energy data, process integration and physical space to accommodate a thermal battery (discussed in the 'Lessons learnt' section).

Misperception of heat pumps cost competitiveness

A poor cost comparison between heat pumps and conventional boilers is often due to the boilers historically being sized for peak demand with much higher rates of heat loss and then the assumption that a heat pump will need to have the same capacity as the boiler/s it is replacing. Combine these assumptions with the higher cost per kilowatt of capacity of heat pumps and they are quickly a distant second (or third) choice for replacing existing equipment. As seen in the benchmarking graphs in Appendix F, many of the studies returned simple paybacks in excess of three years.

However, it was observed across multiple studies that proper consideration to each of the following four factors reveals this does not need to be the case. Apply them together with lessons learnt on optimising the sizing of the heat pump configuration (listed in the following section) and it becomes clear that a heat pump with as little as 50% capacity of the conventional boiler it is replacing can often perform the same services while offering additional benefits and delivering simple paybacks less than three years.

Over-sizing to accommodate peak demand – typically conventional boilers are oversized to accommodate the highest possible peak demand that may be experienced, even if this is only a fraction of the time. Thermal storage (such as hot water tanks) can allow heat pumps to be sized to meet average load, rather than peak load conditions.

A lack of energy and heat data – in many cases there is not a good understanding of heat and energy needed, or the energy and heat that is required. Natural gas consumption was often only available from monthly bills rather than the optimal intervals (approximately every five minutes). Steam consumption was often only available for the entire boiler not for the individual processes that used the steam. Similarly, data for hot water consumption was often not available at a granular enough level. Good energy data that shows the daily heating demand peaks across all heat demands, allows for accurate mapping of heating needs which gives optimal sizing of the heat pump and thermal battery.

A lack of waste heat mapping – Unsurprisingly, in these situations there was also a lack of waste heat information which could be used to identify opportunities for heat recovery to reduce the size of the heat pump or the utilisation of waste heat as a heat source for the heat pump which increases the COP.

A like-for-like approach – a typical process plant will have a single, centralised boiler system supplying heat at one temperature, e.g. steam at 185 °C. However, that approach is not optimal when considering heat pumps. A process plant with heat demands ranging from 60 °C to 150 °C may best be served by a range of smaller solutions. For example, an air-sourced heat pump may be best to serve the 65 °C heating needed for hot water washing, then a water sourced heat pump using waste heat from a refrigeration plant may be best to serve the 85 °C heating needed for a pasteurisation process, and then another technology may be best to serve a need for 150 °C heating in a cooking process. Using a combination of heating solutions can provide the lowest overall energy demand and best utilisation of renewable energy sources.

The importance of capacity factor on economic feasibility

Analysis has also shown that the capacity factor for the heat pump[1] is a highly important determinant on economic performance. The likelihood of favourable economics increased proportionally with the number of hours per year that the heat pump is operating at maximum capacity.

See Appendix F for benchmarking graphs showing economic performance for the feasibility studies via a simple payback calculation for a series of parameters including: heat pump size, heat lift temperature and capacity factor. There appears to be little correlation between heat pump size and economic performance, which indicates that economies of scale are not clearly evident. The heat lift temperature impacts the COP which impacts the electrical demand. While heat lift temperature did not show a consistent correlation to economic performance, capacity factor did show a close correlation, albeit for a small sample size. From this it can be concluded that the capital cost of the heat pump investment needs to be paid back so you need to minimise that capital outlay and maximise the returns from it.

Factoring non-energy benefits of heat pumps

The pre-feasibility and feasibility studies revealed that changing to a heat pump should not just be considered an energy savings project with non-energy benefits often making up a large part of the cost benefit analysis. When coupled with on-site photovoltaic solar generation (solar PV) or a Power Purchase Agreement (PPA), the electrification of process heating can provide large reductions in carbon emissions. Recent modelling by A2EP indicates that a reduction of 10 million tonnes of CO_2 per annum is possible by 2030 by using all forms of heat pumps (compression and mechanical vapour recompression) across all of industry. Most of that reduction comes from the electrification of process heating in the alumina industry. For the food and beverage industry a reduction in CO_2 emissions of more than one million tonnes per annum is possible.

The heat pump should also be considered as an opportunity to remove process bottlenecks and allow higher production. When the heat pump is integrated with a refrigeration system the net reduction in heat load on the cooling tower reduces the water losses and electrical consumption of the refrigeration system. Finally, a heat pump system can have several workplace health and safety benefits such as the reduction in temperature of the heating reticulation network when changing from steam to hot water or utilising the cooling from the heat pump to cool a factory and provide improved employee comfort.

Decarbonisation

Remove bottlenecks/ increase productivity

Water-saving

Workplace health and safety

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[1] Capacity factor is defined as the average consumption, output, or throughput over a period of time of a particular technology or piece of infrastructure, divided by its consumption, output, or throughput if it had operated at full (rated) capacity over that time period.

LESSONS LEARNT & CONTINUING CHALLENGES

Installing a heat pump doesn't need to be a one-for-one swap

With the understanding the heat pump doesn't need to be the same capacity as the conventional boiler or the same temperature as heat source it is replacing and that right-sizing is key to reducing the replacement cost potentially by 20% or more, here are recommended steps to take (which are also illustrated in Figure 3 below):

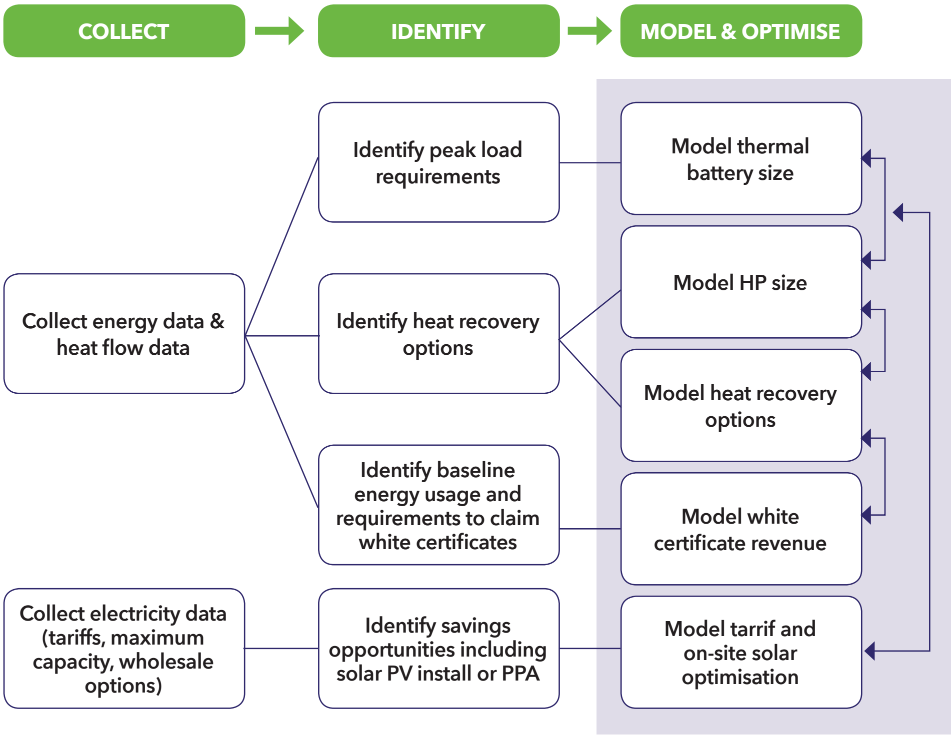

Figure 3: Right-sizing and optimising a heat pump.

Collect heat and energy data to understand peak and baseline requirements

After collecting the necessary heat and energy demand data, it is possible to identify the peak and average load requirements and start to consider heat recovery options. This data will also allow the calculation of baseline date used in calculations white certificate creation. Combining this information with the electricity tariffs and white certificate calculations allows modelling of the optimal sizing of the heat pump, thermal storage and heat recovery equipment to minimise the capital expenditure required.

Figures 4 & 5: Examples of energy monitoring dashboards from Simble and Schneider Electric.

$10,000 of energy monitoring to save $200,000 in heat pump investment costs

When considering the replacement of a 1 MW steam boiler which is being used to heat water for cleaning and sterilisation, the easy solution is to install a 1 MW heat pump. This is also a very expensive solution with the heat pump costing 5-10 times the cost of the boiler for the same capacity. The 1 MW boiler capacity could largely be sized for meeting peak demand, for example a full process line clean at the end of a production run. The average demand over a 24-hour period might be 50% of this demand. When using a heat pump, the peak demand is best met using a thermal battery or hot water tank so that the heat pump is more likely to be running at a higher capacity factor. Given that a 500 kW heat pump and thermal battery will likely cost approximately $200,000 less in CapEx, having energy monitoring data to confirm demand and allow proper sizing of a thermal battery is a critical step in the transition.

Study heat flows and consider process integration to optimise heat recovery

Utility systems should not operate in silos. They need to be integrated with each other and with the process plant to greatly reduce the electricity consumption of the heat pump.

It was observed that the ability for the heat pump to be properly integrated into the process to maximise heat recovery opportunity relied upon:

- Knowledge of the process and energy flows
- Knowledge of heat pump technology, and
- The limitations and factors driving COP

An ability to use methods such as pinch analysis to determine the best ways to utilise waste heat was also observed to be important. A list of energy consultants who have completed training and now use pinch analysis as part of their heat pump assessment is included in Appendix E.

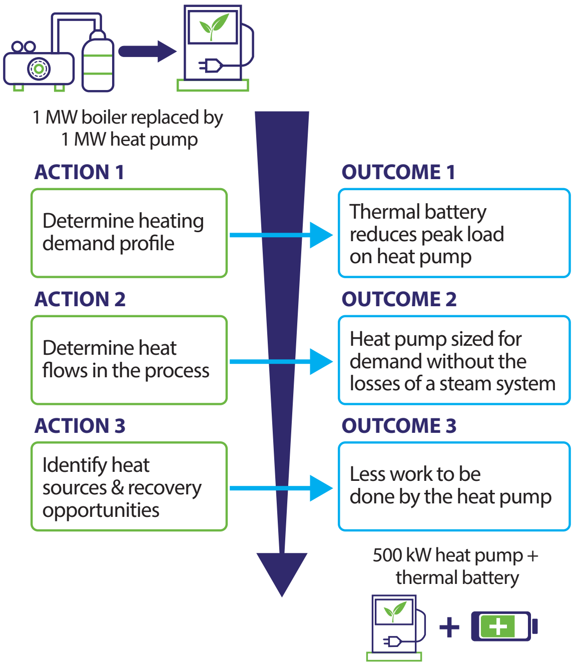

Figure 6: Right-sizing your heat pump.

Consider incorporating a thermal battery for meeting peak demand and other benefits

The primary benefit for a thermal battery is to smooth out peak loads and reduce the heat pump size and capital investment, however, it can be used for more. As electricity costs get more volatile, being able to 'flex' electricity demand up and down will become more profitable. If you are exposed to wholesale markets, you could take advantage of negative electricity prices to generate your hot water. When prices are high, shed your electricity demand by turning off the heat pump and draw hot water from your thermal battery.

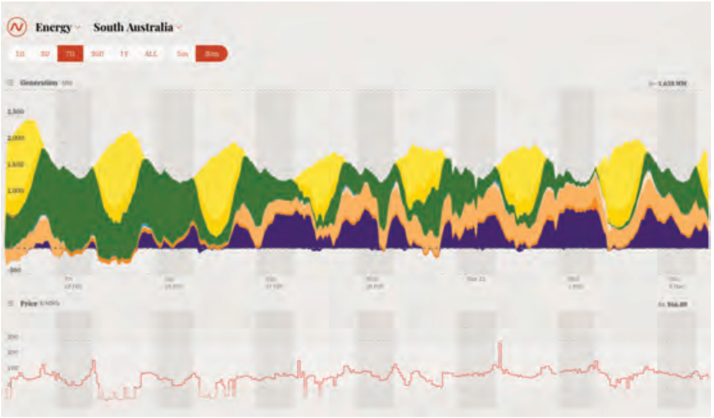

Figure 7: An example of the South Australian electricity market. Source: www.opennem.org.au

Air-sourced heat pumps for utilising waste heat

Electricity consumption is by far the largest part of the operating costs for the heat pump and typically makes up 50-70% of the total cost of heating with the majority of the balance being financing costs.

The simplest method for implementing a heat pump project is to install an air-sourced heat pump which operates in isolation from other utilities and the process but this will likely give the highest operating costs. For every 1 °C increase in the heat source temperature, the heat pump efficiency will increase by approximately 2.5%. Utilising waste heat from the condenser on a refrigeration system or the oil cooler on an air compressor can increase the heat source temperature for the heat pump by more than 10 °C therefore deliver a 25% improvement in efficiency.

Optimising operating expenditure

Analysis has also shown that the capacity factor for the heat pump[2], is a highly important determinant on economic performance. Benchmarking graphs (in Appendix F) show economic performance via a simple payback calculation vs electricity to gas price ratio for a series of parameters including heat pump size, heat lift temperature and capacity factor.

Electricity consumption and electricity tariffs are the most important determinants for OpEx. The electrical consumption can be optimised by integrating the heat pump with waste heat from other utilities (refrigeration plant, compressed air system), other waste heat streams (exhaust air, flue gases, wastewater, sewer mains water etc) or other process streams that needs to be cooled (milk, fruit juices). Most plants will have multiple streams which need heating or cooling. How do you know when to employ heat recovery and when to use waste heat as the heat source for a heat pump? Pinch analysis is a method used to match heating and cooling loads to provide a guide on how to optimise heat recovery and the heat source for a heat pump. A higher temperature heat source for the heat pump will reduce the heat lift temperature which increases the COP which decreases the electrical consumption.

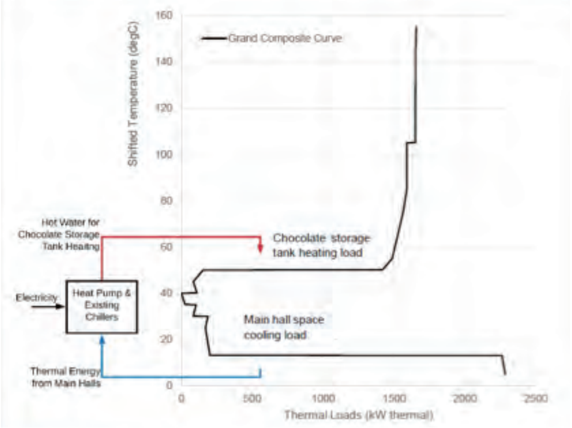

Figure 8: Grand composite curve diagram from a feasibility study

For electricity tariffs, consideration should be given to minimising peak electrical usage and peak electrical time-of-use tariffs. A thermal battery can be used to optimise this for example allowing the heat pump to be turned off between 5 pm and 9 pm each day to avoid peak time-of-use tariffs.

A heat pump installation creates the opportunity to save energy consumption and carbon emissions. This is highly dependent on the emission factors in the relevant state electrical grid and the reduction in total energy usage achieved due to reduce heat losses, higher heat recovery the heat pump COP. Creation of white certificates can generate a significant portion of the capital cost in white certificates which can greatly affect the cost benefit analysis for the project. It is recommended that anyone considering a heat pump project work with an accredited energy consultant for advice on possible white certificate creation.

Hybrid heating solution

It's possible to divide up the heating job between low temperature and high temperature needs to create a hybrid solution where the heat pump performs the low temperature duty and another heating method performs the high temperature duty. The Victorian meat processor case study included in Appendix A used this approach to reduce the fossil fuel consumption by more than 75% whilst still achieving the necessary process temperatures. This hybrid solution helped achieve the least-cost pathway for decarbonisation by minimising the potential need for carbon offsets or switching to solutions expected to have higher costs such as biogas, solar thermal or green hydrogen.

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2. Capacity factor is defined as the average consumption, output, or throughput over a period of time of a particular technology or piece of infrastructure, divided by its consumption, output, or throughput if it had operated at full (rated) capacity over that time period.

Challenges and opportunities to consider when planning for a heat pump

Electrical capacity and upgrades

For sites with historically large natural gas usage relative to electrical consumption, it is likely that moving from solely natural gas for heat to a heat pump may create capacity constraints – to the site's electrical capacity or to a nearby substation which would incur high upgrade costs. This can be mitigated with a thermal battery to reduce peak loads and using on-site solar PV production.

Figure 9: An electrical distribution board.

Space limitations

As noted above, maximising the capacity factor for the heat pump is essential to minimising the heat pump capital expenditure and achieving the best possible economic returns. As explained in Appendix D, this requires the installation of a thermal battery or hot water tank which will typically require additional floorspace. Whilst this can be minimised by using a taller tank, it can still be a major barrier for space constrained sites.

Optimising demand flexibility for increased variable renewables utilisation

With the increasing penetration of variable renewable electricity in the National Electricity Market, technologies that are capable of demand flexibility will become increasingly important. Whilst a heat pump is not capable of being turned on an off like a light switch, it can be scheduled to come on during times of low (or negative) electricity tariffs or high solar PV production to soak up renewable electricity in a thermal battery which can then be despatched as it is needed. The heat pump can also be turned off if needed be to help provide electrical grid resilience and stability as well as optimising on-site electricity costs.

Figure 10: Students standing outside the 'water battery' thermal storage at the University of the Sunshine Coast. Source: Veolia Australia & New Zealand.

Other challenges

The earlier listed aspects are considered to have the largest impact on the viability of a heat pump project, however, the following challenges and limiting factors also need to be taken into account:

- Companies lacking a decarbonisation roadmap to provide a long-term context for assigning resources and assessing proposals within that roadmap.
- Business constraints continue to be a major barrier to progressing changes to fossil fuel alternatives. The limited staff availability and the lack of capital to install metering stopped two projects from proceeding to feasibility.
- The adoption of new technologies for decarbonising process heating can be accelerated with the support of government subsidies via white certificate schemes or targeted grant funding.
- Some sites that have secured relatively low cost gas contracts may not be able to transition to renewable heating until gas supply contracts are renewed.
- The lack of industry awareness of renewably powered alternatives to fossil-fuelled process heating technologies is limiting the adoption of heat pumps.
- Further electrification of manufacturing and transport will inevitably put higher demands on electrical distribution network systems. The planning of such upgrades and the fair distribution of costs will be essential to not discourage first mover businesses from progressing projects that utilise more renewable energy and decarbonise their processes.
- Conversion of long pipe runs from steam to a hot water reticulation system may add significant costs to the project. These could be avoided in cases where heat pumps are deployed to meet discreet local process needs rather than as a centralised system.

CONCLUSIONS AND NEXT STEPS

The necessary transition to non-fossil fuel process heating technologies is still in its infancy. Whilst heat pump technology is very mature for space heating and domestic hot water heating, it has not been thoroughly developed for other sectors and applications. These studies have shown the technical and economic viability of heat pumps for renewable process heating across a range of manufacturing sectors.

The lessons learnt from these process heat studies will help reduce barriers for adoption of heat pumps and help to guide the suitability of different renewable process heating technologies. The main barriers identified to adoption relate to replacing the traditional approach to sizing of heating utilities with a data driven, integrated approach which utilises a thermal battery to minimise the heat pump CapEx and utilises waste heat to minimise the operating costs.

The studies showed several cases where heat pumps are economically viable at typical business hurdle rates (e.g. a simple payback less than three years), however, many of studies gave paybacks greater than three years (see Appendix F). In the absence of decarbonisation commitments, the economic performance of a heat pump investment will slow the adoption of the technology, unless existing white certificate schemes or new ones are utilised.

It should be noted that the lessons learnt have only identified barriers to adoption. There is a long journey ahead before heat pumps are fully accepted as a viable process heating alternative. Energy users are yet to fully understand the heat pump technology across the entire asset life cycle, from installation and commissioning to operation, optimisation and maintenance. Some companies will be able to learn from their own experience and make improvements for future projects. For many companies, the installation of a heat pump will be a one in ten-year event so they may not have past experience to guide them. They will rely heavily on publicly available information, training courses, skilful advisors and a competitive market of heat pumps suppliers.

To support on-going improvement across the entire technology life cycle it will be essential to create and support networks that foster continuous improvement for the technology. Such networks can also support the development of heat pumps that operate at higher temperatures (>100 °C) which are currently at the pilot and demonstration stages.

To support on-going adoption of the technology, development of white certificate schemes to reward businesses for decarbonising will likely be needed to accelerate adoption of the technology. Further investigation is required for the optimal intervention and incentives needed from such schemes.

APPENDICES

Appendix A: Case studies from feasibility reports

3 Ravens Brewery case study by Regenerate Engineering

Feasibility study

Site details

Company:	3 Ravens Brewery
Site:	Thornbury VIC
Application sector:	Beer production (craft sector)
Technologies featured:	Natural refrigerants Chiller with advanced heat recovery ('chiller heat pump') Latent and sensible energy storage (thermal battery) Optimised heat exchange systems
Consultant engaged for this study:	Regenerate Engineering Pty Ltd
Technology partner engaged:	Minus40 Pty Ltd

Context

Established in 2003, craft beer pioneer 3 Ravens Brewery is the oldest independent brewery in Melbourne. It plans to modernise and expand its production facilities by 300% utilising best practice technologies and a holistic integration of their processes. The project commenced in 2020 with the installation of a cool roof and 74 kW of solar PV. In 2021 3 Ravens started the proposed energy works by completing a building fabric upgrade (insulation and tight sealing) of its Co-Brew coworking office space.

Figures 11 & 12: Inside and birds-eye view of 3 Ravens Brewery with modified marketing image, Thornbury Victoria

Renewable energy on site:

- The 2020 solar PV installation is part of the holistic plan which includes the Renewable Energy for Process Heat Opportunity study.
- 74 kW of solar PV using panel-level optimisation and high efficiency panels is designed to maximise output from the cool roof refurbished site footprint.
- Roof space has been left clear for planned CO_2 plant heat rejection equipment and for skylight windows. There is no further opportunity to increase PV on the current site.

Process heat is used for the following processes:

- Steeping and mashing beer ingredients
- Heating up and vigorously boiling wort
- Cleaning in place (CIP)

Process cooling is used for the following processes:

- Fermentation cooling (glycol system)
- Cold liquor production (potable system)
- Crash cooling processes (glycol)
- Cold conditioning (glycol)

The facility uses a 15 kW resistive element to preheat filtered water (hot liquor) and a 55 kW element to further heat then boil the wort produced from that hot liquor and mash ingredients.

It uses two chillers which operate independently to produce chilled Glycol treated water and chilled filtered water (cold liquor), operating all process and ingredient cooling services. Additionally on site there are several ageing electric reverse cycle R22 HVAC split systems and a cold storage facility.

3 Ravens is looking for a better solution than upgrading the current business-as-usual (BAU) equipment to cope with the larger volumes. Such an upgrade would result in a massive increase in energy expenditure, leave a significant liability of the HVAC equipment as the R22 phase-out continues, and cause demand problems with the grid supply. All energy consumption savings and business models are based on a holistic view of the upgraded operation compared with a business-as usual upgrade using current technologies.

Proposal

It is proposed to replace the inefficient heating and cooling processes with a single cycle flexible CO_2 refrigerant machine. This will effectively combine these processes to provide the heating functions as a by-product of the cooling functions. This study has taken an extensive pre-feasibility study with a detailed mass/energy balance of the process, applied pinch analysis principles and solution development. It has detailed how the proposed equipment can be integrated into the current plant including extensive upgrades required. It recommends an expansion of the initial proposal into space heating and cooling (HVAC) services for public spaces at the site due to further thermodynamic and cost efficiencies which were identified in the process.

Batch process becomes near-constant process

Any heat pump system works best operating in a constant state (optimised with variable speed systems), yet brewing is by nature a batch process. Where the heating and cooling services come from the same machine it is a challenge to ensure that the system can produce both thermal streams where they are not required at the same time. The key to success in this application is system flexibility, redundancy, storage and better use of heat exchangers in the process, all driven by advanced PLC control.

Using the thermal model this involves scenario modelling and system flexing according to worst case usage profiles of different brew recipes and brew schedules, as well as average and light profiles. Seasonal performance of the CO_2 systems needs to be accounted for. Further, when HVAC is added, the system needs to be robust to the seasonal extremes in demand that this adds.

Requirements: two intermittent thermal energy streams with storage [cold (-5 °C), and hot (95 °C)] and a third on-demand stream [medium (50 °C)] for improved heat exchange processes.

	Hot	Cold	Medium or gas cooler
TC Operation	Yes	Yes	Yes
SC Operation	No	Yes	Yes

Chiller heat pump operation: trans-critical (TC) or subcritical (SC) mode. In TC mode it can simultaneously produce the three thermal streams, and in SC mode it can do cold and medium. If there is no demand for medium heat in either TC or SC modes, the heat automatically diverts to a gas cooler. The gas cooler and/or the medium heat service is required to cool the CO_2 again to enable the cycle to run. Note that if either of the heating energy services are required cooling cannot be turned off, as the equipment is essentially a chiller, albeit with advanced heat recovery systems.

Technologies:

- 45 kW variable duty CO_2 chiller with advanced heat extraction
    - Heat pump can switch from SC mode to TC mode.
    - External adiabatic gas cooler to complete CO_2 cycle.
    - Additional heat exchanger to intercept and use mid-temp thermal stream for HVAC purposes if required.
- Thermal battery and distribution systems
    - Redundancy to cope with usage extremes includes 29 kWh of latent energy storage
    - Additional heat exchange processes in cold liquor tank and in wort heating process
    - New stratified hot liquor tank.
    - Careful re-design of pipelines and tanks so that they can stratify correctly; addition of multiple temperature sensors to monitor SOC of hot and cold thermal batteries.
- Hydraulic thermal distribution systems and air handling
    - Fully re-designed balanced header glycol circuit, supplying cooling and fan coils for hop freezer and cool room.
    - Mid-temperature thermal loop and tempered cold glycol to supply fan coils in public spaces.
    - CO_2-controlled full HVAC in occupied spaces including analytical energy modelling of spaces post building fabric upgrade.

Applications, reduction of resistive heating duty and other emissions

Although all of the hot liquor and cleaning in place, and part of the wort heating process, is carried out with the renewable heat technology (heating from 67 °C to 85 °C) there is still a residual wort heating process followed by a vigorous boil to be carried out by the elements.

Overall, 57% of the process heating is carried out by the chiller heat pump with the rest carried out by the heating elements.

Although difficult to quantify due to a lack of certainty of leakage rates, the removal of 35 kW of R22 HVAC equipment adds to the environmental performance by retiring a high GWP refrigerant nearing end of life. It also reduces input energy required significantly for that service due to reduction of demand from building fabric improvement and increase in HVAC COP. This addition, which has increased the chiller heat pump's size from 18 kW to 45 kW has reduced the payback period by 2.5 years when compared to BAU replacement.

Energy productivity, use of renewable energy and co-benefits of the upgrade

The upgrade will improve brewing quality by the integration of best practice brewing automation equipment and better process control. Comfort and ventilation will be improved for patrons of the bar area and the co-working office space.

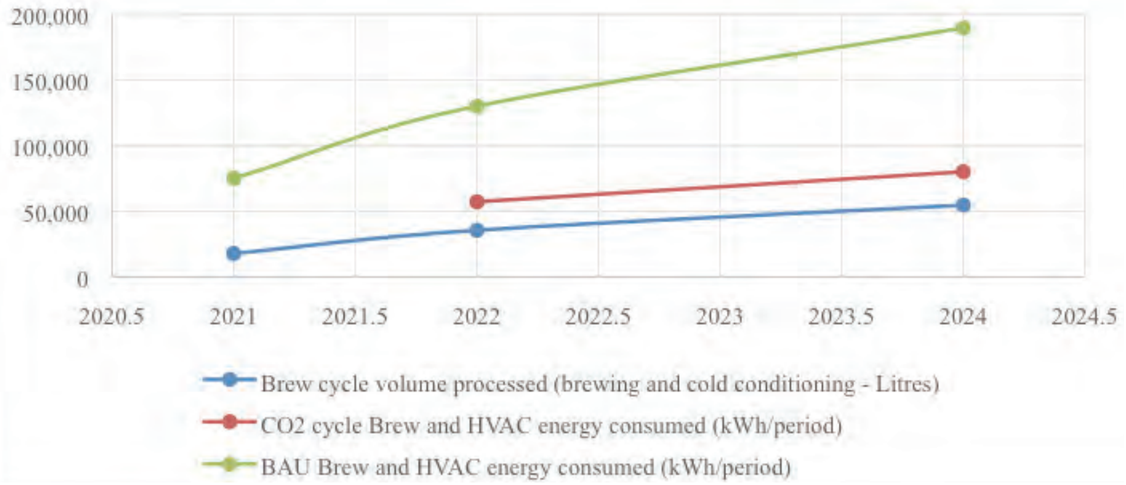


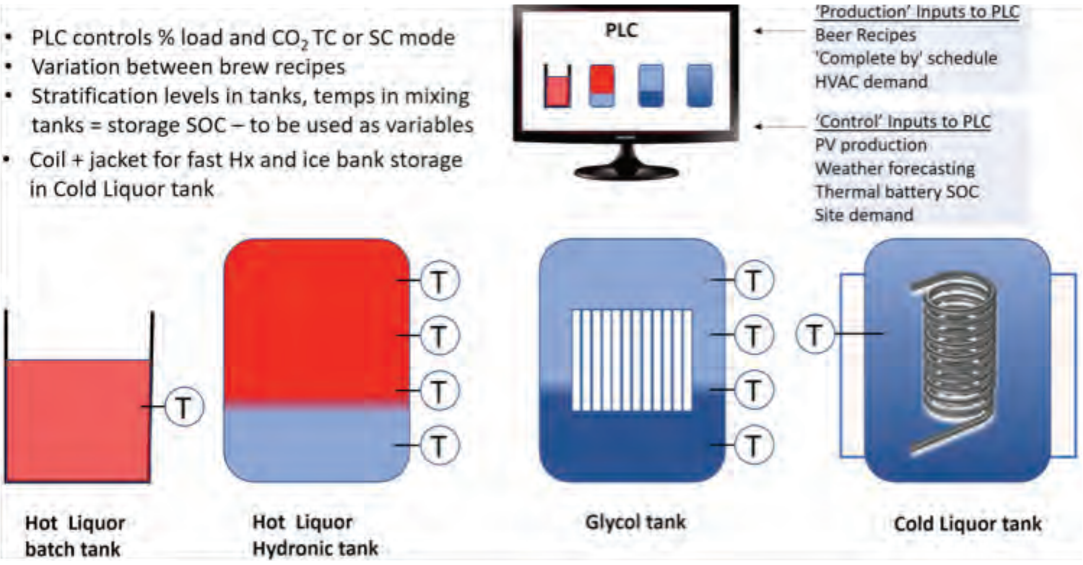
Figure 13: Energy productivity over upgrade stages compared with BAU upgrade

The current renewable energy fraction of 44% supplied will increase significantly at the first stage of the upgrade (Q1 2022). With the full upgrade it is planned to maintain this at 50%, and then utilise GreenPower for the remainder.

Financial model

Compared to a business-as-usual capacity upgrade (new chillers, expanded resistive heating processes, new lowest cost HVAC and expanded re-designed glycol network).

Capital cost (excluding GST)	$220,000
Net energy cost savings	$33,800
Net reduction in energy consumption	525 GJ/year (76% reduction)
Reduction in GHG emissions (Vic Scope 2+3)	159 t CO_2
Simple payback period	6.5 years



- PLC controls % load and CO_2 TC or SC mode
- Variation between brew recipes
- Stratification levels in tanks, temps in mixing tanks = storage SOC – to be used as variables
- Coil + jacket for fast Hx and ice bank storage in Cold Liquor tank

Figure 14: Key focus - PLC controlled thermal management to support batch process from heat pump output

Meat processing case study

Feasibility study

Site details

Site location:	Victoria, Australia
Application sector:	Red meat processing
Technologies featured:	High temperature ammonia heat pump

Context

Main site activities

The site specialises in processing and supplying beef, lamb and goat in carcase and carton form via an extensive distribution network which enables them to service customers across metropolitan and regional Victoria, South Australia, New South Wales and Queensland. In addition to the domestic market, the business holds a Tier One export license and has been exporting to approved countries for almost two decades.

Main uses for process heat

The heating of water to different target temperatures (82 °C steriliser and 40 °C wash streams) requires a large heat demand while at sub-ambient temperatures the refrigeration plant provides both for freezing and chilling product processing at the site. Heating water is currently provided by natural gas hot water units whilst chilling and freezing is via vapour compression cycle ammonia refrigeration systems. The main focus of this project has been the interaction between, on one hand, energy demands above ambient temperature and, on the other, cooling needs below ambient temperature. The heat pump selected provides an opportunity to recover low grade heat to replace fossil fuel used to heat water and at the same time reduce the power demand on the condensing circuit of the plant's refrigeration systems.

Old technology to be replaced

Heating water is currently provided by natural gas hot water boiler units. Currently there is a BRKT 240 reverse flame hot water heater de-rated to provide an output of 2,000 kW of thermal energy. There are also three older Raypak atmospheric type hot water units (two 505 kW and one 960 kW output capacities) that are now used as back-up to the main 2000 kW boiler.

Proposal

Proposed technology

A high temperature heat pump designed to produce approximately 1,000 kW heat output to satisfy the majority of the heat demand for the hot water at the site. It is estimated that this new system will reduce the natural gas consumption of the site by about 75% on an annual basis and increase the site's power use by around 12%.

The unit will run 24 hours a day during weekdays delivering hot water to the thermal storage to smooth out the demand. On weekends there is also a requirement for this water for batch type cleaning cycles. This system will mainly replace the base hot water service delivered by the existing gas water heater with gas planned to be employed for topping only once the heat pump energy recovery system is installed. Whilst the existing boiler has a capacity of 2,000 kW the 1,000 kW to be provided by the heat pump will satisfy the load as it operates continuously with resultant hot water stored in two thermal storage tanks with a capacity of 160,000 litres. The heat pump will also reduce existing condenser load on the central ammonia system by an estimated 800 kW thermal heat rejection with consequent savings in water losses and power used by condenser fans and refrigeration compressors.

In conjunction with the heat pump it is also proposed to install oil cooler heat recovery systems on three ammonia screw compressors to increase total heat recovery from the site.

Applications

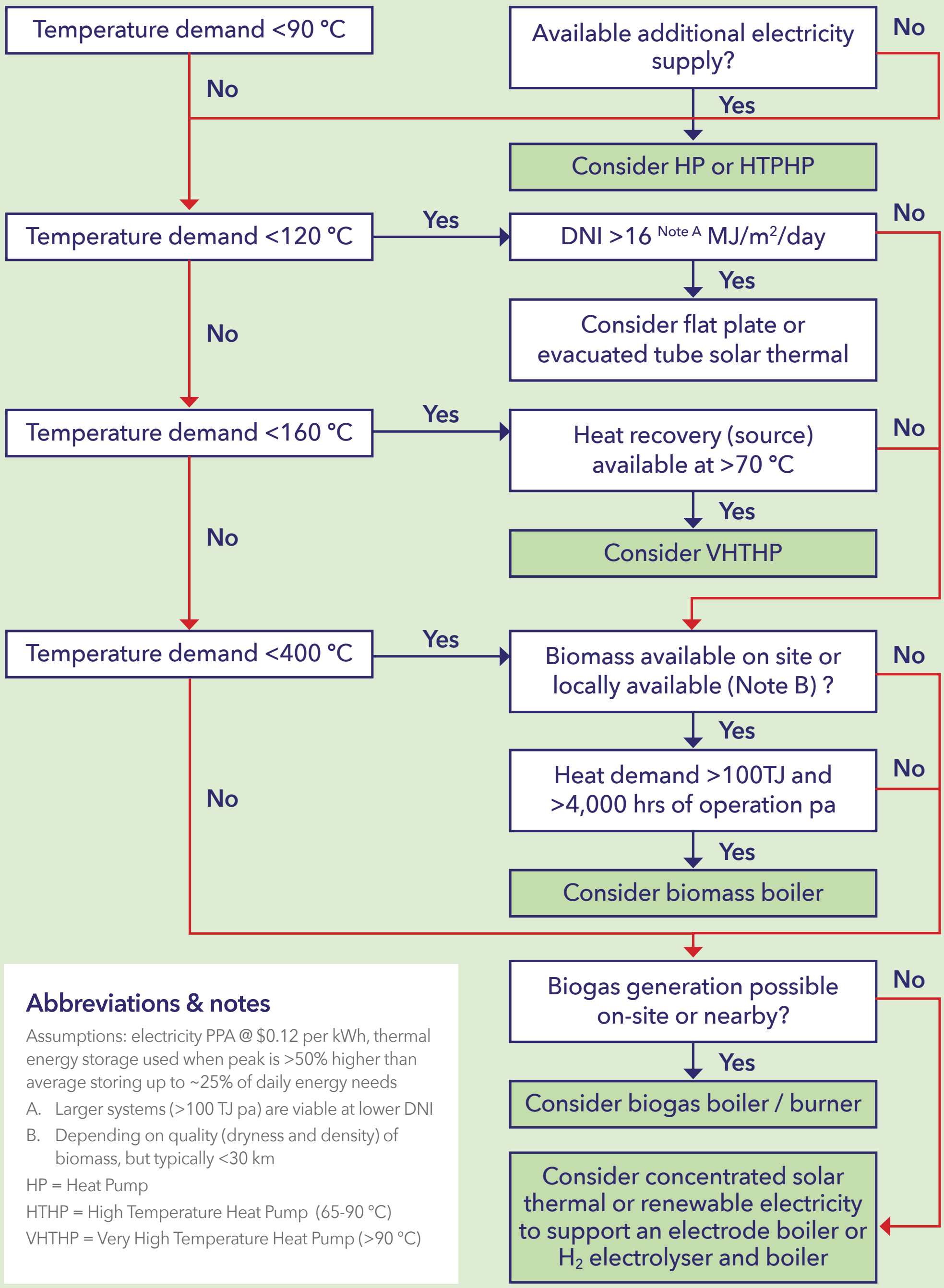
This technology can be applied at plants with requirement for large volumes of process hot water that also has large refrigeration capacity. This characteristic allows low grade heat to be elevated into useful high grade by the use of heat pump technology. Typical industries where this is applicable are other meat and poultry plants, dairy liquid, solids and powder processing, fruit and wine production.

Project benefits

- Annual net energy cost savings: 16%
- Annual net reduction in energy consumption: 44% of total energy
- Annual reduction in fossil fuel consumed for process heating: 80%
- Additional renewable energy consumption which would result from the project: 3,856 GJ per year
- Renewable energy fraction averaged over a year (GJ renewable energy used / GJ total energy used) for the site: 36% on completion of the heat pump
- Annual reduction in greenhouse gas emissions: 1,007 tonnes CO_2-e (22%)
- Annual potable water reduction in condenser: 8,631 kilolitres giving ewaulting water cost savings: $46,704 per year
- Productivity benefits of improved availability/reliability of steriliser water flow and temperature improved refrigeration condenser capacity available and reduced chemical use for condenser water treatment.
- Potential to avoid future refrigeration condenser and gas boiler expansion requirements.

Appendix B: Fossil-free heat selection flowchart

Fossil-free heat selection



Abbreviations & notes

Assumptions: electricity PPA @ $0.12 per kWh, thermal energy storage used when peak is >50% higher than average storing up to ~25% of daily energy needs

A. Larger systems (>100 TJ pa) are viable at lower DNI

B. Depending on quality (dryness and density) of biomass, but typically <30 km

HP = Heat Pump

HTHP = High Temperature Heat Pump (65-90 °C)

VHTHP = Very High Temperature Heat Pump (>90 °C)

Appendix C: Heat pump diagnostic tools

Heat pump questionnaire

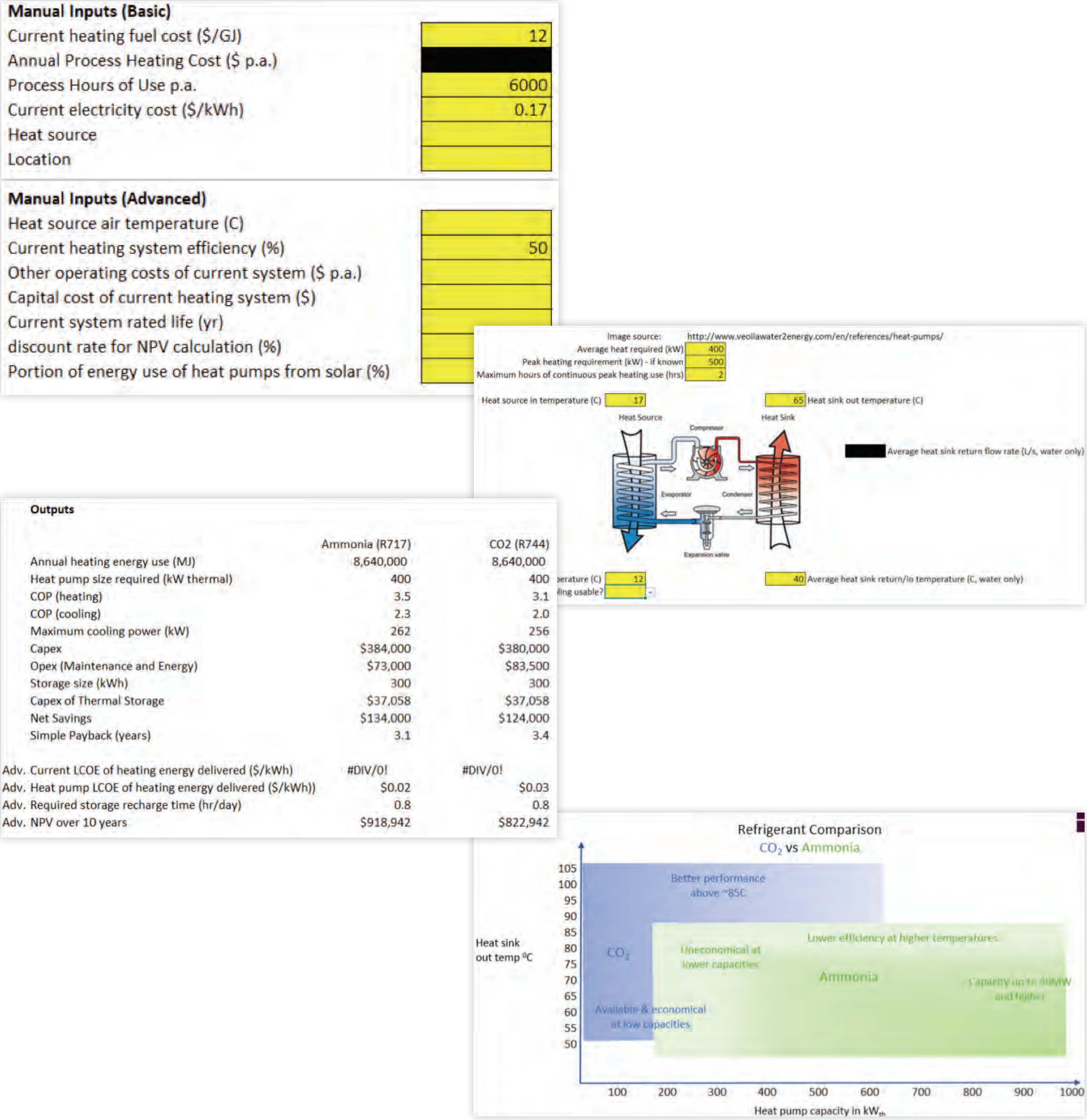
As a result of the lessons learnt in these studies, the below questions and diagnostic tool were developed to help assess if a site is ready to consider heat pump technology or if other conditions precedent should be fulfilled before the investigating the technology. A 'yes' answer to each of the questions below increases the likelihood that a heat pump is suitable for the process heating.

- Does the organisation have sustainability or decarbonisation commitments?
- Is the existing boiler due for replacement or major repair works in the next three years?
- Does the site operate more than 40 hours per week? (Ideally more than 76 hours)
- Does the site operate more than 2,000 hours per year? (Ideally more than 4,000 hours)
- Can the site exit existing gas contracts within the time frame needed to implement a heat pump project (approximately six months)?
- Does the site have higher minimum accepted return on investment for decarbonisation projects? e.g. 4 - 6 year simple payback, internal rate of return
- Does the site have sufficient metering in place to determine energy flows i.e. electricity, gas, thermal?
- Does the site have excess solar PV production during the day?
- Does the site have heat load profile data to determine peak load and thermal battery sizing?
- Is >25% of the site heating demand less than 90° C?
- Is the current boiler/hot water heater efficiency less than 85%?
- Is the overall steam system efficiency <70%? (GJ used in processes/ GJ in)
- Is there detailed process data available? (e.g. heat loads and required temperatures)
- Does the site need additional heating capacity to increase production? (i.e. bottlenecks)
- Does the site have spare electrical capacity?
- Does the site already have a hot water storage tank?
- Does the site have spare space equivalent to 150% of the current boiler for a heat pump installation?
- Is the spare space already covered/enclosed?
- Is there a hot water reticulation system in place?
- Does the site have refrigeration plant?
- Does the site have waste heat leaving site? Hot flue gases or hot water or hot product or hot by-products?
- Are the waste heat flows mapped/known?
- Does the site have experience with heat exchangers?
- Is there value in reducing the water consumption from the cooling towers?

Heat pump selection tool

An Excel-based tool was developed to allow a site to enter basic heating requirements to determine approximate heat pump performance characteristics and costs.

Visit https://www.futureheat.info/tools to access the tool.



Manual Inputs (Basic)	
Current heating fuel cost ($/GJ)	12
Annual Process Heating Cost ($ p.a.)	[redacted]
Process Hours of Use p.a.	6000
Current electricity cost ($/kWh)	0.17
Heat source	
Location	

Manual Inputs (Advanced)	
Heat source air temperature (C)	
Current heating system efficiency (%)	50
Other operating costs of current system ($ p.a.)	
Capital cost of current heating system ($)	
Current system rated life (yr)	
discount rate for NPV calculation (%)	
Portion of energy use of heat pumps from solar (%)	

Image source: http://www.veoliawater2energy.com/en/references/heat-pumps/

Average heat required (kW)	400
Peak heating requirement (kW) - if known	500
Maximum hours of continuous peak heating use (hrs)	2

Heat source in temperature (C) 17

65 Heat sink out temperature (C)

[redacted] Average heat sink return flow rate (L/s, water only)

perature (C) 12

ling usable?

40 Average heat sink return/in temperature (C, water only)

Outputs

	Ammonia (R717)	CO2 (R744)
Annual heating energy use (MJ)	8,640,000	8,640,000
Heat pump size required (kW thermal)	400	400
COP (heating)	3.5	3.1
COP (cooling)	2.3	2.0
Maximum cooling power (kW)	262	256
Capex	$384,000	$380,000
Opex (Maintenance and Energy)	$73,000	$83,500
Storage size (kWh)	300	300
Capex of Thermal Storage	$37,058	$37,058
Net Savings	$134,000	$124,000
Simple Payback (years)	3.1	3.4
Adv. Current LCOE of heating energy delivered ($/kWh)	#DIV/0!	#DIV/0!
Adv. Heat pump LCOE of heating energy delivered ($/kWh))	$0.02	$0.03
Adv. Required storage recharge time (hr/day)	0.8	0.8
Adv. NPV over 10 years	$918,942	$822,942

Figures 15-18: Images of the heat pump selection tool.

Appendix D: How to minimise CapEx and OpEx

Increasing the capacity factor of a planned heat pump will minimise the CapEx required. Capacity factor can be increased by reducing the nameplate capacity and increasing the operating hours of the heat pump.

Reduce the nameplate capacity

Action #1: Determine heating demand profile

When choosing the appropriate size for a heat pump or steam boiler, consideration must be given to the peak heating demand which may occur at a particular time of year or time of day. The peak heating demand can be determined from an existing steam system by obtaining heating demand data and natural gas usage data. Heating demand data will typically come from a steam flow meter or feedwater flow meters and steam tables. For a gas burner that creates hot air, the heat demand will likely come from the natural gas consumption. This data should provide intraday heating profile and intra-seasonal heating profiles similar to that shown in Figures 20 and 21.

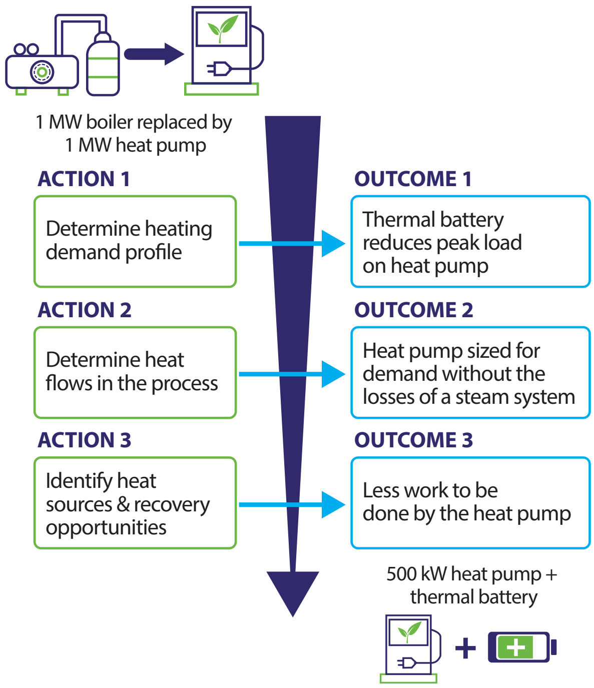
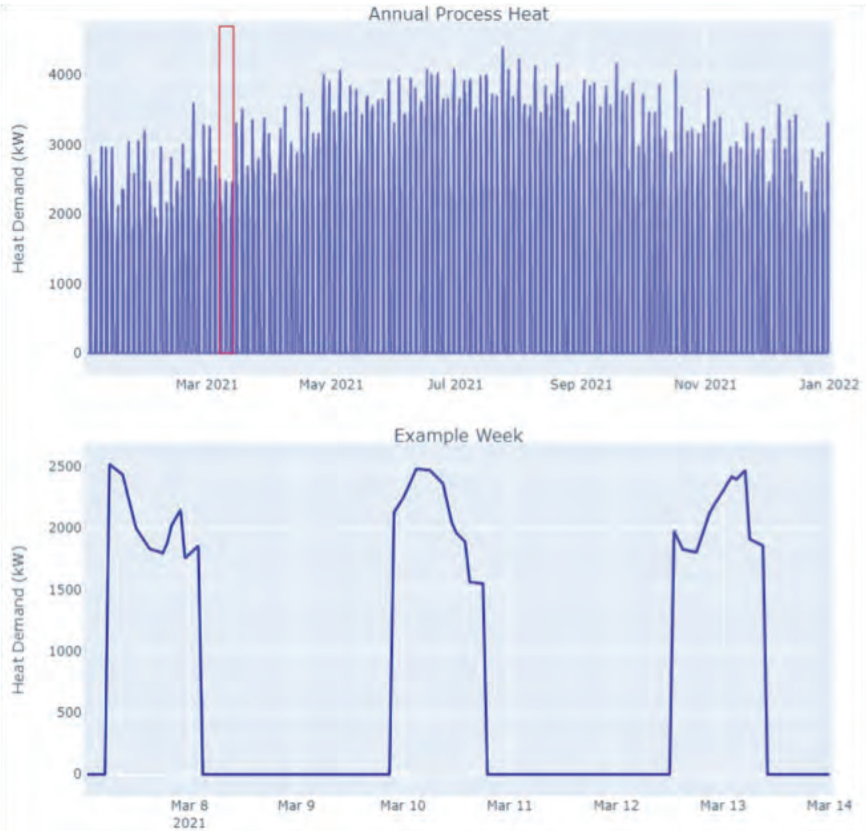


Figure 19: Right-sizing your heat pump.



Figures 20 & 21: Weekly and annual views of heat demand.

Action #2: Determine heat flows

To maximise heat recovery and heat pump performance, heat flows need to be mapped. These can be done via a Sankey diagram or Mass and Energy Balance flow diagram. A sample Sankey Diagram is shown in Figure 22.

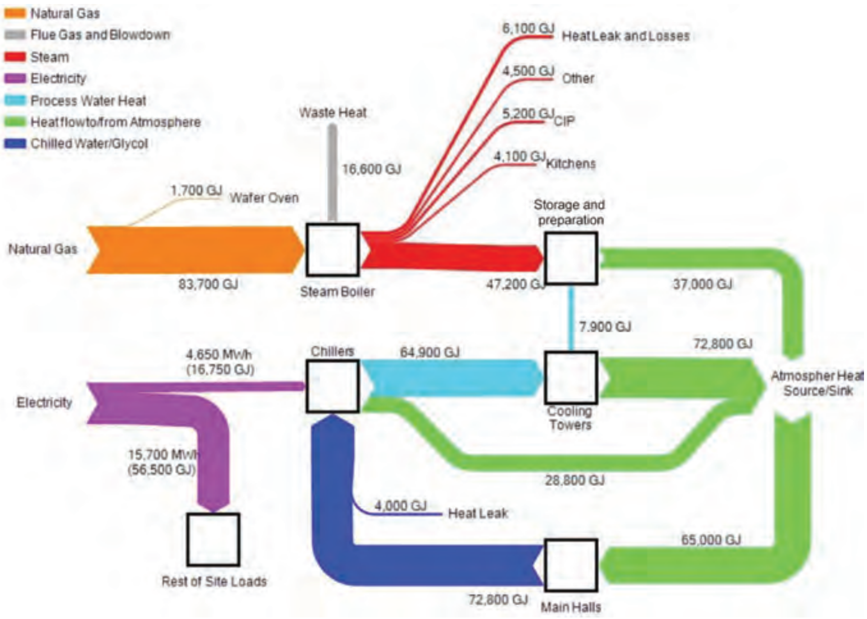


Figure 22: An example of a Sankey Diagram from a feasibility study.

Action #3: Determine heat recovery opportunity and heat sources for a heat pump

Once energy flows are mapped, pinch analysis can be used to determine heat recovery opportunities and identify suitable heat sources for the heat pump to reject cold to.

Heat losses from a heat pump will be significantly less than for a steam boiler system. See Figure 23 below for a summary of losses which often result in a steam system being less than 70% efficient.

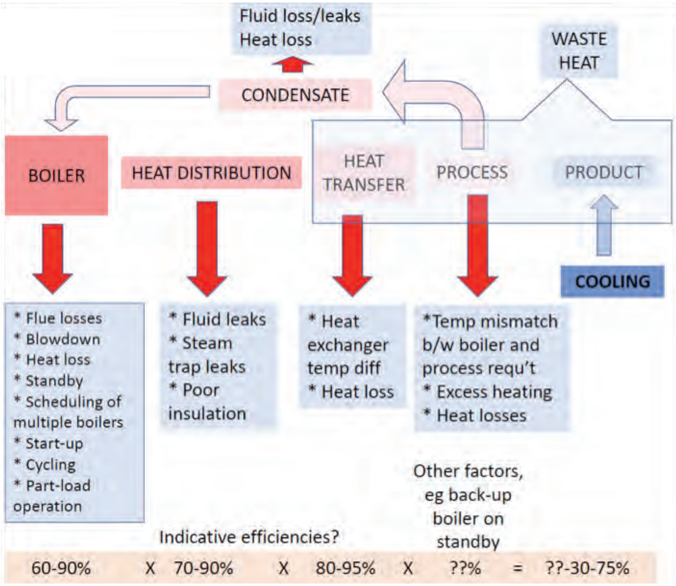


Figure 23: An example of a heat loss summary for a steam system. Source: Pears, A, 10 April 2018, Towards a Post-Promethean World: beyond process heat from fire *[conference presentation] A2EP Innovation X-change, Sydney, Australia.*

Action #4: Size heat pump and thermal battery

After determining which heat flows to use for heat recovery and assessment of the peak heating demands, the heat pump and thermal battery can be sized.

As shown in Figure X, heat demands can fluctuate over a day, week or year. A thermal battery or hot water storage tank is ideal for smoothing these heat demands throughout the day or week. The ideal sizing of a thermal battery would give the nameplate capacity of the heat pump equal to the average demand for the operating day or week. From Figure X above, the average weekly demand is 1,500 kW vs the peak demand of 2,500 kW. Sizing the heat pump for 1,500 kW and a thermal battery is likely to save >20% of the required CapEx for the project.

Consideration should also be given to maximising on-site solar PV production and optimisation of time-of-use electricity tariffs. Modelling may result in the selection of a large heat pump capacity and large thermal battery to take advantage of different electricity costs. An example of a modelling output is shown in Figure 24.

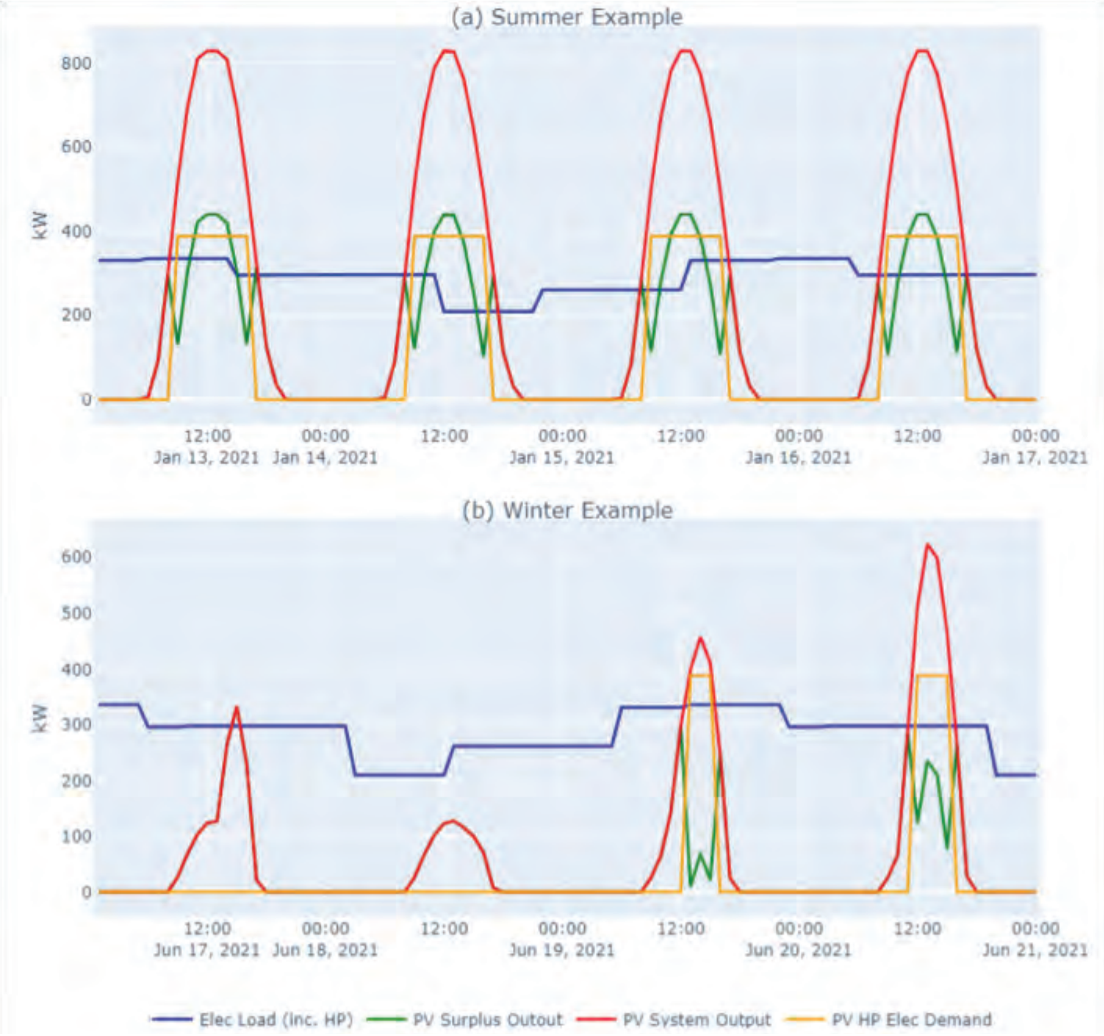
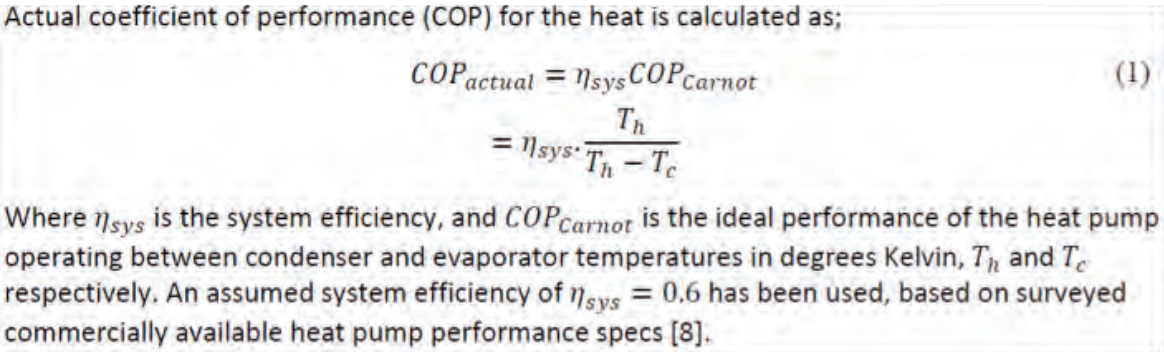


Figure 24: Summer and winter output and demand summaries.

How to minimise OpEx

The activities to minimise OpEx and similar to those for minimising CapEx. Understanding heat demand and mapping heat flows both assist in minimising OpEx. OpEx for the heat pumps is dominated by electricity costs as this will be a magnitude higher than maintenance costs. Electrical costs are determined by the efficiency of the heat pump system design and by the laws of thermodynamics. The heat pump design can be affected by compressor efficiency, refrigerant selection, controls, heat recovery options, economisers, etc. The laws of thermodynamics predict the heat pump Coefficient of Performance due to the operating parameters for the heat pump as determine by the following equation:



Actual coefficient of performance (COP) for the heat is calculated as;

$$COP_{actual} = \eta_{sys} COP_{Carnot} \qquad (1)$$
$$= \eta_{sys} \cdot \frac{T_h}{T_h - T_c}$$

Where η_{sys} is the system efficiency, and COP_{Carnot} is the ideal performance of the heat pump operating between condenser and evaporator temperatures in degrees Kelvin, T_h and T_c respectively. An assumed system efficiency of $\eta_{sys} = 0.6$ has been used, based on surveyed commercially available heat pump performance specs [8].

Figure 25: COP calculation.

$T_h - T_c$ is referred to as the heat lift and refers to the heating temperature required or heat sink temperature (T_h) and the temperature of the medium to be cooled or heat source (T_c). Optimisation of T_h and T_c offers the best way to improve OpEx for the heat pump and requires investigation and modelling. The heating temperature required is often fixed by process requirements, however, it is often beneficial to select the heat pump to perform part of the heating demand for example, if 100 °C hot water is required, the heat pump could be selected to deliver 95 °C hot water and another heating method could be used to deliver the final 5 °C. The second part of the equation, T_c, describes the temperature of the heat sink which will be used to evaporate the refrigerant. Choosing the heat sink temperature often has the most opportunity for optimising the heat pump COP. Waste heat sources could be from the refrigeration plant, a wastewater stream, a waste air stream, ambient air or water from a nearby sewer main.

Reducing electricity costs

Time-of-use tariffs and maximising usage of on-site solar PV production represent the best ways to reducing electricity costs. Sizing of a thermal battery or hot water storage system allows flexibility of operation to optimise electricity costs. How to do this is described in the above section on reducing CapEx.

Reducing maintenance costs

Similar to a refrigeration system, a preventative maintenance program is essential for keeping maintenance costs predictable and reduce the risk of major failures. It should be noted that higher heating temperatures are likely to result in higher maintenance costs.

Appendix E: Pinch analysis

Energy consultants who have completed pinch analysis training and use the technique for assessing the best way to integrate a heat pump with available heat sources include:

- 2XE – www.2xe.com.au
- Advisian - https://www.advisian.com/en
- DETA Consulting – www.deta.global
- Energetics – www.energetics.com.au
- Flexigen – https://www.flexigen.co/
- Northmore Gordon – www.northmoregordon.com
- pitt&sherry – www.pittsh.com.au
- Regenerate Engineering – https://regeng.com.au/
- Shell Energy – https://shellenergy.com.au/

Appendix F: Benchmarking graphs

Each of the pre-feasibility studies reported techno-economic results for various renewable process heating technologies. This data was used to develop benchmarking graphs to help analyse various factors affecting the economic performance of the heat pump Various factors considered were: the size of the project (CapEx) to determine if economies of scale were relevant, heat lift temperatures, capacity factor and heat pump capacity versus the boiler capacity it is displacing/replacing.

Note, the bubbles represent the same site throughout this series of graphs. The bubble size represents gigajoules of natural gas reduction per annum for the first graph and then the electricity to gas price ratio in the other graphs. The green bubbles represent the same site going from pre-feasibility estimate (light green) to feasibility estimate (medium green) to final investment decision estimate (dark green). The large increase from feasibility to final investment decision relates to upgrading of on-site electrical systems which was deemed necessary to keep sufficient site capacity.

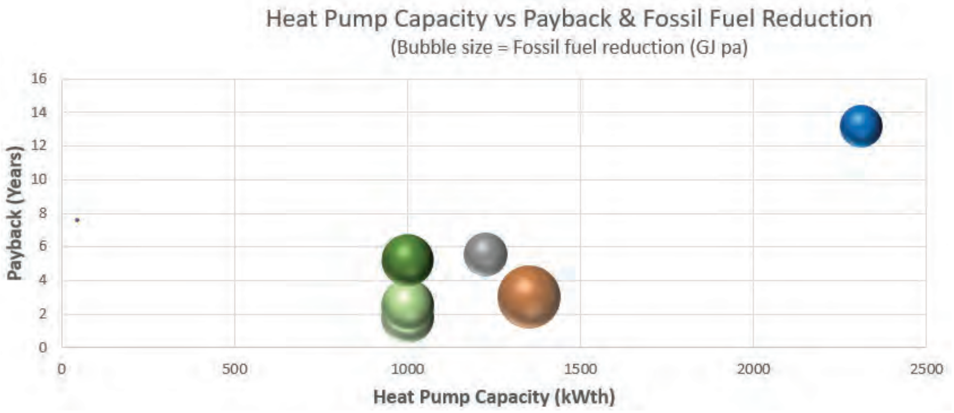


Figure 26: Payback, capex including new RE power supply, fossil fuel reduction

Note the large increase in the final CapEx for the green site due to the need to upgrade on-site electrical infrastructure.

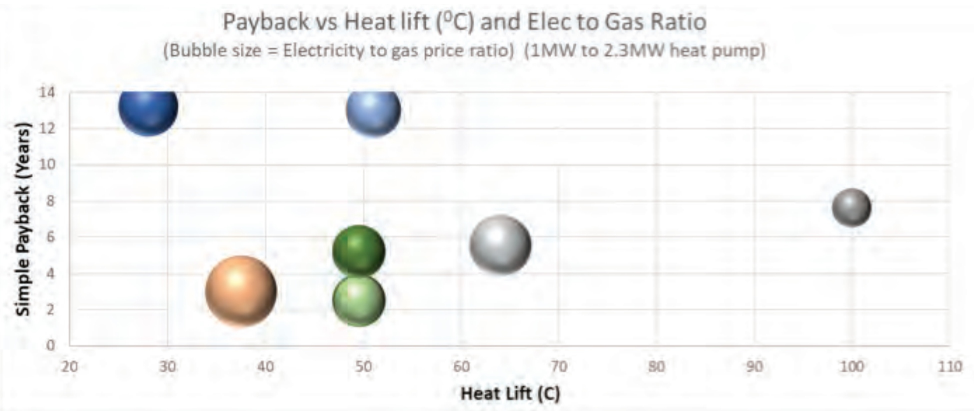


Figure 27: Simple payback vs heat lift vs electricity to gas price ratio

A correlation between heat lift and simple payback was expected with lower heat lift giving a shorter payback, however, this was not clearly evident. Outliers (in blue) are due to low-capacity factor from low number of operating hours per year (<4,000 hours per annum). A correlation between bubble size was expected with small bubbles, i.e., cheaper electricity/more expensive gas, expected to give shorter paybacks. In theory a smaller heat lift should overcome a large electricity to gas price ratio as seen for the orange bubble where the highest observed electricity to gas price ratio of 3.4 was offset with the small heat lift of 38 °C and high COP of 5.3.

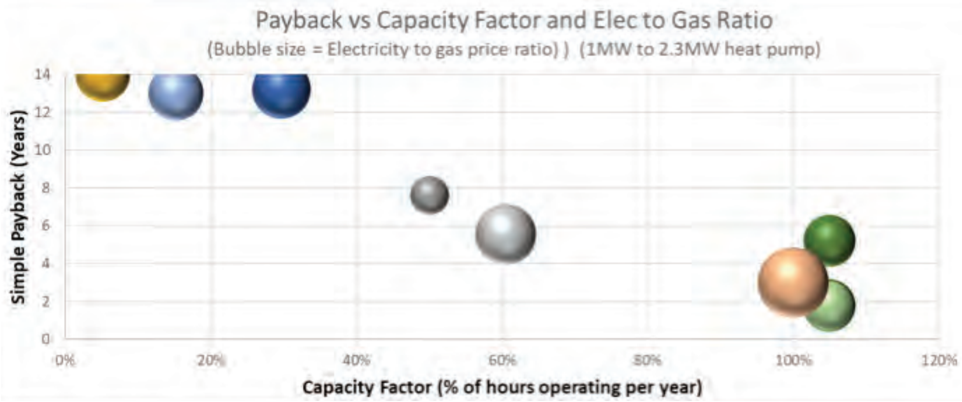


Figure 28: Simple payback vs capacity factor vs electricity to gas price ratio

Capacity factor showed the most consistent correlation to simple payback. The yellow site had the lowest capacity factor of 11.5% and gave the longest payback period. It should be noted the capacity factor for the green sites is greater than 100% due to additional heat recovery from the refrigeration plant oil coolers providing approximately 10% of the needed heat.

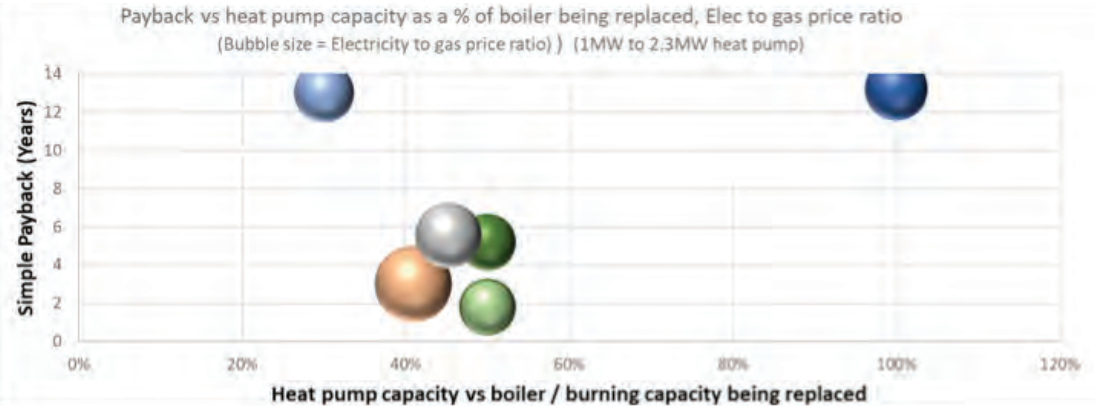


Figure 29: Simple payback vs capacity factor vs electricity to gas price ratio

Heat pump capacity vs the boiler load it was replacing was typically less than 50%. For the dark blue site, the heat pump replaced a burner to generate hot air with a capacity factor of approximately 30%. This site did not have sufficient space to install a thermal battery, therefore the heat pump could only operate when the heat was demanded. For the light blue site, the heat pump replaced an oversized boiler, however, it still had a very low capacity factor as seen in Figure 28.

Combining data from reports and the ITP Thermal *Renewable Energy Options for Industrial Process Heat* report (2019) chart showing Levelised Cost of Heating (LCOH) for different technologies, gives the following results:

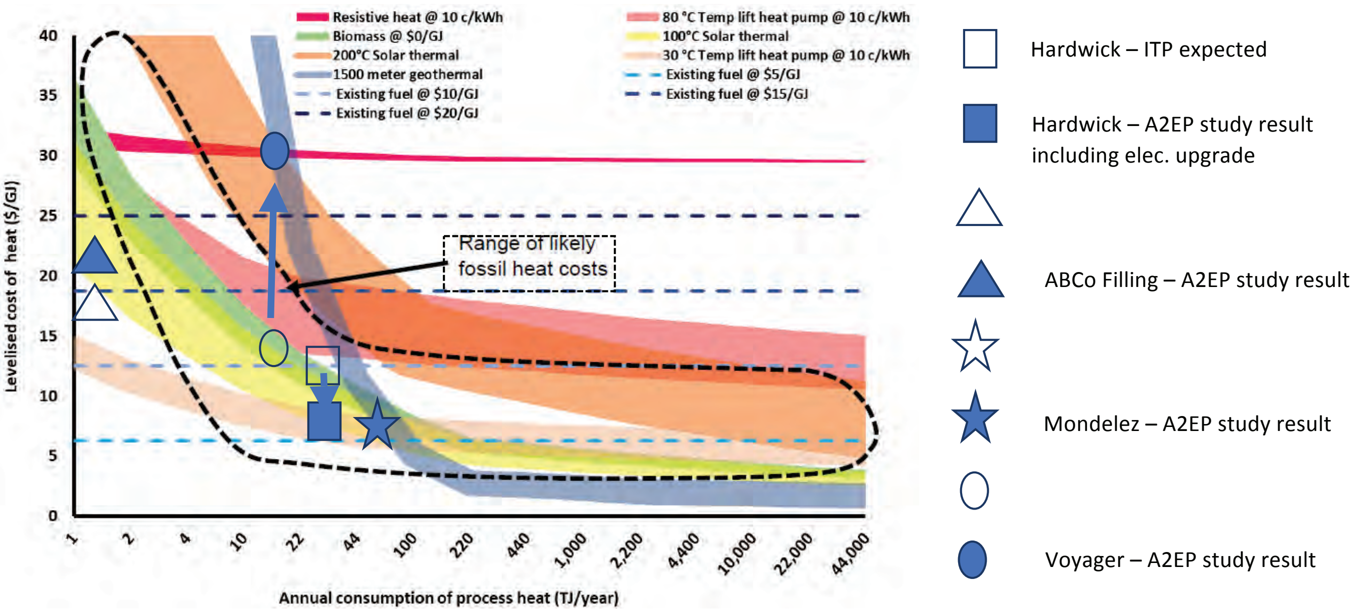


Figure 30: Levelised Cost of Heating: feasibility studies vs ITP study. Source: ITP Thermal Renewable Energy Options for Industrial Process Heat *report, 2019.*

LCOH summary

1. The expected LCOH was comparable to that estimated in the ITP Thermal report with many results falling in to the LCOH expected for fossil fuels.
2. The square site gave a lower than forecast LCOH, mainly due to the high capacity factor.
3. The triangle site a higher than expected LCOH mainly due to the low capacity factor.
4. The star site had a LCOH as predicted, despite having a high capacity factor, mainly due to the lower lift temperatures not giving the large drop in LCOH as predicted by ITP Thermal.
5. The circle site had much higher than expected LCOH mainly due the higher cost of peripheral equipment (heat exchangers, large thermal battery, etc.) for the total project.

Main findings from benchmarking analysis

1. The size of the project or CapEx did not show improving economical returns, i.e. little evidence of economies of scale.
2. Strong relationship between capacity factor (hours of operation per year) for the heat pump and payback
3. Electricity to gas price ratios were in a similar range. The Mondelez feasibility study had the highest price ratio however the low heat lift (giving a high COP) and high-capacity ratio overcame this ratio to give a good payback.
4. When replacing a steam boiler it is typical that the heat pump will average less than 50% of the boiler capacity it is replacing.

References

Arpagaus, C (3 September 2020) *Advances in industrial heat pumps* [webinar], Australian Alliance for Energy Productivity, accessed 5 January 2022.

ITP Thermal Pty Ltd (2019) Renewable energy options for industrial process heat [PDF 5.41 MB] , Australian Renewable Energy Agency, accessed 20 February 2022.