Industrial Electrification Through Heat Pump Adoption for Process Loads

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Definition of Terms and Acronyms

A2EP - Australia Alliance for Energy Productivity

CARD – Conservation Applied Research and Development

COP_h – Coefficient of performance, heating output/electric input

Dth – Dekatherm or 10 therm

DOE – Department of Energy

ECO – Energy Conservation and Optimization

EPA – Environmental Protection Agency

EPRI - Electric Power Resource Institute

HWHP – Hot water heat pump

GHG – Greenhouse Gas

GWh – Giga watt hours of electric use

IHP – Industrial heat pump

IRA – Inflation Reduction Act

MDth – Million dekatherm

MNPCA - Minnesota Pollution Control Agency

MnTAP – Minnesota Technical Assistance Program

MVC - Mechanical vapor compression

MVR - Mechanical vapor recompression

M&V – Measurement and verification

NEMA - National Electrical Manufacturers Association

NGIA – Natural Gas Innovation Act

psig – pounds per square inch gauge (pressure relative to the ambient atmospheric)

ROI – Return on investment

RTC – Renewable Thermal Collaborative

SHP – Steam generating heat pump

Spark gap - The ratio of electric cost divided by gas cost per unit of energy

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Executive Summary

Industrial heat pump (IHP) development began in earnest in the 1980s, associated with uncertain gas markets, but the technology gained limited penetration in the United States industrial market due primarily to low cost-effectiveness and a lack of incentive for research and development. In recent years, the technology has become relevant to the modern economy due to greater focus on carbon reduction by way of electrification. For example, the 2018 Minnesota Energy Efficiency Potential Study (Nelson et al. 2018) found that the industrial sector had the second highest potential for natural gas savings. One of the largest opportunities in the sector is process heating – which is 13% of all industrial potential savings. However, many market and mechanical limitations remain.

Objectives

The primary goals for this market assessment were to identify and evaluate best candidates for moderate- to high-temperature heat pump applications and determine steps needed to establish market adoption of these technologies. This was accomplished by completing the following tasks:

- Survey and catalog existing IHP systems that can meet typical industrial process loads.
- Identify Minnesota industries with process loads that are candidates for electrification.
- Gather feedback from key stakeholders to understand the barriers related to the adoption of electrification measures.
- Conduct site surveys and evaluate heat pump opportunities of industrial facilities to identify candidates for piloting IHPs.
- Extrapolate findings from the sites and published literature to estimate the technical, economic, and maximum potential for heat pumps applied to Minnesota industrial facilities.
- Create a roadmap for market adoption.

Heat Pump Products and Applicable Processes

The IHP product market can be dissected in a few ways. One categorization is packaged vs. custom units. There is a recent increase in the prevalence of packaged units with a variety of sizes and temperatures available in the U.S. Some select applications and particularly high capacities still require custom component selection. A second categorization is the source/sink fluid. Current products are either air or water source, and either water or steam output. Typically, the minimum source temperature is near 68°F (20°C) for water source products, and 14°F (-10°C) for air source products.

The systems fall into two primary designs: mechanical vapor compression (MVC) and mechanical vapor recompression (MVR). MVC systems working fluid define the technical limit for discharge and suction temperatures, while compressor design determines capacity and lift. Both natural and synthetic refrigerants are used, with tradeoffs between global warming potential (GWP), ozone depletion potential (ODP), safety, and performance. Ammonia (see Figure 1) and synthetic refrigerants (R1000 series mixtures of traditional HCFC/HFC hydrofluoroolefins) are most common for high-temperature subcritical-cycle applications. Carbon dioxide (R744) units capable of up to 190°F (88°C) supply water are common and allow for more flexible designs. Units with supply temperatures from 212°F (100°C) to

300°F (149°C) are also offered by most industrial manufacturers possessing multiple stages of compression to manage the larger lifts. For leading heat pumps with highest capacities and supply temperatures >300°F (149°C), a booster steam compressor is added to the process fluid condenser output due to working refrigerant limitations. MVR systems have narrower applications where they can provide high COP_h and higher temperatures than MVC systems, but they require a process with waste low-pressure steam and typically do not provide simultaneous cooling.

Figure 1: Ammonia Screw Compressor

The technical potential for electrifying industrial process loads with IHPs depends on matching the IHP thermal operating constraints to the thermal load requirements. About half of process heat loads require too high of a temperature for commercially feasible IHP units. Large customers are more likely to have optimal applications for heat recovery, while small customers are more likely to have suitable process loads for lower temperature or air source applications. By industry, Food Processing and Pulp and Paper are of particular interest due to their temperature suitability.

Stakeholder Interviews

The interviews gathered information from key stakeholders regarding the market potential for heat pumps in Minnesota industrial facilities and identify facilities appropriate for an IHP demonstration project. We interviewed representatives from four stakeholder categories: (1) plant managers, (2) industrial designers and energy professionals, (3) manufacturers' representatives, and (4) utility staff who support industrial customers. The plant manager interviews determined their types of thermal processes, heat transfer opportunities, level of familiarity with IHPs, company sustainability goals, and decision-making process for system retrofits. The latter included questions about decision-making mechanisms at sites and funding mechanisms for energy projects. The plant manager interview questions were modified slightly, with additional questions for other stakeholders based on their role in the industrial facility market.

Interviews with plant managers, industrial designers, manufacturers, and utility representatives revealed growing interest in IHPs, particularly driven by corporate sustainability goals and greenhouse gas reduction targets. While plant managers were generally unfamiliar with IHP technologies, especially for high-temperature applications, they expressed strong willingness to explore pilot projects when aging equipment or sustainability initiatives were present. Manufacturers and consultants were well-informed and noted increasing market traction, particularly in Europe, with investments in packaged IHP systems. Utilities are beginning to support industrial electrification through custom programs and pilot funding, though there was no consensus on whether prescriptive or custom rebates would be most effective. The 2021 Energy Conservation and Optimization Act (ECO Act) and the Natural Gas Innovation Act (NGIA) have opened new pathways for funding and technical support, with demonstration projects underway. Overall, stakeholder feedback highlighted both the promise and the challenges of IHP adoption—while technical capabilities and funding mechanisms are improving, economic viability and operational constraints remain key barriers.

Site Surveys and Heat Pump Evaluations

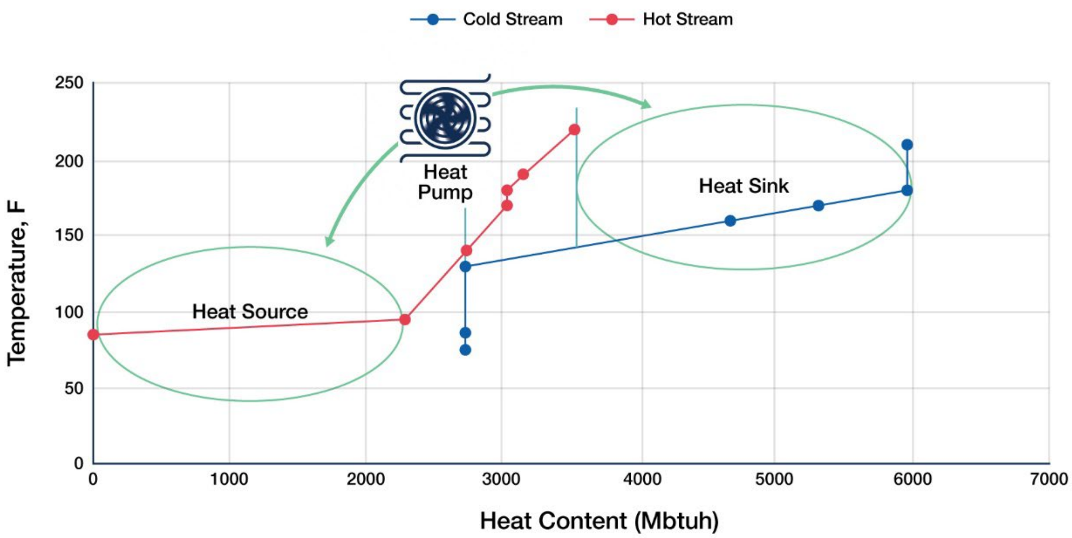
The goal of this task was to identify sites with thermal processes that may be suitable for the installation of moderate- to high-temperature heat pumps that lead to reduced carbon generation and energy cost savings. This was a focused engagement of plant managers through site surveys and follow-up meetings to discuss system features, estimated costs, opportunities, and barriers most relevant to their needs. Six industrial sites were selected for evaluation of heat pump applications, representing a range of sectors including food and beverage and pharmaceuticals/cosmetics (see Table 1). The surveyed facilities included diverse thermal processes such as cooking, pasteurization, refrigeration, and cleanroom air treatment, with varying heating and cooling demands. Each site provided input to identify feasible heat recovery opportunities, and field surveys were conducted to assess process characteristics, space constraints, and potential for heat pump integration. IHP feasibility was evaluated using pinch analysis to identify viable source-sink pairings and estimate temperature lift requirements. Hot water heat pumps (HWHP) and steam generating heat pumps (SHP) were assessed based on their ability to meet heating needs and recover available waste heat. Figure 2 shows the composite curve for site 3. The green circles show the potential for a heat pump to transfer energy from the available sources to the appropriate sinks. The heat pump would take that energy rejected at lower temperature and deliver it at a higher temperature to meet process hot water or steam needs.

For heat pump applications to be financially viable, the COP_h must exceed the spark gap. For the six surveyed sites, the IHP COP_h was always lower than the spark gap. For each site, the HWHP applications provided better economics than SHPs. However, in all cases, both types of IHPs had higher energy costs than the current gas systems that they would replace. This illustrates why Minnesota's relatively high spark gap presents a major barrier to cost-effective IHP adoption. Based on EIA reported 2023 industrial energy costs (IEA 2025), Minnesota had a spark gap of 4.62 which ranked 41st of the 50 U.S. states. However, excluding electric demand charges from the spark gap calculation improves the economics of heat pump applications. In some cases, this adjustment brings COP_h above the spark gap, suggesting that thermal storage, demand management strategies, or modified rate structures could make certain installations financially viable.

Table 1. Key Characteristics of Selected Sites

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Market Sector	Food / Canned Products	Food / Egg Processing	Pharmaceutical / Cosmetics	Food / Diary	Food / Egg Processing	Food / Brewing
Floor Area (sq. ft.)	500,000	150,000	180,000	105,000	323,000	41,800
Approx Annual Electric Use (GHW)	15	30	8	12	30	NA
Approx Annual Gas Use (Dth)	300,000	30,000	6,000	90,000	130,000	NA
Key Process Operations	Sauce making, Blanching, Cooking, Hot water	Cooking, Pasteurization, Hot water	Batch Process Heating, Hot water	Pasteurization/ HTST process has been optimized to include heat recovery and thermal storage	Pasteurization, Sterilization, Cooking, Hot water	Process heating, Hot water
Spark Gap (w/o demand)	4.68 (3.51)	5.05 (3.78)	3.98 (2.98)	NA (NA)	5.03 (3.77)	5.03 (3.77)
Utility programs, sustainability initiatives	10+ yrs	10+ yrs	10+ yrs	10+ yrs	5+ yrs	Relatively new plant 0–2 yrs

Figure 2: Site 3 Pinch Analysis Composite Curve

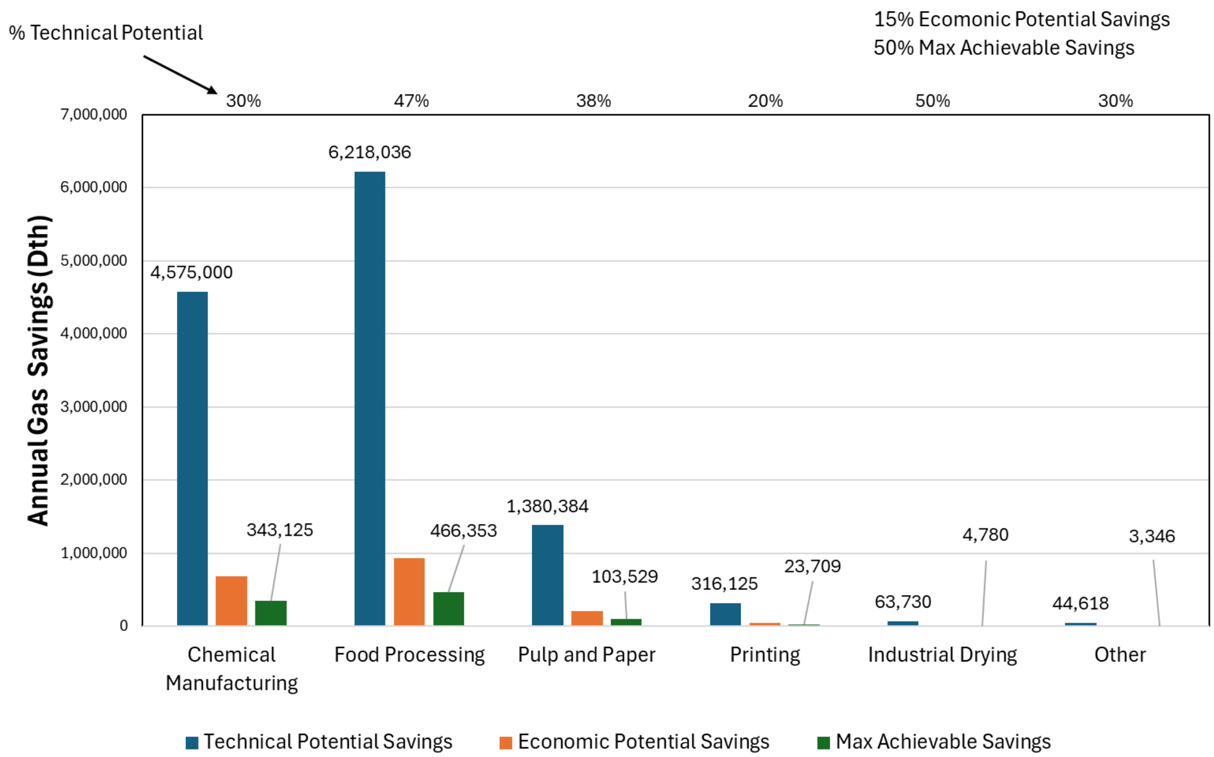


Market Potential

Market potential calculations were used to estimate annual gas use savings for IHP installations in Minnesota. The savings were computed for three levels of potential: technical, economic, and maximum achievable. First, the percentage of industrial thermal process gas use that could be satisfied with IHPs by sector was gathered from published information. Those percentages were then refined using results from project stakeholder interviews and IHP evaluations for Minnesota plant surveys. Finally, the percentages were applied to reported gas use by market sector for Minnesota industrial plants to compute annual gas savings for each of the three levels of potential.

Figure 3 shows results for the eight primary sectors analyzed by a 2010 MnTAP study (2010). Food processing operations typically involve both process heating and process cooling, including operator experience with ammonia refrigeration systems and the associated network of equipment vendors. With these factors — prevalence, thermal suitability, and market connectivity — food sector applications should be the largest focus for development and represent the highest savings potential (6.2 MDth). Pulp and paper and printing sectors are a secondary focus, with good technical potential of 1.4 MDth, but less operational similarity between incumbent systems and IHPs. For all Minnesota industrial plants IHPs have the potential to replace up to 32% of Minnesota's industrial natural gas consumption, equivalent to approximately 12.6 million Dth annually. This technical potential is concentrated in sectors with suitable temperature ranges for heat pump operation. Food processing, pulp and paper drying, and chemical manufacturing emerged as the most promising sectors, with food processing alone accounting for nearly half the total technical potential. However, when economic factors are considered, the potential drops significantly. With current Minnesota industrial gas and electric rates, only 4.7% of industrial gas use is economically viable for heat pump replacement, and just 2.4% is considered maximum achievable under current market and policy conditions.

Figure 3: Minnesota Industrial Heat Pump Potential Energy Savings by Sector



The analysis indicated that IHPs have the potential to replace up to 32% of Minnesota's industrial natural gas consumption, equivalent to approximately 12.6 million Dth annually. This technical potential is concentrated in sectors with suitable temperature ranges for heat pump operation. Food processing, pulp and paper drying, and chemical manufacturing emerged as the most promising sectors, with food processing alone accounting for nearly half the total technical potential. However, when economic factors are considered, the potential drops significantly. With current Minnesota industrial gas and electric rates, only 4.7% of industrial gas use is economically viable for heat pump replacement, and just 2.4% is considered maximum achievable under current market and policy conditions.

Roadmap for Market Adoption

IHPs have had limited penetration in the United States industrial market due primarily to low cost-effectiveness that did not incentivize research and development for the U.S. market. More recently, IHPs have become relevant due to greater focus on carbon reduction by way of electrification, but many financial, market, and mechanical limitations remain. The roadmap for greater adoption of IHPs used a combination of knowledge gained from research and heat pump evaluation activities for this project, the project team's extensive experience in providing energy efficiency recommendations for industrial plants, and reviews of roadmap recommendations from previous studies (CalNEXT IHPMS 2023; DOE 2022; and Rightor et al 2022). We identified a five-step roadmap to accelerate IHP market adoption:

1. Identify high-potential sectors and processes, especially in food and pulp/paper industries.
2. Develop screening tools and design guides to simplify feasibility assessments.

3. Implement and publicize demonstration projects to build market confidence.
4. Expand utility program services, including identification of best opportunities, incentives, and rate design innovations.
5. Educate stakeholders and promote IHPs through workshops, peer learning, and targeted outreach.

Successful implementation will require collaboration among utilities, manufacturers, plant managers, and policymakers. Improved screening tools, adjustments to rate structures, and broader education efforts are essential to overcome current barriers and unlock the full potential of IHPs in Minnesota. Demonstration projects will be a key step to build confidence and showcase successful applications. Demonstration sites should ideally be widely applicable, economically viable, and capable of replacing a significant portion of heating loads. Lower-impact but replicable installations (e.g., recovering heat from cooling towers for hot water) are good candidates for utility support. Two utility-led pilots—CenterPoint Energy's NGIA Industrial Electrification Pilot and Xcel Energy's Strategic Electrification Incentive Program—have been approved. These projects will provide full or partial funding for heat pump installations and performance verification, helping to address economic and technical uncertainties.

Conclusions

IHPs that can produce hot water to just below water boiling temperatures are available using a variety of refrigerants. Many manufacturers have systems with supply temperatures from 212°F (100°C) to 300°F (149°C) using multiple stages of compression and supply temperatures >300°F (149°C) can be produced using a booster steam compressor. About half of process heat loads require too high of a temperature for commercially feasible IHP units. Large customers are more likely to have optimal applications for heat recovery, while small customers are more likely to have suitable process loads for lower temperature or air source applications.

The stakeholder interviews revealed growing interest in IHPs, particularly driven by corporate sustainability goals and greenhouse gas reduction targets. While plant managers were generally unfamiliar with IHP technologies, especially for high-temperature applications, they expressed strong willingness to explore pilot projects when aging equipment or sustainability initiatives were present. Manufacturers and consultants were well-informed and noted increasing market traction, particularly in Europe. Utilities are beginning to support industrial electrification through custom programs and pilot funding, though there was no consensus on whether prescriptive or custom rebates would be most effective.

The site surveys of six industrial plants found that HWHPs provided better economics than SHPs when applied to the same heating process. However, in all cases, both types of IHPs had higher energy costs than the current gas systems that they would replace. This is due to the relatively high spark gap for Minnesota which ranked 41st of the 50 U.S. states. However, excluding electric demand charges brings COP_h above the spark gap, suggesting that thermal storage, demand management strategies, or modified rate structures could make certain installations financially viable.

The market potential analysis indicated that industrial heat pumps IHPs have the potential to replace up to 32% of Minnesota's industrial natural gas consumption, equivalent to approximately 12.6 million Dth annually. Food processing, pulp and paper drying, and chemical manufacturing emerged as the most promising sectors, with food processing alone accounting for nearly half the total technical potential. However, with current Minnesota industrial gas and electric rates, only 4.7% of industrial gas use is economically viable for heat pump replacement, and just 2.4% is considered maximum achievable under current market and policy conditions.

The roadmap for greater adoption of IHPs identified five-steps to help achieve that goal. Identification of high-potential sectors, improved screening tools, and broader education efforts are essential to overcome current barriers and unlock the full potential of industrial heat pumps in Minnesota. Demonstration projects will be a key step to build confidence and showcase successful applications. The sites should ideally be widely applicable, economically viable, and capable of replacing a significant portion of heating loads. Two Minnesota utilities have approved demonstration projects. In addition, refined metrics, rate innovation, program bundling, and enhanced customer services — create a pathway for utilities to accelerate industrial electrification. With careful alignment, they can reduce cost barriers while building confidence and replicability across the market.

Background

Industrial heat pump (IHP) development began in earnest in the 1980s, associated with uncertain gas markets, but the technology gained limited penetration in the United States industrial market due primarily to low cost-effectiveness and a lack of incentive for research and development. In recent years, the technology has become relevant to the modern economy due to greater focus on carbon reduction by way of electrification, but many market and mechanical limitations remain.

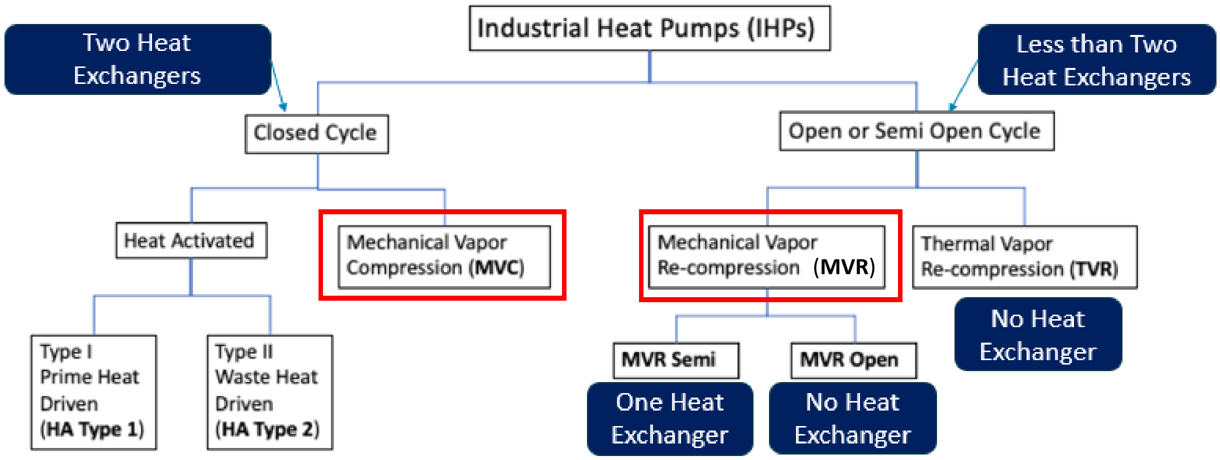
Center for Energy and Environment's (CEE) research through this study is preceded by academic research characterizing European and international markets by International Energy Agency (IEA) Annex 58, American Council for an Energy-Efficient Economy (ACEEE) studies (Rightor et al 2022; Chen, Elliott, and Hoffmeister 2024) characterizing market factors and resistances to industrial electrification, and select utility-oriented market evaluations, most notably *CalNEXT Industrial Heat Pump Market Study* (CalNEXT IHPMS 2023). Our work coincides with further IEA development in *Annex 58* (IEA Annex 58 2024). Specifically in Minnesota, our work is preceded by a 2010 Minnesota Technical Assistance Program (MnTAP) study of industrial gas consumption and electrification potential (MnTAP ECMS 2010) and is coincident with Minnesota utility studies funded through the Natural Gas Innovation Act (NGIA).

Technology

Electric process heat can be generated by direct conversion, i.e., electric resistance boilers, with an efficiency close to 1.0 but the decarbonization effect of such systems relies on low-carbon electricity generation. IHPs can provide an efficiency or coefficient of performance (COP= heating output/electric input) greater than 1.0. They require a heat source to provide electric driven heat of compression. In the optimal case, the heat pump will provide both useful heating and cooling.

Many heat pump technologies can accomplish high capacities and high temperatures. As shown in Figure 4, IHP technology for electrification falls into two categories: mechanical vapor compression (MVC) and mechanical vapor recompression (MVR). In MVC systems, refrigerants define the technical limit for discharge and suction temperatures, while compressor design determines capacity and lift (sink minus source temperature). Heat exchanger design allows for application to source and sink flows of different phase and temperature. Additional design components and configurations inform the system's efficiency. MVR systems have narrower applications where they can provide high COP_h and higher temperatures than MVC systems, but they require a process with waste low-pressure steam and typically do not provide simultaneous cooling. IHPs often have additional cycle features, such as economizer vapor injection and internal heat exchanger, whose presence distinguishes individual IHP products. Heat-driven and thermal-velocity-driven compression heat pump systems exist but are not within the scope of electrification.

Figure 4: Family Tree Classification of Industrial Heat Pumps



Adapted from ACEEE 2023, originally credited to Gluckman et al. 1988. Figure is augmented for our purpose with component distinctions (heat exchanger count). Boxed items are within the electrification scope of this study.

Products

The IHP product market can be dissected in a few ways. One categorization is packaged vs. custom units. There is a recent increase in the prevalence of packaged units with a variety of sizes and temperatures available in the U.S. Some select applications and particularly high capacities still require custom component selection.

A second categorization is the source/sink fluid. Current products are either air or water source, and either water or steam output. Products that produce steam from feedwater like a typical boiler are dubbed steam-generating heat pumps (SHP) and differ in configuration mostly with respect to their condenser side heat exchanger design.

Another key product characterization is the working fluid used. Both natural and synthetic refrigerants are used, with tradeoffs between global warming potential, ozone depletion potential, safety, and performance. In the modern refrigerant landscape, ammonia (R717) and synthetic refrigerants (R1000 series mixtures of traditional HCFC/HFC hydrofluoroolefins) are most common for high-temperature subcritical-cycle applications. Carbon dioxide (R744) is also used in a handful of the products surveyed, applied as a transcritical cycle. Finally, it is useful to divide products by sink temperature. Units capable of up to 190°F (88°C) supply water are common and allow for more flexible designs, e.g., single-stage compression, and refrigerant flexibility. For example, current R744 systems have a maximum heat sink around 90°C (194°F). Units with supply temperatures from 212°F (100°C) to 300°F (149°C) are also offered by most industrial manufacturers possessing multiple stages of compression to manage the larger lifts. For leading heat pumps with highest capacities and supply temperatures >300°F (149°C), a booster steam compressor is added to the process fluid condenser output due to working refrigerant limitations.

Table 2 gives an overview of products currently serving the IHP market in the U.S., adapted from the CalNEXT report (CalNEXT IHPMS 2023). In the table, each unit or unit family is categorized by type: MVC or MVR; refrigerant; supply temperature; capacity; cycle code, which gives some high-level characterization of each system design; and manufacturer category, which is designed to illustrate how the company has entered the IHP market, including whether its primary business is another type of equipment or the manufacturer is dedicated to heat pumps. The characteristics and market favorability of products belonging to each manufacturer category are a particular opportunity for further investigation. Many of the row entries in the table encompass several distinct product lines with different cycle configurations, and capabilities for temperature and capacity. Table 2 does not list design heat source temperatures, but typically the minimum source temperature is near 20°C (68°F) for water source products, and 14°F (-10°C) for air source products. Several smaller European companies manufacture flagship units not available in the U.S. Notably, Trane Technologies also manufactures several models of 194–248°F (90–120°C) sink temperature heat pumps, but they are only available in Europe.

Table 2. IHP Products

IHP Type	Manufacturer Category	Manuf.	Product	Cycle Code[a]	Refrigerant	Max supply °C	Low-High Capacity (kW)
MVC	Industrial	Vilter	VSH, VSSH, VHP	S-1/2-CW-HW	R717, R744	90	600–1,700
MVC	Industrial	GEA	RedGenium, RedAstrium	R/S-1/2-CW-HWS	R717, R744	150	1,800–2,900
MVC	Industrial	Kobelco	SGH 120, 165, HEM-HR-90A, HEM-90A	S-1/2-CAW-HWS	134a, R245fa	175	60–800
MVC	Industrial	Fuji	Steam Gen HP	R-1-CW-HS	R245fa	120	30
MVC	Industrial	Mayekawa	Unimo Series, Plus+HEAT, Ecocircuit	R-1/2-CAW-HAWS	R744, R717, R1234ze	120	75–475
MVC	Commercial	Johnson Controls	Sabroe Series	R/S-1/2-CW-HW	R717	90	300–13,000
MVC	Commercial	Carrier	AquaForce	S-1-CW-HW	R1234ze, R1233zd	120	200–2,500
MVC	Dedicated - New Company	AtmosZero	AtmosZero 2.0	U-2-CA-HS	Not Published	150	750 (est)
MVC	Dedicated - New Company	Flow	AWHP Split/Packaged, WWHP	R-1-CAW-HW	R744	82	400–550
MVR	Industrial	GEA	Open Type HP	R-1-CW-HW	R717	95	3,500
MVR	Industrial	Kobelco	MSRC160	R-1-CS-HS	R718	175	800
MVR	Industrial	Piller	MVR	R-1/2-CS-HS	R718	230	1,000
Mixed	Industrial	Siemens	Ravv	C-2-CW-HWS	R1233zd, R1234ze	180	8,000–70,000
Mixed	Dedicated - Established	MAN Energy Solutions	ETES CO2	C-2-CW-HWS	R744	150	10,000–50,000
Mixed	Dedicated - Established	Turboden	Custom	C/R-2-CW-HWS	Many	200	3,000–30,000
MVR	Dedicated - Established	Skyven	Arcturus SGHP	C-2-CW-HWS	R718	215	37,000

Cycle Code: X-N-CYY-HZZ: A – compressor: S = screw, R = reciprocating, C = centrifugal, U = unknown. N – number of stages. CYY and HZZ – Cold/Source and Hot/Sink: A = air, W = water, S = steam.

Applicable Processes

The potential for electrifying industrial process loads with heat pumps depends primarily on thermal, spatial, and existing electric service constraints. Thermal constraints can be dealt with by proper design, matching the appropriate product to the process in question, but about half of process heat loads require too high of a temperature for commercially feasible IHP units. Spatial constraints within the plant define whether an existing heat-recovery heat source can be leveraged economically. If a facility already has enough electric demand capacity to add the load required by the heat pump, the application is much more likely. Each constraint and their interactions present efficiency and cost tradeoffs. This section describes suitable subindustries and Minnesota market features.

Table 3 shows thirteen suitable subindustries for heat pump application, nine of which belong to the food and beverage industry. Each figure is represented in energy intensity per ton of product, gigajoules per ton (GJ/T) for heat energy, and kilowatt hours per ton (kWh/T) for electric energy required. The first column, “Direct Fuel” involves heat applied to a process with a dedicated or integrated burner, so such a heat load being served by steam or hot water from a heat pump is unlikely. By contrast, the second column, “Boiler Fuel” is deemed 100% electrifiable for the first pass of this analysis. Electricity consumption is also reported in the “Electricity” column, to show the interplay of electrifiable process heat with present electric infrastructure. The “Elec Gain Factor” column references CalNEXT’s heat pump performance model, originally reported in kWh/T added and summarized here as a ratio of future to current electric consumption. The final two columns of Table 3 are not addressed in the following figures, but they represent site energy savings achieved by electrification.

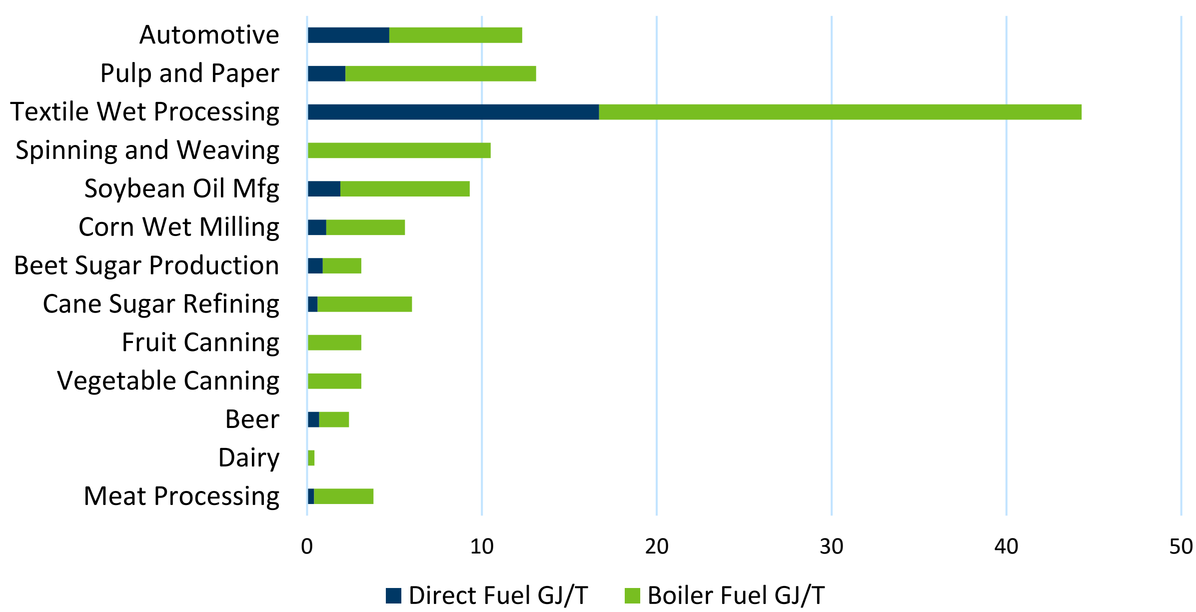
Table 3’s information is visualized in Figure 5 and Figure 6 for further clarity. Figure 5 displays the first two columns of the table, showing the process heating energy intensity of subindustries by direct and boiler fuel, while Figure 6 contrasts ‘Elec Gain Factor’ column with electrifiable fuel use to show that electrifiable processes do not always coincide with large present electric service at their respective facility.

Table 3. Suitable Subindustries – CalNEXT IHP Market Study 2023

Sector	Direct Fuel (GJ/T)	Boiler Fuel (GJ/T)	Electricity (kWh/T)	Current Total (GJ/T)	Elec Gain Factor	Future Total (GJ/T)	Total GJ % Reduced
Meat Processing	0.4	3.4	197.5	4.51	2.6	2.24	50.4%
Dairy	0.06	0.36	88.2	0.74	1.5	0.53	28.5%
Beer	0.7	1.7	88.4	2.72	2.5	1.50	44.8%
Vegetable Canning	0	3.1	49.7	3.28	7.8	1.39	57.6%
Fruit Canning	0	3.1	45.2	3.26	6.9	1.12	65.6%

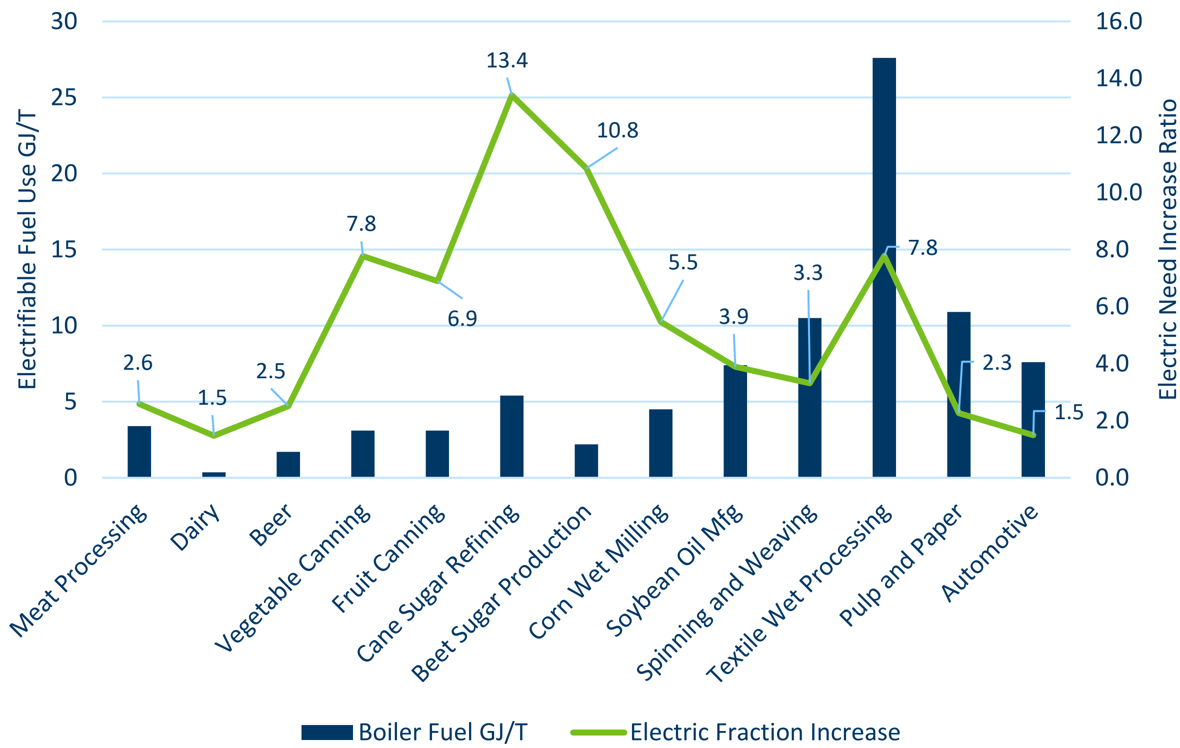
Sector	Direct Fuel (GJ/T)	Boiler Fuel (GJ/T)	Electricity (kWh/T)	Current Total (GJ/T)	Elec Gain Factor	Future Total (GJ/T)	Total GJ % Reduced
Cane Sugar Refining	0.6	5.4	41.4	6.15	13.4	2.60	57.7%
Beet Sugar Production	0.9	2.2	24.6	3.19	10.8	1.86	41.7%
Corn Wet Milling	1.1	4.5	129.2	6.07	5.5	3.64	39.9%
Soybean Oil Mfg.	1.9	7.4	203.5	10.03	3.9	4.75	52.7%
Spinning and Weaving	0	10.5	646.1	12.83	3.3	7.70	39.9%
Textile Wet Processing	16.7	27.6	484.6	46.04	7.8	30.27	34.3%
Pulp and Paper	2.2	10.9	989.2	16.66	2.3	10.27	38.4%
Automotive	4.7	7.6	875.5	15.45	1.5	9.40	39.2%

Figure 5. Suitable Subindustries: Normalized process load



CalNext IHP Market Study 2023. Graphical representation of Table 2 data, per-ton-of-product heating process load served by direct and boiler fuel for several subindustries, nine of which belong to food industry. Note, 1 GJ ~ 0.95 Dth.

Figure 6. Suitable Subindustries: Electric Increase Required



Further graphical representation of Table 2 data, showing boiler fuel GJ/T with 100% electrification ratio to represent heat-pump-electrifiable process load, and the accompanied N-fold increase in electric consumption per ton of product. Note, 1 GJ ~ 0.95 Dth.

Figure 6 specifically illustrates the constraint of current electric service. There is a diversity of existing electric load magnitudes for each of the analyzed subindustries, which does not correlate directly with the magnitude of electrifiable load. The capacity of present electric service plays a large part in the cost-effectiveness of electrifying process heat loads. In other words, the best suited facilities will have substantial electrifiable process loads as well as significant existing electric consumption. For example, cane sugar refining has significant electrifiable process heat, but low existing electric load, so lower application potential. We seek to quantify a cross-sectional application potential metric through this research.

Table 4–Table 6 show our application of product-process knowledge to the Minnesota process heat market. The 2010 data from MnTAP (included in the tables is the most recent available. It is reported across each of the primary Minnesota utilities with industrial customers. Large customers are more likely to have optimal applications for heat recovery, while small customers are more likely to have suitable process loads for lower temperature or air source applications. By industry, Food Processing and Pulp and Paper are of particular interest due to their temperature suitability, though customers from each industry are being evaluated as interview candidates.

Utilities in Table 4 are, from left to right, CenterPoint Energy (CPE), Alliant Energy (AE), Minnesota Energy Resources (MERC), Great Plains Gas (GPG), and Xcel Energy (XE). These are the Minnesota utilities with significant industrial gas customers. Since many customers are served by separate gas and electric utilities, the corresponding electric utility whose load would grow by electrification is not known for each of the gas loads and customer counts in the table. Due to the age of the data, it provides a better picture of customer count than consumption, but neither is expected to have evolved substantially.

Table 4. Minnesota Potential: Total Gas Use (therms)

	CPE	AE	MERC	GPG	XE	Total
Food Processing	82,181,222	2,932,776	858,161	20,157,010		106,129,169
Fabricated Metals	15,712,688	745,257	2,211,582	9,938,430		28,607,95
Primary Metals	13,084,766			913,480	3,898,995	17,897,241
Printing	8,244,000				4,401,000	12,645,000
Industrial Drying			502,010			502,010
Pulp and Paper					28,758,000	28,758,000
	119,222,676	**3,678,033**	**3,571,753**	**31,008,920**	**37,057,995**	**194,539,377**

Table 5. Minnesota Potential: Number of Sites

	CPE	AE	MERC	GPG	XE	Total
Food Processing	98	5	61	14		178
Fabricated Metals	68	12	193	416		689
Primary Metals	26			2	45	73
Printing	30				300	330
Industrial Drying			12			12
Pulp and Paper					39	39
	222	**17**	**266**	**432**	**384**	**1321**

Table 6. Minnesota Potential: Average Gas Use Per Site (therms)

	CPE	AE	MERC	GPG	XE	Total
Food Processing	838,584	586,555	14,068	1,439,786		596,231
Fabricated Metals	231,069	62,105	11,459	23,890		41,521
Primary Metals	503,260			456,740	86,644	245,168
Printing	274,800				14,670	38,318
Industrial Drying			41,834			41,834
Pulp and Paper					737,385	737,385
	537,039	**216,355**	**13,428**	**71,780**	**96,505**	**147,267**

Objectives

The primary goals for this market assessment were to identify and evaluate best candidates for moderate- to high-temperature heat pump applications and determine steps needed to establish market adoption of these technologies. This was accomplished by completing the following tasks.

- Survey and catalog existing IHP systems that can meet typical industrial process loads.
- Identify Minnesota industries with process loads that are candidates for electrification.
- Gather feedback from key stakeholders to understand the barriers related to the adoption of electrification measures.
- Conduct site surveys and evaluate heat pump opportunities of industrial facilities to identify candidates for piloting industrial heat pumps.
- Extrapolate findings from the sites and published literature to estimate the technical, economic, and maximum potential for heat pumps applied to Minnesota industrial facilities.
- Create a roadmap for market adoption.

Stakeholder Interviews

The interview goals were to gather information from key stakeholders regarding the market potential for heat pumps in Minnesota industrial facilities and identify facilities appropriate for an IHP demonstration project. The plant manager interviews determined their types of thermal processes, heat transfer opportunities, level of familiarity with IHPs, company sustainability goals, and decision-making process for system retrofits. The latter includes questions about decision-making mechanisms at sites and funding mechanisms for energy projects. The plant manager interview questions were modified slightly, with additional questions for other stakeholders based on their role in the industrial facility market.

Heat Pump Screening Guide

The screening guide provides a method to evaluate potential IHP applications based on key design considerations. This guide helps jumpstart adoption of moderate- to high-temperature heat pumps by quickly identifying appropriate applications for more extensive evaluation. Appendix B includes a discussion of available screening tools and benchmarks their functions.

Site Surveys and Heat Pump Evaluations

The goal of this task was to identify sites with thermal processes that may be suitable for the installation of moderate- to high-temperature heat pumps that lead to reduced carbon generation and energy cost savings. This was a focused engagement of plant managers through site surveys and follow-up meetings to discuss system features, estimated costs, opportunities, and barriers most relevant to their needs. The site survey objectives were as follows.

- Obtain a high-level summary of process heating and cooling requirements.

- Understand typical operating schedules.
- Develop initial considerations (issues / concerns) for potential heat pump application.

The methods described in the heat pump screening guide were used to identify technically feasible heat pump installations. The COP and fraction of heating addressed were then determined for each installation to identify systems that may be appropriate for pilot projects.

Market Potential

Market potential calculations were used to estimate annual gas use savings for IHP installations in Minnesota. The savings were computed for three levels of potential: technical, economic, and maximum achievable. First, the percentage of industrial thermal process gas use that could be satisfied with IHPs by sector was gathered from published information. Those percentages were then refined using results from project stakeholder interviews and IHP evaluations for Minnesota plant surveys. Finally, the percentages were applied to reported gas use by market sector for Minnesota industrial plants to compute annual gas savings for each of the three levels of potential.

Roadmap for Market Adoption

IHPs have had limited penetration in the United States industrial market due primarily to low cost-effectiveness that did not incentivize research and development for the U.S. market. More recently, IHPs have become relevant due to greater focus on carbon reduction by way of electrification, but many financial, market, and mechanical limitations remain. A comprehensive effort for identifying the best applications for IHPs, the distribution of screening and design tools, implementing demonstration projects with wide application, and utility program services are described to improve market adoption.

Methodology

Stakeholder Interviews

We interviewed representatives from four stakeholder categories: (1) plant managers, (2) industrial designers and energy professionals, (3) manufacturers' representatives, and (4) utility staff who support industrial customers. Interview questions targeted three topics:

- Characterization of industrial thermal processes applicable to heat pump systems.
- Level of familiarity with IHPs.
- Decision-making process for implementation of process modifications.

The initial interview instrument was designed for plant manager interviews and included questions regarding their facility and company energy efficiency and/or sustainability goals (see Appendix B). For other stakeholders, the questions were adapted to apply to the general industrial market. Additional questions were included for other stakeholder groups:

- Industrial designers and energy professionals were asked which factors tend to motivate a customer to change a process design, types of measures most often implemented, and implementation barriers.
- Manufacturers' representatives were asked about the IHP products they have on the market and how helpful utility rebates would be to increase market penetration.
- Utility staff were asked for information on their industrial rebates and programs. We also asked if there was information that would help them create or adjust industrial programs.

Respondents were encouraged to answer questions in an open-ended fashion, with interviewers probing for follow-up questions when relevant. Respondents often covered the content of several interview questions in response to a single prompt. When that occurred, the applicable questions were skipped. The responses were summarized by category, which provided a comparison between respondents within the category and between stakeholder categories. Each interview lasted about one hour and was recorded.

Heat Pump Screening Guide

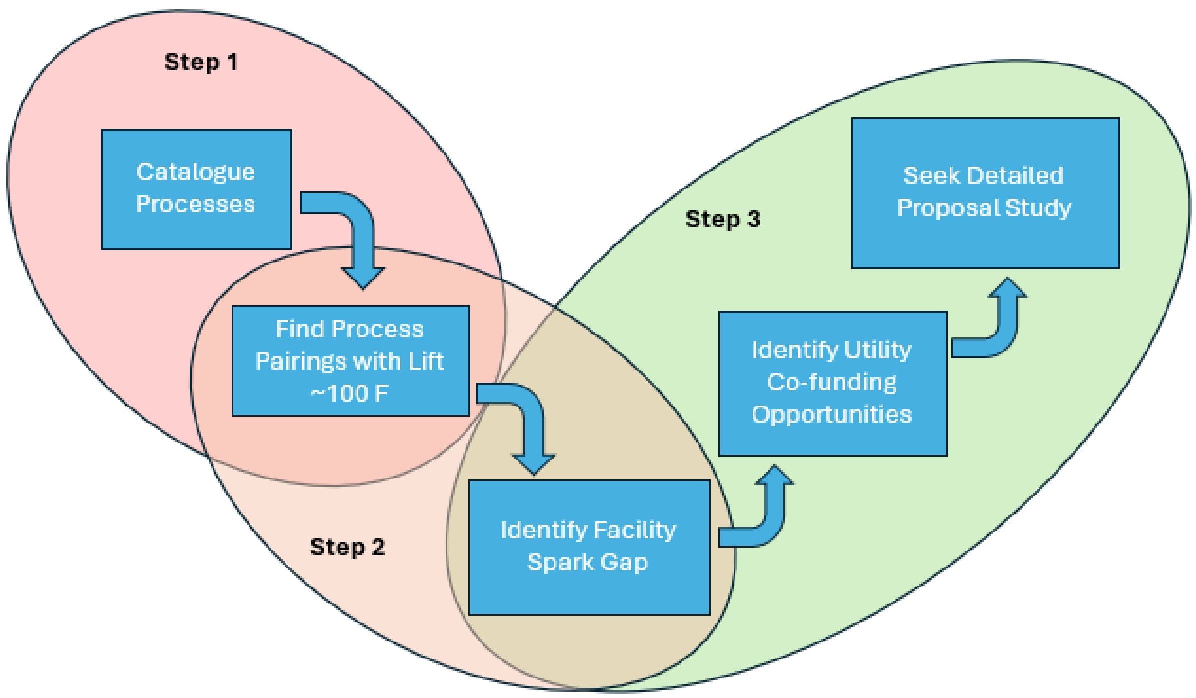
The analysis shown in Figure 7 provides a guide to heat pump screening that follows three progressive levels of scrutiny for feasibility, suitability, and applicability. A plant manager or energy consultant assisting a plant manager should complete the following three-step process to determine whether a more extensive feasibility study by an industrial designer is warranted. The determination is based on identifying a suitable process heat transfer pairing, the change in energy costs meets company requirements, and any application or company barriers can be addressed. A detailed description of each step is included below.

Step 1. Process feasibility – Where in the process can you absorb heat and where can you use it to offset current heating requirements? Do paired heating and cooling processes overlap in time?

Step 2. Suitability of available equipment – Does the IHP reduce energy costs or is a small cost increase justified by company sustainability goals (as evaluated by comparing the spark gap to the IHP system COP)?

Step 3. Applicability based on case-specific or organizational factors – What else gets in the way? Is there an opportunity for the project to support company sustainability policies, utility co-funding, or rate negotiation?

Figure 7: Three Steps to Identify Industrial Heat Pump Applications



Each level of inquiry — feasibility, suitability, and applicability — are elaborated below.

Feasibility

A plant manager or energy consultant starts addressing feasibility by producing a catalogue of process characteristics. Our proposed feasibility test first documents existing thermal process loads and their operating temperatures (see Table 7). The user can also evaluate the replacement of lower-grade prime heat. Such applications require an external heat source, like a neighboring facility, solar thermal, or ground loop, which should be identified as a source stream in Table 7. In Minnesota, outside air temperatures are generally too low to provide a high enough COP for cost-effective annual operation of air source heat pumps, but they can be evaluated for warmer temperature operation, or as a final step in decarbonization once existing facility heat sources are exhausted.

Table 7: Process Catalog

			Type		Temperature Range, °F		
Application	**Site Stream Name**	**Thermal Energy**	**Sink**	**Source**	**Min**	**Max**	**Tag**
Process heating	**Wort heating**	Sensible	**1**		40	180	A
Boiling	**Brewing Kettle**	Latent	**1**		212	212	B
Process cooling	**Wort Cooling**	Sensible		**1**	40	180	1
Hot water	**Clean-In-Place**	Sensible	**1**		140	170	C
Refrigeration Plant	**Chillers Air Cooled**	Latent		**1**	85	95	2
Flue gas heat recovery	**Boiler Stack**			**1**	300	320	3

Once the thermal signature of the plant in question is defined in tabular form, as shown in Table 7, appropriate pairings for process heat recovery can be generated. In general, the best applications will have lifts less than 100°F and sink temperatures less than 200°F. In this example case, two pairings meet these criteria, and are defined in Table 8. Process pairing C-2, for example, sources heat from the plant's refrigeration load. That heat is a waste stream because it is currently being rejected to ambient conditions through refrigeration condensers. On the sink side, the recovered heat is upgraded and rejected to the plant's hot water clean-in-place system, which requires only a moderate temperature.

Two qualitative rating factors are then applied in Table 8, called simultaneity and locality, indicating whether the source stream is available while the sink stream is required. This is a high-level rating function to compare feasibility of applications, so the precise value is less important than the relative ranking between candidate process pairings.

Table 8: Source-Sink Pairings

Process Pairing	Temperature Characteristics			Qualitative	
	Sink	**Source**	**Lift**	**Simultaneity**	**Locality**
A-1	180	80	100	80%	80%
C-2	170	95	85	100%	40%

Suitability

Having identified candidate process sources and sinks, the next step is to find the best-fit application. For feasible applications, the suitability is unlikely to hinge on the efficiency of available equipment. Of course, with any selection of mechanical equipment, there will be a best fit machine for the operating envelope required by the application. However, if the application is thermally appropriate, equipment selection is an exercise in optimization rather than feasibility testing.

It is important to define the operating COP in a bit more detail. Carnot and Lorenz efficiencies represent useful heat output extracted against a source temperature; they both assume that the heat extracted would otherwise have been wasted. In cases where useful process cooling is provided by the evaporator side of the heat pump, the effective COP is nearly doubled. Situations with the greatest benefit are those where the heating and cooling are needed at the same time as part of the same process. Take, by analogy, a typical heat recovery chiller for HVAC applications, which can simultaneously provide both useful heating and cooling at high COP due to single power input.

$$\eta_{waste\ heat} = \frac{Q_{out}}{W_{in}} = \frac{Q_{in}+W_{in}}{W_{in}} = 1 + \frac{Q_{in}}{W_{in}} \quad (1)$$

$$\eta_{useful\ cooling} = \frac{Q_{out}+Q_{in}}{W_{in}} = 1 + 2Q_{in}/W_{in} \quad (2)$$

$$\eta_{useful\ cooling} = \left(1 + \frac{\frac{Q_{in}}{W_{in}}}{\frac{Q_{in}}{W_{in}}+1}\right) \times \eta_{waste\ heat} \quad (3)$$

To begin suitability testing, the normalized fuel cost or spark gap (the ratio between electric and gas cost per unit energy) is compared to the annual average COP_h. The COP_h needs to be higher than the spark gap for the electric costs for the IHP to be less than the cost for the gas system it replaces. For example, if the electric rate is $0.0974 per kWh and the gas rate is $4.0 per dekatherm (Dth) the spark gap is 7.14 and the COP_h must be greater than 7.14 for the cost of operating the IHP to be less than the cost of operating the gas system that it replaces.[1] Figure 8 provides a visual representation of this analysis. The red line indicates the breakeven COP_h for equal energy costs for an electric cost of $0.0975/kWh. A higher gas rate decreases the breakeven COP and lower rates increase the breakeven COP_h.

A conservative approach for this analysis is to include both the electric use and demand costs in a blended electrical rate. The demand cost is typically responsible for about 25% to 30% of the blended cost. The actual contribution of the IHP's demand on the plant's demand charges depends on the percentage of the IHP demand that is coincident with the plant's maximum demand. This is defined as the coincidence factor. If it is possible to operate the IHP so that it does not add to the plant's demand

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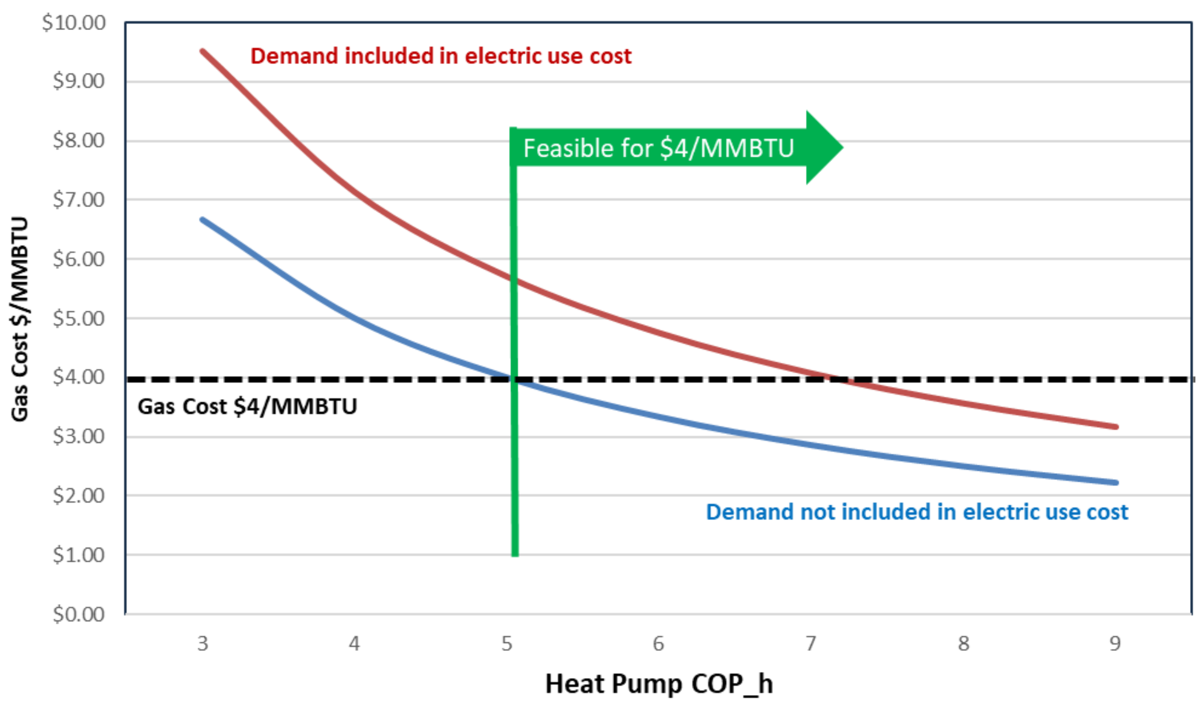
[1] Is assumes a gas system efficiency of 100%. A more detailed analysis adjusts the spark gap by multiplying by the gas system efficiency. For example, if the efficiency is 93%, the COP_h would need to be greater than the spark gap of 7.14 multiplied by the efficiency of 93% or 6.64.

costs, the blended electric rate is reduced by about 25% to 30%. This is represented by the blue line in Figure 8 and indicates that the breakeven COP_h is reduced to about 5 when electric demand charges are not included.

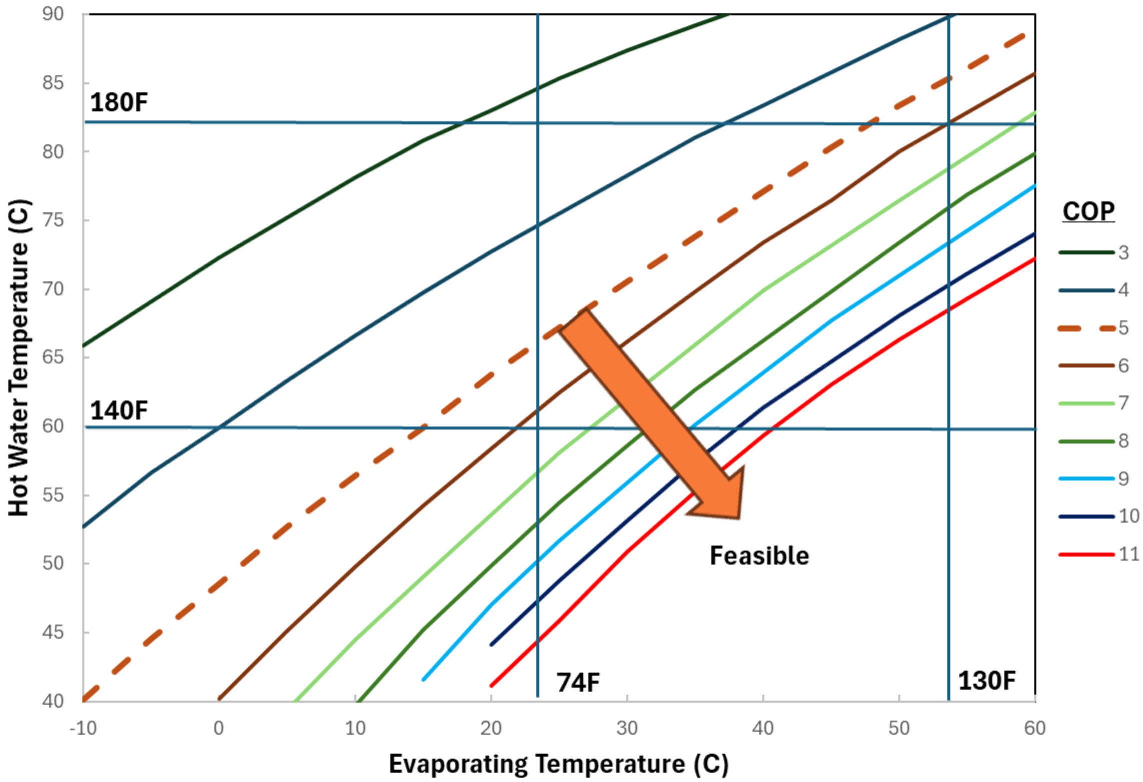
Figure 8: Heat Pump Feasibility Cost per MMBtu



The user inputs their gas and electric costs and is provided with a breakeven COP.

Next, the breakeven COP is found on a COP vs. Temperature map, and the user verifies whether their operating point is in the feasibility range from step 1. The chart shown in Figure 9 is specific to a single manufacturer but will be generalized for the final report. The source-sink pairings in Table 8 are then placed on the plot to visualize whether they lie in the appropriate COP range of application, and those remaining candidates are brought to the final applicability testing step.

Figure 9: Heat Pump Suitability



Minnesota currently does not have a favorable spark gap when compared to other areas of the United States. For the five sites that were surveyed for this project and provided energy cost information the spark gap ranged from 3.98 to 5.05 and had a median value of 5.03. The Energy Information Administration (EIA) reported that for Minnesota the 2023 industrial sector cost for natural gas was $5.84 per million Btu and the blended electricity cost was $26.98 per million Btu ($0.092 per kWh), which is equal to a spark gap of 4.62 (EIA 2025). When compared to other states Minnesota has the 18th highest industrial gas cost and the 38th highest electric cost (see Figure 10). Overall, it has the 41st highest spark gap (see Figure 11).

Figure 10: 2023 Industrial Natural Gas and Electric Costs for 50 States

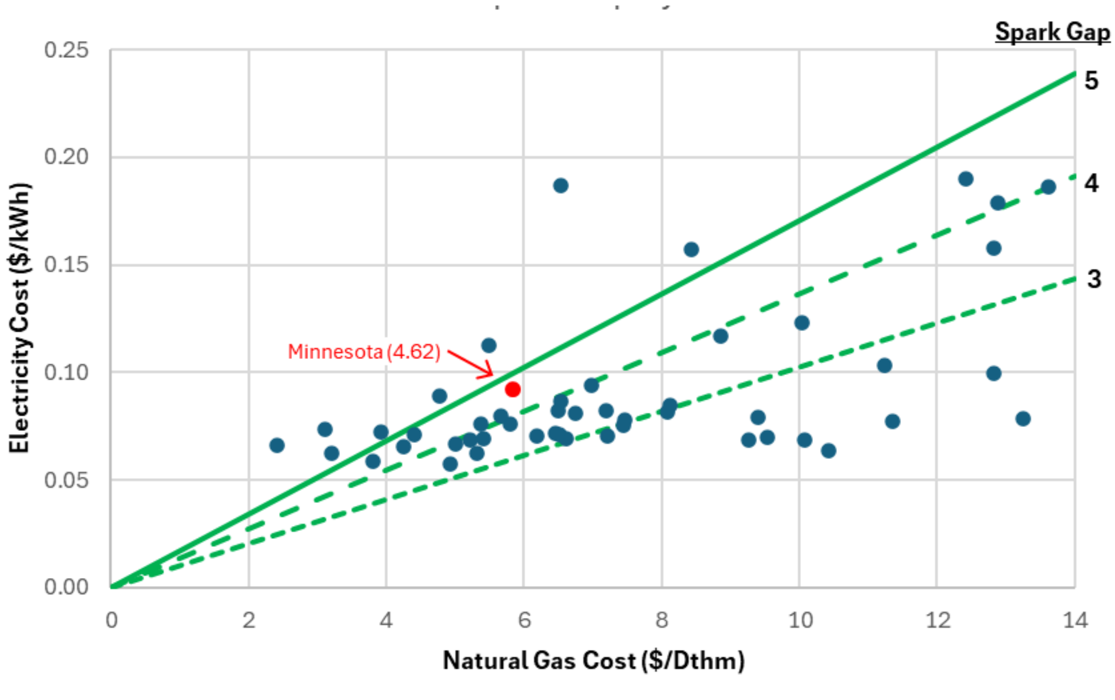
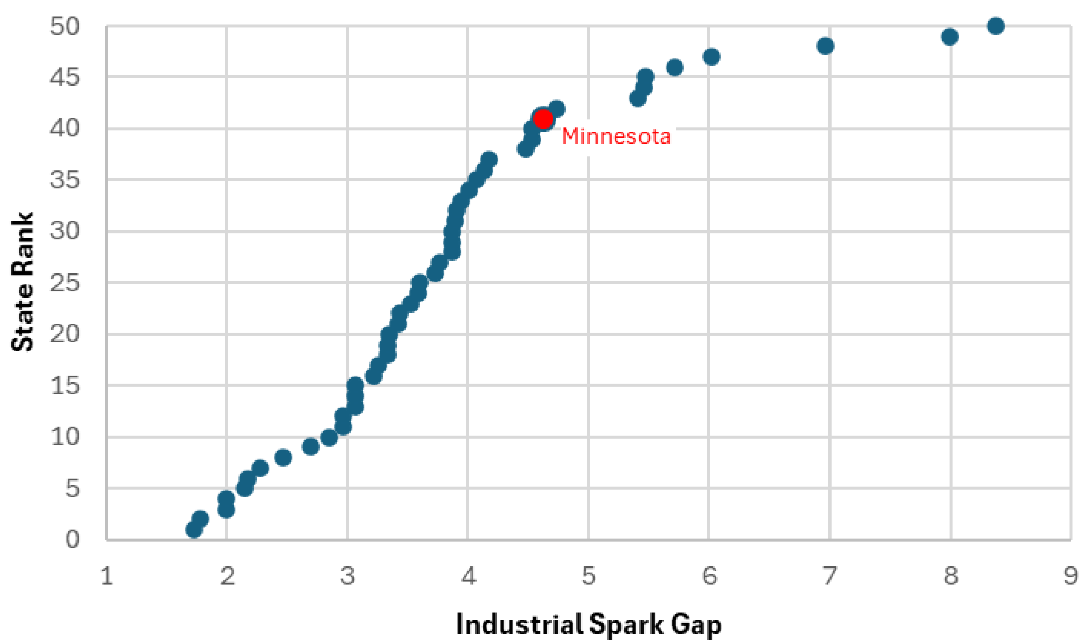


Figure 11: Cumulative Distribution of 2023 Industrial spark gap for 50 States



Applicability

Having found a selection of candidate source-sink pairings in the suitability section, this final decision to proceed with the project requires a review of organization-specific requirements for an application. This may include barriers to decision-making regarding probable payback, associated uncertainty/risk, generalized greenhouse gas (GHG) reductions, and other organizational priorities identified through plant manager conversations during other project tasks. Each priority or decision criteria acts as a filter or amplifying function on the solution set collected by the suitability section.

There are two categories of considerations in this applicability section: discrete and continuous. Discrete considerations are related to:

- Sufficient space for new equipment.
- Feasibility of connecting to the source stream.
- Funding for the design, equipment, installation, and commissioning.
- Time availability to train operators on the equipment and preventative maintenance practices.

If any of these factors are not met, the project is not a good candidate or may need to be delayed until the factors can be addressed. Identifying these factors with plant staff serves as an effective guide to selecting process streams with appropriate size and criticality for heat pump application.

The key continuous applicability function is return on investment (ROI); it is composed of first cost and operating cost, which is itself a function of both utility cost and equipment performance. We assessed utility cost vs. equipment performance but without the magnitude of heat at the given temperatures or the runtime dimension. Tools like Renewable Thermal Collaborative (RTC) Tool 2 adequately evaluate ROI at the next level of detail for decision-making, including additional variables like thermal storage and its impacts to capital cost and operation.

Tolerable risk in its many forms is also a continuous function. Some examples include variations in utility cost that will change operational cost of the prospective system and evolutions in plant production demand that would cause the system to run less often or to not have the capacity for expansion to serve greater production demand.

Some tradeoffs between the continuous functions of risk and ROI certainly exist. For example, installing equipment to deliver higher COP for the same process temperatures will increase complexity, operational risk, and maintenance required. The organization must judge independently whether added complexity can be managed operationally in a manner that justifies higher COP.

Some benefit functions without a downside exist as well, and stakeholders have indicated these are present. Chief among them is an organizational goal for scope 1 emissions reduction. Replacing any on-site fossil fuel generated heat with heat pump heat will reduce scope 1 emissions. Some companies may be motivated to pursue projects that reduce their fossil fuel use without as much sensitivity to payback considerations. On the capital cost side, organizations with dedicated sustainability funding are more likely to propose projects aimed at reducing on-site emissions.

It should be noted that positive source carbon emission savings are present with almost all site carbon emission savings in Minnesota due to the state's low grid emissions factor. Select cases and operational conditions exist where electrification is not beneficial if the electricity in question was generated with a lbCO2e / kWh emissions rate greater than COP*0.399.

Site Survey and Heat Pump Evaluation

We selected sites that had a high likelihood of having thermal processes that would be suitable for installation of a retrofit heat pump installation and a manager who was interested in participating in a pilot project. Two or three project team members conducted a site visit. The site visit protocol is outlined as follows.

- Project team met with the plant manager or appropriate facility staff. The team leader described the project and site visit objectives. The facility representative described the plant processes with an emphasis on process heating and cooling requirements.
- Project team and plant manager conducted a site walkthrough (in select areas of interest to identify feasible opportunities).
- The team held wrap-up discussions and brainstormed potential applications for heat pump systems.

The outcomes of the site visits included:

- Understanding key characteristics of the heating and cooling processes that had the greatest potential to apply an IHP system
- Overview of site operations' critical needs and receptivity
- Initial ideas on potential areas for heat pump applications

The Heat Pump Screening Guide describes the tools and process used to conduct the IHP evaluations for the plants included in this project.

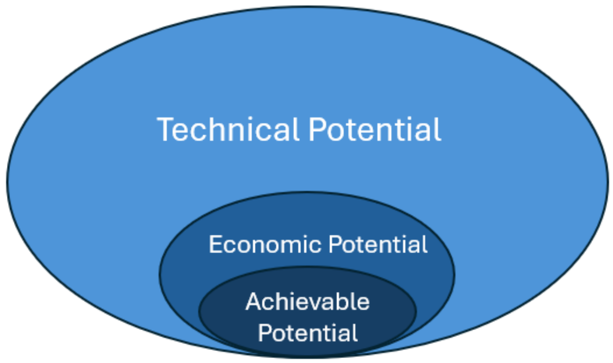
Market Potential

Three levels are visualized in Figure 12 and described below**.**

1. **Technical potential:** This is the maximum theoretically possible implementation of IHP systems when only engineering and physical limits are considered, and all non-engineering factors like cost, policy, and market adoption are disregarded. It represents the maximum amount of industrial natural gas consumption that could be displaced by heat pumps.
2. **Economic potential:** This is the subset of the technical potential that is possible when economic considerations are applied. These are cases where the applicable process lift allows for a COP equal to or higher than the spark gap, so that electric energy use costs for an IHP systems are equal or less than the gas use displaced by the IHP system.
3. **Maximum achievable potential:** This is the subset of economic potential that is achievable considering market barriers. In this study, the project team assumed financial incentives would cover 100% of the incremental costs of installations.

Identified levels of potential were applied across the subsets of Minnesota industry obtained from MnTAP ECMS (2010). The Market Potential portion of the Results and Discussion section provides the results of the market potential analysis.

Figure 12: Concentric Levels of Potential



Roadmap for Market Adoption

The roadmap for greater adoption of IHPs used a combination of knowledge gained from research and heat pump evaluation activities for this project, the project team's extensive experience in providing energy efficiency recommendations for industrial plants, and reviews of roadmap recommendations from previous studies (CalNEXT IHPMS 2023; DOE 2022; and Rightor et al 2022). The roadmap addresses the need to identify sectors and processes with the greatest potential for this technology application and develop screening tools and design guides. Demonstrations of successful implementation projects are underway, and future work is also discussed.

Results and Discussion

Stakeholder Interviews

A total of 15 interviews were completed for seven plant managers, two industrial designers and energy professionals, two manufacturers' representatives, and four utility staff who support industrial customers (Table 9). The following three sections provide results summarized for each of the four stakeholder categories. The discussion section provides key findings from all the interviews.

Table 9. Interview Respondents Summary

Stakeholder Type	Quantity Interviewed	Industries Active	Region Active	Base of Operations
Plant Staff	7	Food, Cosmetics, Medical Devices	MN	MN
Design Engineer and Energy Consulting Firm	2	All	National	OH, WI
Manufacturer	2	Refrigeration, Space Heating and Cooling, Industrial Heat, District Energy	Europe, North America	Finland, U.S.
Utility Representative	4	Electric and/or Natural Gas Utility	MN (SD, ND, WI)	MN

Plant Managers

The interviewed plant managers operated plants belonging to several industries, including food and beverage, medical device manufacturing and testing, and cosmetics. Annual plant electric consumption ranged from 10 to 30 GWh with a similar magnitude of gas site energy consumption as electricity, 300,000 to 1,000,000 annual DTh consumption.

Plant Characteristics

Three of the seven plants are food processing plants, each with ammonia refrigeration and steam boilers. The fourth, a cosmetic plant, has a steam boiler and process chilled water. Two of the food plants produce cooked-then-frozen egg patties and adjacent egg products, while the third produces processed milk products like coffee creamers and ice cream mixes. The fifth and sixth have lower critical temperatures and most of their heating load is related to air treatment for cleanrooms in manufacturing and lab spaces, and the only summer heating loads are associated with reheat required due to dehumidification. The seventh is a midsize brewing operation running at reduced capacity due to recent lower demand. It has steam boilers for process heating and an air-cooled chiller for process cooling.

Heat Pump Familiarity

The plant managers were generally unfamiliar with IHPs or potential applications to their facility (Table 10). This is especially true with respect to heat pumps for heat recovery and heat pumps serving moderate- to high-temperature loads. Regarding previous work toward effective thermal energy management, two respondents had recently implemented heat recovery in the form of boiler stack economizing, and one plant had significant thermal efficiency options that they deploy depending on heating and cooling load magnitude and balance. One of the “somewhat familiar” plant managers was aware of the present market’s temperature constraints, where the required heat content of steam for pasteurization is difficult to achieve with MVC heat pumps. To comment on this observation, some products do exist that can produce steam, and even 100 psi steam when units are outfit with a discharge steam compressor, but the resulting steam would be superheated and potentially less suitable for retrofit to existing steam heat processes. We aim to study this element during site visits.

Table 10. Level of Familiarity with IHPs

Stakeholder Type	Very	Somewhat	Not At All
Plant Managers	2	2	3
Design Engineer, and Energy Consulting Firm	2		
Manufacturer	2		
Utility Representative	1	3	
Total	7	5	3

The two medical device company participants were more familiar with applications of heat pumps to their facilities. This is expected for two reasons. First, both held portfolio-level positions, thus were familiar with several facilities and had been engaged in discussion around heat pump design for large-scale mechanical retrofits or new buildings. Second, their applications tend to have a lower critical temperature, so popular technologies including single-stage air source heat pumps can meet their thermal requirements. Outside of large mechanical retrofits, each noted that practical application concerns limit their capacity to electrify their heat load as a partial retrofit. This was particularly due to the challenge of meshing the operation and maintenance of new equipment with an existing maintenance paradigm, as well as simply pairing mechanical operation with existing equipment (e.g., existing heat exchangers being undersized and unsuitable for lower supply water temperatures associated with heat pumps).

Sustainability Goals and Decision-Making

Respondents represented a diversity of mechanisms of decision-making and funding for potential energy efficiency projects. All plants had discretionary budgets, and our respondents had various levels of oversight in their positions. Plants and their umbrella organizations interacted differently with budgeting toward improvements beyond their annual discretionary budget, with some having dedicated sustainability goals and budgets, and some requiring ad hoc corporate approval based on payback or ROI.

With respect to corporate sustainability goals and their impact on decision-making, three respondents indicated that their corporations have clear, publicly committed sustainability goals with dedicated budgets. However, there are no specific plant-level goals for any of the three. Their process for scoping projects and submitting for sustainability funding is nascent, but each reflected perceptions that the sustainability budgets allow them more flexibility to investigate opportunities. They are likely to receive corporate approval for projects that would not have been possible otherwise. The new sustainability paradigm contrasts with the status quo, where a plant's discretionary budget was a single sum. As such, energy efficiency projects had to compete distinctly with process quantity/quality projects, so only the quickest payback elements were able to move forward. One respondent indicated, "Production trumps energy efficiency every time."

The other four respondents did not have dedicated sustainability budgets. One was aware of clear corporate sustainability goals but without a dedicated budget. His work as a utility engineer focused directly on the interface with utility programs and opportunities to save energy. Several efficiency projects with clear paybacks have been scoped and approved through this focused work. Another manager, by contrast, indicated that they have plant-level energy consumption and efficiency goals, but these are not tied to an overall X reduction by X year type goal. Both of the medical device company representatives budget and oversee discretionary facility improvement efforts for a large stock of buildings. Projects find a mixture of orientations in both infrastructural improvement and energy efficiency.

When prompted around the usefulness of pilot or demonstration projects, all respondents agreed they would be somewhat useful. One of the corporate sustainability engineers for the cosmetics plant independently shared that pilot projects, particularly internal to the plant's parent organization, would be useful for his own project proposal work.

Industrial Designer, Energy Consultant, and Equipment Manufacturers

Company Characteristics

The designer was the president of a small- to medium-size firm specializing in industrial design and thermal applications. The energy consultant was an Ohio-based firm that specializes in providing energy consulting services for energy savings improvements, both through utility programs and direct-to-customer. The manufacturer respondents consisted of one large (>$5 billion annual revenue) and one small manufacturer (<$100 million annual revenue).

Heat Pump Familiarity

Each respondent was aware of the initial investment in IHP technology during the 1980s amid uncertain energy markets. Both the large and small manufacturers had experience in the European market, where the most significant difference is a lower spark gap due to high natural gas prices. The design engineer provided significant insights on successful applications for heat pumps and electrification over a long career, and a detailed understanding of limiting factors including equipment performance, plant application, or financial.

Successful applications in recent projects include an MVR system applied to a custom evaporation process and a hybrid system with solar PV electricity installed in parallel to offset increased electric capacity requirements. The engineer uses a beneficial electrification factor dubbed K_B for operating cost, which blends equipment COP, expected load-hours, and customer electric and natural gas costs. The factor is compared with equipment upfront cost for each case to determine payback. Specific limiting forces to K_B in evaluated projects include a shrinking landscape of efficient refrigerants to match with process heat requirements and the amount of overlapping heat recovery hours where equipment functions at its highest COP.

The energy consultant has evaluated heat pumps for industrial applications. With each customer, they define high-priority improvements, an estimated 70% of which reach implementation during the consulting engagement. Currently, one IHP application is identified in this category for their customer, but it has not yet been implemented. When probed around repeatability or any cookie-cutter type applications, they believe that brewing applications would be a viable candidate, but the opportunity for thermal optimization is distinct for each application, even within the same industry. This effect is amplified by considerations for spatial constraints for tapping into a relevant thermal energy source within the plant.

The large manufacturers' packaged products were all reciprocating ammonia compressor-driven products, aligned with their prevalence in the ammonia refrigeration market. The smaller manufacturer has a wider selection of refrigerants, compressor types, and capacities in their product line.

Sustainability Goals and Decision-Making

Manufacturers are preparing to serve a growing market. Both manufacturers tout large-scale flagship projects in Europe and a handful of smaller applications in North America. The larger manufacturer is set to debut a new mass production packaged product line in the coming year. The smaller manufacturer is set to complete construction of a new manufacturing facility dedicated to industrial heat pumps in the Carolinas in the next two years. Their sales network has expanded through a distribution contract and a future branding agreement with a large American commercial HVAC company.

The energy consultant indicated that markets are evolving in the direction of industrial heat pumps, and sustainability goals/budgets are the most likely variables to increase uptake, but non-energy ROI elements like downtime and increased process complexity hold more inertia. They report high risk aversiveness for industrial customers would likely help customer attitudes, as well as giving the consultants confidence in making similar recommendations to the pilot in question.

The industrial designer indicated that packaged equipment would provide more opportunities for low first-cost, but it's clear that financial constraints related to spark gap play the largest role. He believes utilities developing mechanisms to support industrial electrification with favorable operating costs or other long-term financing agreements would open the door for a wealth of applications, to work toward fulfilling the capacities of existing technology.

Utility Advisors

Utility Characteristics

We conducted interviews with representatives from four different Minnesota utilities: Xcel Energy, CenterPoint Energy, Otter Tail Power, and Minnesota Power. These four utilities account for 95% of Minnesota's annual industrial electricity consumption and 86% of Minnesota's annual industrial natural gas consumption (MnTAP ECMS 2010). They also served on the project's utility advisory group. Xcel Energy's service territory in Minnesota spans 1.6 million electric customers and 0.6 million natural gas customers. CenterPoint Energy is exclusively a natural gas provider, serving 0.9 million customers. CenterPoint provides natural gas service to many of Xcel Energy's electric-only customers. Otter Tail Power is a smaller electric-only utility and serves 0.1 million customers. Minnesota Power is an electric-only utility as well, headquartered in Duluth. It serves 150,000 customers but covers an area of 26,000 square miles through the northern half of the state, about a quarter of Minnesota's total land area. To gather perspectives from each utility, we spoke to company representatives familiar with Minnesota's Energy Conservation and Optimization (ECO) programs. Our Xcel Energy contact is a product developer assigned to industrial heat pumps. In addition, our CenterPoint contact recently assumed a role managing implementation of their approved NGIA plan.

All four utilities have industrial production customers. Otter Tail Power serves less densely populated regions of Western Minnesota. Their process customers include turkey processing and sugar processing. Minnesota Power serves industries including foods, metal parts fabrication, and primary metals. Several of the primary metals sites are among Minnesota's largest electric consumers. In cases where customers' electric demand exceeds 20 MW, they are allowed to opt out of state efficiency programs, presenting a barrier to utility program engagement on industrial electrification as well. Xcel Energy serves the Twin Cities metro and several southeast Minnesota communities, with process customers in the paper milling industry and many food processing plants in smaller industrial blocks. CenterPoint Energy serves the Twin Cities and surrounding communities with process customers including a large-scale vegetable oil producer, among others.

Heat Pump Familiarity

As shown in Table 10, utility representatives had varying degrees of familiarity with IHPs. One was lightly exposed by way of a particular recent manufacturer contact from a marketing/technology training session; another had experience overseeing rebates for larger size heat pumps, but mostly for commercial spaces. One was exposed by their own cursory research, but familiar with the company's sponsorship of an IHP feasibility study conducted by a consultant for a particular meat processing operation completed in the last several months. The final representative was quite familiar with the critical temperature constraints that dictate market capacities for adoption. Xcel Energy and CenterPoint Energy contacts were both aware of the regulations around fuel switching for beneficial electrification in the ECO Act, as they are beginning to offer more prescriptive and custom incentives for those applications.

Utility Initiatives

All utilities rebate industrial electric heat improvements against an electric baseline through their custom programs, and several project rebates have been provided in recent years. The ECO Act legislation created frameworks for rebating efficient fuel-switching specifically, which can yield higher net benefits and qualify more projects. In the last year, NGIA has opened the door for additional targeted studies, and utilities are interested in pursuing pilot projects, as well as developing screening criteria for effectively targeting study participants. The Xcel Energy representative believed leveraging existing holistic programs like process efficiency and commercial efficiency, with their respective consultants, would make studies and demonstration projects more possible. They also indicated that offering a prescriptive incentive would not likely influence the market at this stage, and stated, “The Company is getting involved early” with respect to product development initiative, which will begin in earnest upon approval of Xcel Energy’s own NGIA plan, such that the product development initiative is informed by NGIA scope and potential intersections. That NGIA plan was under review by the MN Department of Commerce at the time of the interview. CenterPoint is deep in the strategizing process of implementing their own approved NGIA plan, the largest in the state. On the other end of the level-of-detail spectrum for program planning and budgeting, Otter Tail Power has experience with rapidly publishing prescriptive rebates, and our contact believed generating a prescriptive rebate would be possible, but the prospect is not currently being evaluated. Minnesota Power can rebate through their custom program, and sees customers’ motivations toward GHG reductions increasing, but cost barriers still restrict implementing projects.

Discussion

Several themes emerged from the interviews. Plant managers are lightly to moderately informed about IHPs (Table 10), but the prevalence of sustainability goals is rising, and separate funding streams reduce friction for projects targeted directly at energy or carbon savings versus production goals. All the manufacturers, the energy consultant, and the design engineer were very familiar with IHPs. However, we targeted individuals who were likely to be familiar with IHPs, so this should not be considered a representative sample.

The design engineer provided significant insights on successful applications for heat pumps. The energy consultant has evaluated heat pumps for industrial applications and has identified one application that has not yet been implemented. The manufacturers tout large-scale flagship projects in Europe and a handful of smaller applications in North America. They see enough traction for HPs to invest in packaged industrial heat pumps. Both design/consulting engineers and manufacturers describe technical limitations that limit some higher temperature applications and produce a diversity of payback efficacies related to available heat sources. The design engineer believes utilities developing mechanisms to support industrial electrification with favorable operating cost or other long-term financing agreements would open the door for a wealth of applications, to work toward fulfilling the capacities of existing technology.

The utilities rebate industrial electric heat improvements against an electric baseline, and the ECO Act legislation created frameworks for rebating efficient fuel-switching. There was no consensus as to whether prescriptive or custom rebates would be most effective. In addition, NGIA has opened the door for further targeted studies, and utilities are interested in pursuing pilot projects. The Xcel Energy contact believed it would be best to leverage existing holistic programs like process efficiency and commercial efficiency. Their NGIA product development initiative was under review at the time of their interview. CenterPoint's NGIA proposal for a three-site demonstration project was approved and expected to start in 2025.

Interviews display the interactive system of our stakeholders, but the diversity of resistance within each party and between parties warrants further inquiry. That said, a few categorical findings are evident. Plant teams showed great interest in exploring this avenue for sustainability and energy efficiency initiatives with their trusted partners. There was a willingness to work with industry experts that could understand their technical systems, operational requirements, and constraints. Stakeholder interviews describing the supply side of the IHP market show first costs and equipment availability are moving in a favorable direction. On the demand side, dedicated funding mechanisms for plant-level or corporate sustainability efforts present opportunities for more analysis of IHP projects that would otherwise not be pursued, but navigating constraints around operating cost remains challenging.

The seven plants belong to several different industries including three food processing, two medical devices, one brewing, and one cosmetic. The food processing and brewing plants were included in the 13 subindustries that the CalNEXT IHP Market Study (2023) as likely being suitable for IHP installations. All the plant managers agreed to participate in the site survey portion of the study. Six of the seven will be included in the next step of the evaluations of sites for IHP demonstration projects.

Site Surveys and Heat Pump Evaluations

Six sites were selected to evaluate potential for application of IHPs. Site participation in the study was initiated with an interview process to obtain current site awareness, sustainability goals, and business priorities. Several sites have had a positive experience leveraging utility programs to achieve energy efficiency. The key factors for success were the presence of corporate initiatives for energy efficiency, plant-level sponsorship, and experienced energy champions. Sustainability was a key driver for two of the sites.

Table 11 provides an overview of the site participants in the study, the market sector they belong to, approximate plant area, and annual energy consumption. Of the six sites selected, five are in the food and beverage sector and one in pharmaceuticals/cosmetics. A high-level description of processes that are relevant to heat pumps are also identified. The pharmaceuticals/cosmetic plant has a steam boiler and process chilled water. Two of the food processing plants have ammonia refrigeration and steam boilers. Two of the food plants produce cooked-then-frozen egg patties and adjacent egg products, while the third produces processed milk products like coffee creamers and ice cream mixes. Two have lower critical temperatures and most of their heating load is related to air treatment for cleanrooms in manufacturing and lab spaces, and the only summer heating loads are associated with reheat required due to dehumidification. The midsize brewing operation was running at reduced capacity due to recent lower demand. It has steam boilers for process heating and an air-cooled chiller for process cooling.

Table 11. Key Characteristics of Selected Sites

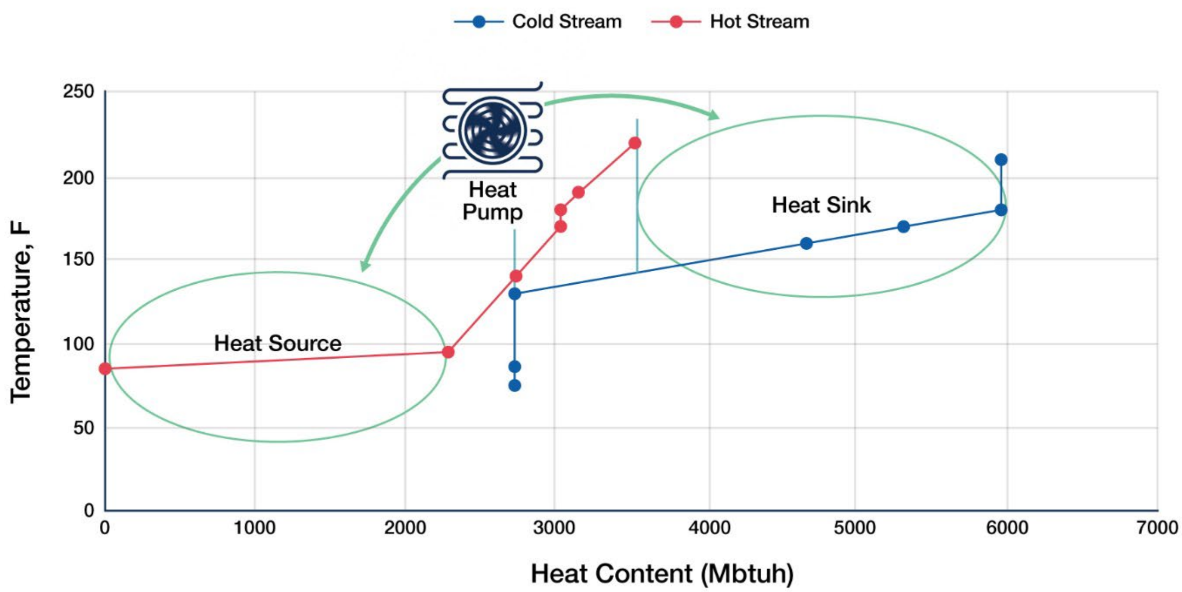
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Market Sector	Food / Canned Products	Food / Egg Processing	Pharmaceutical / Cosmetics	Food / Diary	Food / Egg Processing	Food / Brewing
Floor Area (sq. ft.)	500,000	150,000	180,000	105,000	323,000	41,800
Approx Annual Electric Use (GHW)	15	30	8	12	30	NA
Approx Annual Gas Use (Dth)	300,000	30,000	6,000	90,000	130,000	NA
Key Process Operations	Sauce making, Blanching, Cooking, Hot water	Cooking, Pasteurization, Hot water	Batch Process Heating, Hot water	Pasteurization/ HTST process has been optimized to include heat recovery and thermal storage	Pasteurization, Sterilization, Cooking, Hot water	Process heating, Hot water
Spark Gap (w/o demand)	4.68 (3.51)	5.05 (3.78)	3.98 (2.98)	NA (NA)	5.03 (3.77)	5.03 (3.77)
Utility programs, sustainability initiatives	10+ yrs	10+ yrs	10+ yrs	10+ yrs	5+ yrs	Relatively new plant 0–2 yrs

Each of the sites provided input to prioritize potential thermal sources and best candidates for utilizing heat pumps. Holistic prior knowledge of the plant systems and previous studies were applied to establish the process sources (streams that need to be cooled) and process sinks (streams that need to be heated). Field surveys were conducted to understand key operations, heating and cooling requirements, site space constraints, and key success factors.

Evaluation of heat pump potential is based on site knowledge of heat sources and sinks and the application of a pinch analysis methodology where possible to understand the potential for heat recovery utilizing heat pumps for all process streams. The pinch analysis composite curve consists of two curves: hot streams requiring cooling (sources in red) and cold streams to be heated (sinks in blue). The composite curves visualize heat recovery potential for the process at a given temperature difference between sources and sinks, for heat. Figure 13 shows the composite curve for one of the sites (site 3).

The green circles show the potential for a heat pump to transfer energy from the available sources to the appropriate sinks. The heat pump would take that energy rejected at lower temperature and deliver it at a higher temperature to meet process hot water or steam needs.

Figure 13. Site 3 Pinch Analysis Composite Curve



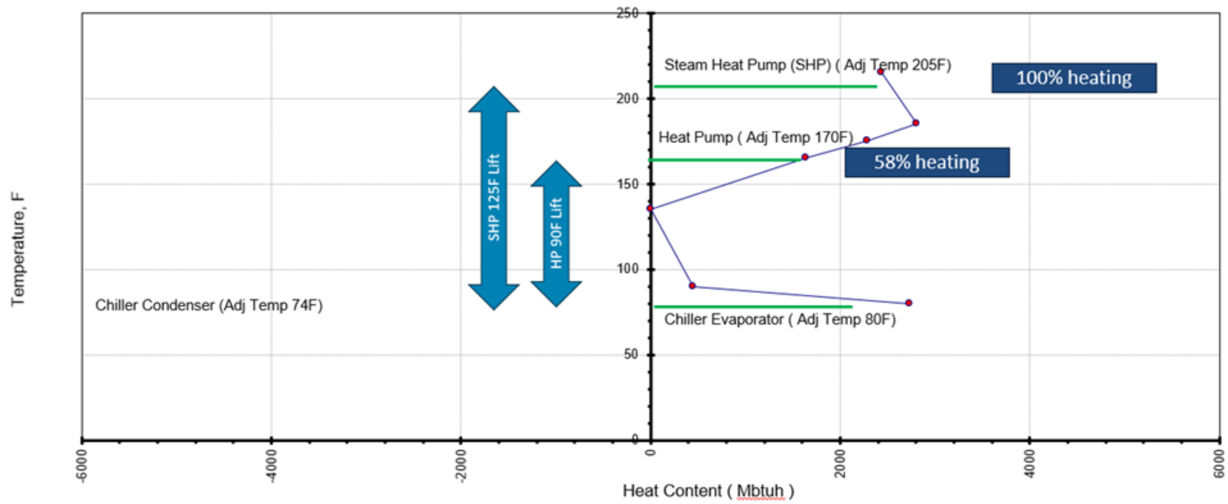
The pinch analysis composite curve allows visualization of the combined process heating and cooling streams as a single stream. The grand composite curve is a plot of a single stream using common adjusted stream temperatures.

The grand composite curve depends on the nature of the plant processes and represents the thermal signature for the plant. For site 3, the grand composite curve is shown in Figure 14. For the grand composite curve, it is possible to define the following.

- Possible applications for heat pumps.
- Thermal lift needed.
- Energy that can be provided by the heat pump application for meeting process needs.

For site 3, a hot water heat pump (HWHP) with a temperature lift of about 90°F would recover heat from chiller evaporator to heat hot water. About 58% of the total heating requirement could be met by a hot water heat pump. An SHP for site 3 would require a lift of 125°F and could provide up to 100% of the heating.

Figure 14. Site 3 Pinch Analysis Grand Composite Curve



The ROI, which is a key criterion for decision-making, depends on two factors, the spark gap and the efficiency of the heat pump system COP_h. Average utility costs were used to estimate the spark gaps for each site. Heat pump efficiency (COP_h = heating output / electric input) needs to be greater than the spark gap to provide a reduction in total energy cost for the site. If COP_h is less than the spark gap, there is no ROI. Even though the heat pump provides significant reduction in GHGs, in this case the reduction in GHGs is accompanied by an increase in operating energy costs.

Table 12 provides a summary of the six sites and possible heat pump applications. For each of the sites, the use of HWHPs and SHPs were evaluated. The percentage heating shows how much of the site heating needs can be met by the heat pump and the % source recovery shows how much of the available heat is being recovered. Figure 15 shows the heat pump COP_h vs. spark gap. COP_h for the heat pumps is always lower than the spark gap. This results in a higher energy cost per unit of heating for the heat pump system. Figure 16 presents a summary of heating from the heat pump systems, percentage of available source recovered, and impact on energy cost.

Based on the current spark gap in Minnesota, heat pump applications do not have a ROI. It would be possible for sites interested in driving GHG lower to consider the use of thermal storage or peak demand control for heat pump implementations to actively manage the unit cost for electricity for any heat pump solutions. The best pilot projects would have to be where the COP_h is closer to the spark gap. The key drivers for the pilots are sustainability goals and possibly evaluation of heat pumps instead of replacement of aging gas fired equipment. The three hot water heat pump applications where the COP_h approaches the spark gap should be investigated further for potential pilot projects. If electric demand charges can be mitigated by thermal storage, the average electric cost is expected to be about 25% lower. For the three hot water heat pump applications, this would result in a positive ROI (see Figure 17), but the simple paybacks on energy costs alone are expected to be greater than 40 years.

Table 12. Summary of Heat Pump Potential for the Six Sites

Site Number		Adj Source, F	Lift, F	Adj Sink, F	COP_h	Efficiency	% Heating	% Source Recovery	Energy Cost Savings %	Annual Dth	CO2 Reduction tons
1	HP	74	87	161	3.8	54%	15%	16%	-25%	28,000	1,883
1	SHP	74	132	206	2.8	55%	67%	100%	-72%	126,096	8,479
2	HP	75	75	150	4.3	53%	46%	13%	-17%	27,220	1,830
2	SHP	75	155	230	2.5	55%	79%	39%	-105%	47,000	3,160
3	HP	80	90	170	3.7	53%	58%	16%	-6%	9,816	660
3	SHP	80	125	205	2.9	55%	100%	35%	-37%	16,800	1,130
4											
5	HP	75	75	150	4.3	53%	25%	3%	-20%	13,569	912
5	SHP	75	145	220	2.6	55%	100%	21%	-99%	54,785	3,684
6	SHP	75	145	220	2.6	55%	100%	92%	-99%	15,432	1,038

Figure 15: **Relationship Between Heat Pump COP_h and spark gap**

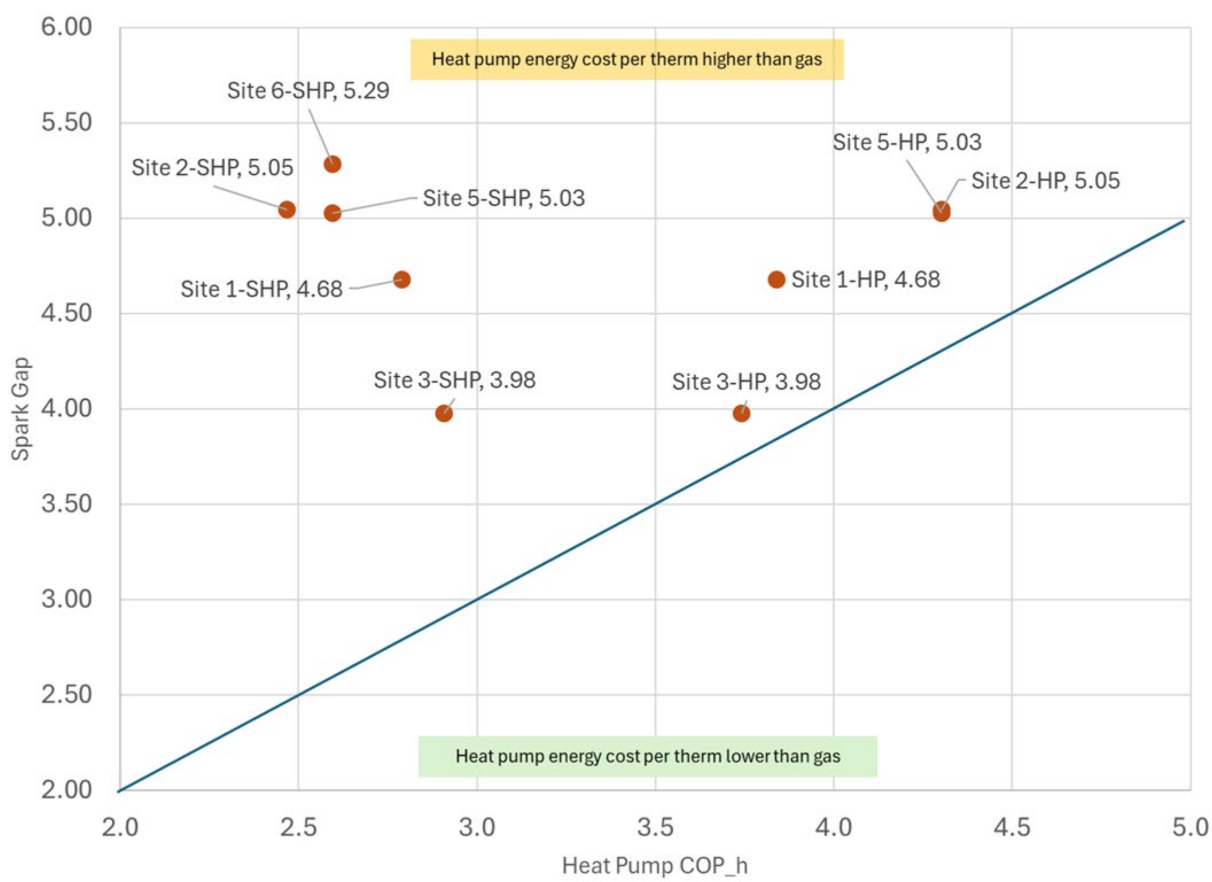


Figure 16: **Heating Potential, Source Recovery, and Energy Cost Impact for the Six Sites**

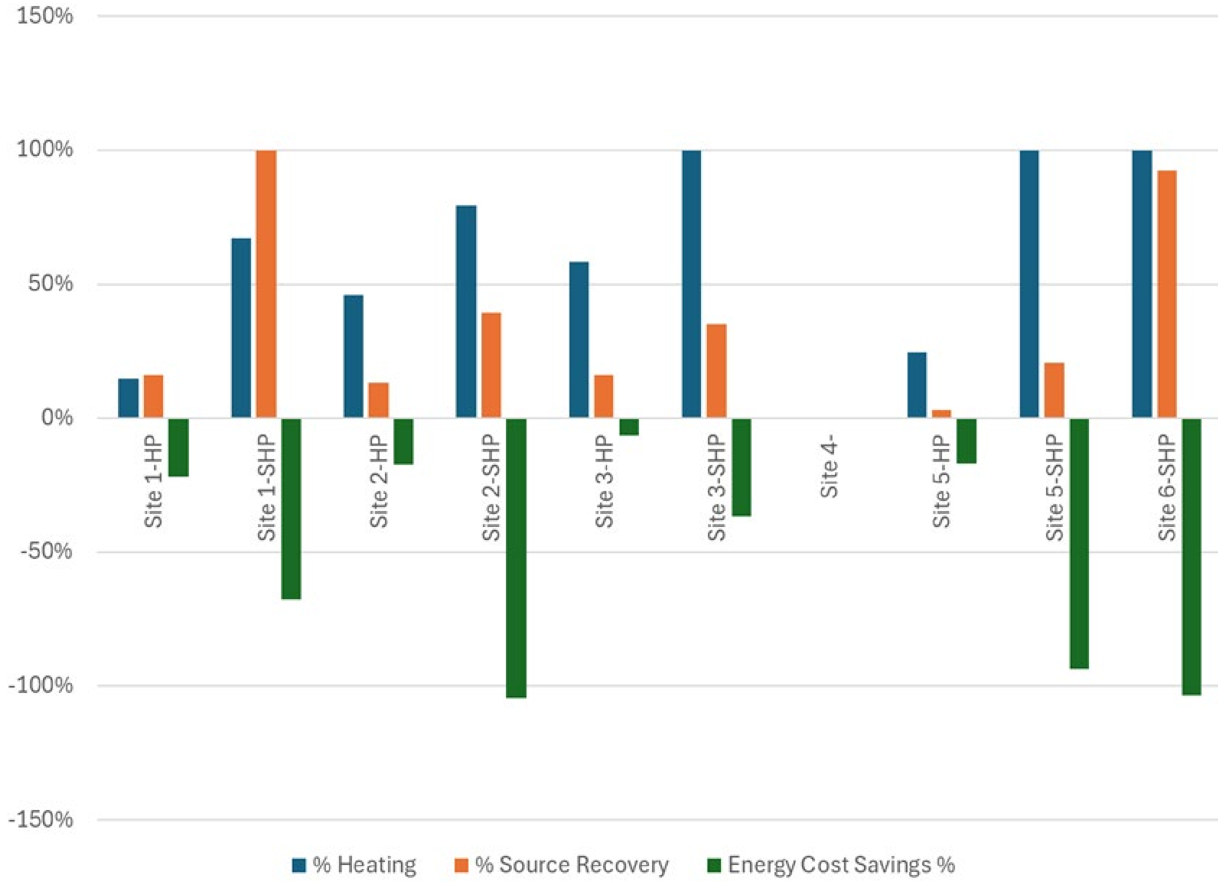
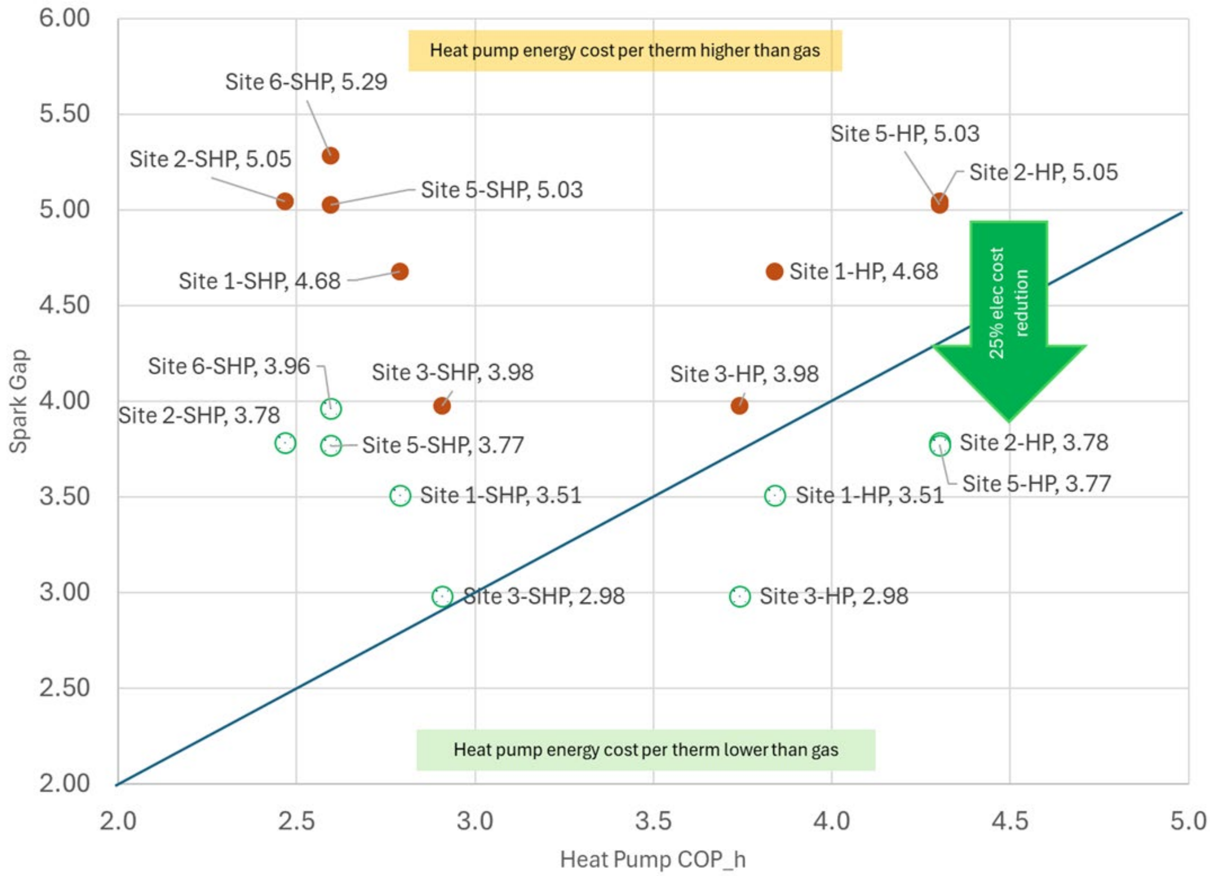


Figure 17: **Relationship Between Heat Pump COP_h and spark gap Without Electric Demand Charges**



Market Potential

The annual gas use savings for IHP installations in Minnesota were calculated for three levels of potential: technical, economic, and maximum achievable. The corresponding sections here describe the methods used to determine the percentage of industrial thermal processes that meet the criteria for the three potential levels. Those percentages are multiplied by the sector-level thermal process gas use to estimate IHP gas use savings.

Technical Potential: The technical potential is defined by the fraction of fuel consumed in the industry that is produced by boilers. Direct fire solutions are not good candidates for heat pump adoption and are not included. We included the displacement of all steam boiler fuel, which in some cases is tenable with hot water heat pumps, and in a minority of cases, is possible with steam heat pumps. However, steam heat pumps operate with a lower COP and are less likely to be economically viable. The specific fractions were synthesized from CalNEXT's thermochemical modeling for boiler fuel fraction referenced earlier (Table 3Table 3. Suitable Subindustries – CalNEXT IHP Market Study

2023). Then, gaps were filled by project team estimates for the Minnesota industries not represented in CalNEXT's modeling.

Economic Potential: In the six sites surveyed, our high-level analysis indicated that one or two solutions were cost-neutral without altered rate structures. There was a high degree of thermal similarity between processes, so using our results to extrapolate to the heat pump side of the cost-effectiveness balance was sound. On the fuel cost side, the spark gap was fuel cost dependent, which makes it difficult to characterize the present and the future state. In the present, rate structures vary significantly between utilities and from facility to facility. For the future, it was difficult to confidently extrapolate whether the spark gap will widen or shrink due to fuel cost's dependence on policy and macroeconomic factors. In light of this, we selected a value on the conservative end of the spectrum; economic potential for all industries was set at 15% of technical potential. Approximately one out of six sites were economically viable without altered rate structures.

Maximum Achievable: Even with full funding available for capital cost, and cost-neutral operation, the decision to proceed with a project is subject to layers of approval between site personnel and corporate decision-makers. Site-level assessments of risk are less quantifiable and more a matter of preference. Given this, we simply assumed that half of the viable, incentive-aligned applications are achievable.

Minnesota sector-wide consumption is most well presented by MnTAP ECMS (2010). The fraction that each sector participates to the whole is assumed to have remained constant, while overall economic growth has increased production across all sectors. The degree of total growth between 2010 and 2025 is based on CEE's 2018 Minnesota Potential Study (Nelson et al. 2018), resulting in a baseline industrial natural gas consumption of about 40 million Dth per year.

The results of the analysis are shown in Table 13 and Figure 18. The eight primary sectors are the same as those analyzed in MnTAP ECMS (2010). Notably, chemical manufacturing has the highest consumption (15.5 MDth), but the second highest technical potential (4.58 MDth) due to higher temperature needs and greater focus on thermal optimization during chemical plants' original design. In the largest chemical facilities, like refineries, the application of heat pumps gives way to interventions like combined heat and power (CHP) as a focus for thermal process improvement. Ethanol plants have a hybrid of thermal loads from typical food processing and chemical manufacturing facilities. Some additional focus may be warranted for MVC heat pumps at ethanol plants, though the highest potential opportunities (MVR) are usually exhausted.

Minnesota's rich farming and milling provide a strong food processing sector, representing a third of industrial natural gas consumption (13.3 MDth). Food processing operations typically involve both process heating and process cooling, including operator experience with ammonia refrigeration systems and the associated network of equipment vendors. Much of the equipment and several industrial refrigeration manufacturers share in the growing IHP market. With these factors — prevalence, thermal suitability, and market connectivity — food sector applications should be the largest focus for development and represent the highest savings potential (6.2 MDth).

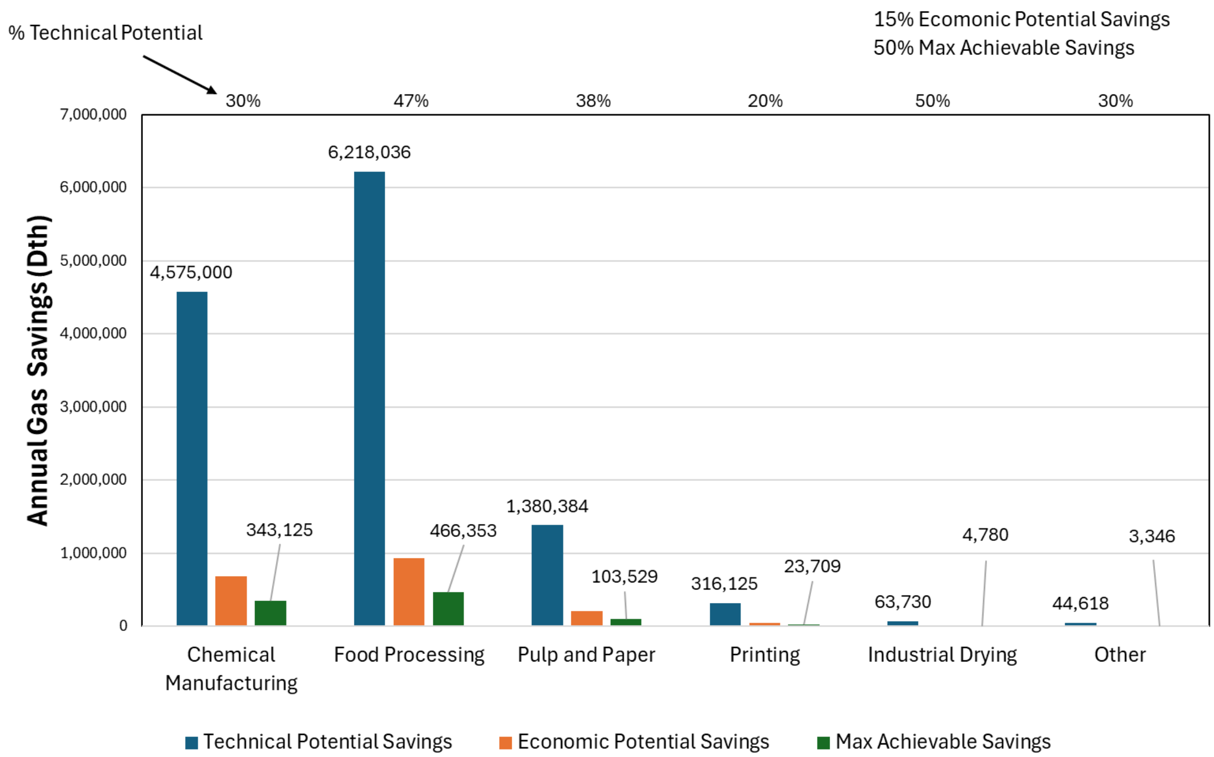
Pulp and paper and printing sectors are a secondary focus, with good technical potential of 1.4 MDth, but less operational similarity between incumbent systems and IHPs. Drying processes in pulp/paper, along with standalone industrial drying facilities have strong technical potential, but without a site survey in those domains within our six sites, this study did not produce any results or insights toward those applications.

Primary metals and secondary metals are deemed to have no technical potential. For primary metals, this is because heat is required at too high a temperature (e.g., melting/casting, smelting). For secondary metals, there is no relevant process sink for process cooling source heat (e.g., oil cooling heat must be rejected to atmosphere when it exceeds space heating needs).

Table 13: Minnesota Industrial Heat Pump Potential Energy Savings by Sector

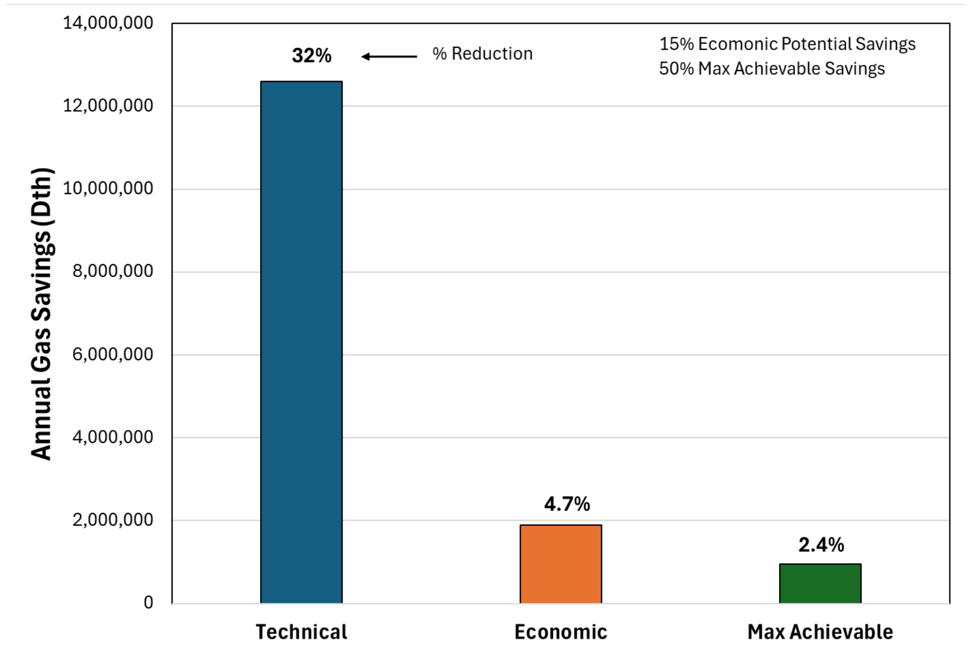
Sector	# of Facilities	2025 Annual Use (Dth)	% of Total Use	Tech. Potential (%)	Tech. Potential (Dth)	Economic Potential (Dth)	Max Achievable (Dth)
Chemical Manufacturing	126	15,300,000	38.3%	30%	4,580,000	686,000	343,100
Food Processing	178	13,300,000	33.3%	47%	6,218,000	933,000	466,300
Pulp and Paper	39	3,600,000	9.0%	38%	1,380,000	207,000	103,500
Printing	330	1,580,000	4.0%	20%	316,000	47,400	23,700
Industrial Drying	49	127,000	0.3%	50%	63,700	9,560	4,780
Other	28	149,000	0.4%	30%	44,600	6,700	3,350
Fabricated Metals	693	3,610,000	9.1%	0%	0	0	0
Primary Metals	73	2,240,000	5.6%	0%	0	0	0
Total	1,516	39,900,000	100.0%	32%	12,600,000	1,890,000	945,000

Figure 18: Minnesota Industrial Heat Pump Potential Energy Savings by Sector



For heat pump application to Minnesota industrial natural gas consumption, we estimate technical potential gas savings are 32%, economic potential savings are 4.7%, and maximum achievable savings are 2.4% (12,600,000, 1,890,000, and 945,000 Dth respectively), under present conditions (see Figure 19). The maximum achievable scenario would involve installation of 100–200 IHPs. Achieving a higher fraction of technical savings will require further market interventions.

Figure 19: **Minnesota Industrial Heat Pump Potential Gas Savings**



Roadmap for Market Adoption

The industrial sector currently lags commercial and residential buildings in adoption of heat pumps for energy savings and emissions reduction. The following is a five-step roadmap for IHP market adoption:

1. Identify sectors and processes with greatest potential.
2. Develop screening tools and design guides.
3. Implement Minnesota demonstration projects and disseminate results.
4. Develop options for utility program services.
5. Educate stakeholders and promote industrial heat pump applications.

The first step is to identify sectors and processes that could benefit from the application of heat pumps. The second is to evaluate site potential at a high level to screen for feasibility. These first two steps are described in previous sections of this report (Applicable Processes and Heat Pump Screening Guide). A key challenge is the high spark gap for Minnesota plants, which often results in poor return on investment for heat pump application. Regardless, there are sustainability, equipment replacement, and GHG drivers. Out of the six sites we surveyed, four had the potential for heat pump application, with minimal impact on operational energy costs.

The third step would be to create demonstration projects and disseminate results. CenterPoint Energy and Xcel Energy have funded NGIA pilot projects for IHP demonstrations. Two additional future steps are required to drive adoption of industrial heat pumps. As utilities recognize the benefits of IHPs, they can provide services to identify opportunities and financial incentives to improve the ROI of IHPs (step 4). Finally, with a market identified, educational activities will promote the technology to a wider audience (step 5).

Identify Sectors and Processes with Greatest Potential

As described in more detail in the Background section of this report, our application of product-process knowledge generated by other studies and applied to the Minnesota process heat market indicates that large customers are more likely to have optimal applications for heat recovery, while small customers are more likely to have suitable process loads for lower temperature or air source applications.

By industry, Food Processing and Pulp and Paper are of particular interest due to their temperature suitability. The site surveys and heat pump evaluations for this project identified strong potential in our sample within the food sector, particularly for rejecting heat from tower water to serve hot water applications. This potential generalizes to a sizable population of plants in Minnesota among those enrolled in utility process efficiency programs and those not yet engaged with utilities. A few other site attributes have could drive interest in applications including existing heat recovery activity and upcoming boiler replacements. Existing heat recovery activity is relevant because site personnel will be familiar with the concepts pertaining to the application of heat pumps, and upcoming boiler replacements call attention to alternative solutions during design inquiry. As these first-of-their-kind projects in Minnesota come to the fore, we can learn from them and apply lessons at other plants/processes where heat recovery has not been incorporated.

Large-scale vegetable oil processing, oil refining, and ethanol production facilities have a distinct interest in thermal process optimization and stand to gain from application of heat pumps, provided they are associated with an appreciable payback and limited downtime. In the same vein, the lowest hanging fruit, such as mechanical vapor recompression in ethanol facilities, is usually already picked.

Develop Screening Tools and Design Guides

The application of IHPs requires site-specific understanding of processes, operations, and other site constraints. The ability to screen a site's suitability for heat pump application requires evaluation of processes and possible options for improving efficiency, heat recovery, and waste heat. IHPs need to be customized for the site. Screening tools and design guides can facilitate the process and reduce time to implementation.

As described in more detail in the Heat Pump Screening Guide and Appendix B: Heat Pump Evaluation Tools sections of this report, this project referenced and reviewed several existing tools, including heatpumpestimator.com and RTC's suite of tools. HeatPumpEstimator.com, from the Australian Alliance for Energy Productivity, recently underwent an update to add some supportive features that will allow plant personnel to better evaluate heat pump potential. A new, comprehensive guide is expected during fall 2025 for market actors of each category, produced by RTC and the IHP Alliance.

The proposed approach for feasibility testing we took in the design guide section of this report will be folded into another free tool that has recently come to market from the Lawrence Berkeley National Lab. That tool also integrates pinch analysis elements, and with appropriate training, will allow plant engineers to conduct their own feasibility assessment to the same degree of detail as those executed in the site survey section of this project.

Minnesota Demonstration Project

In addition to economic concerns, Minnesota IHP demonstrations are required to provide examples of successful implementation that other plants can confidently follow. This will require coordination between plants, utilities, and funding sources. An ideal installation would have wide application and good economics and would replace a significant fraction of the heating load (i.e., high impact). Lower impact and wide application installations are typically better suited to utility program support because assumptions with respect to cost and energy savings can be made en masse, simplifying repeated utility support. High impact and limited application installations are less likely to be captured by streamlined utility programs and will rely on more technical convening for project success. Finally, an ideal demonstration site will be open to publicizing the installation to interested parties.

The initial demonstration projects may meet some, but not all three criteria. For example, the approximately cost-neutral heat pump opportunities identified by this project are a good example, where cooling tower load is recovered for process-support hot water. This is a good and lower risk framework that many sites could implement but would generate a relatively small decrease in site energy. A more integrated heat pump system for thermo-chemical processing served by independent heating and cooling resources is a good target, but time to market will be longer and less generalizable.

Initial demonstration projects will likely require extensive financial incentives. The system designers, contractors, and plant managers may have limited experience with the systems, which could result in higher economic safety factors for the installations. Utilities and governments have both had funding for demonstration projects. Further discussion of existing utility support and options for expanded support are present in the next section. On the public side, IRA-origin EPA funding distributed through the Minnesota Pollution Control Agency climate-aware food system program[2] further targets technical assistance (screening) and implementation assistance (project funding) and is expected to move forward in the coming months.

This project identified several demonstration project candidates. The pool can be expanded by surveying interested parties through industry organizations, utility industrial efficiency program participation, and by engaging directly with sustainability or energy managers at companies with stated energy efficiency and GHG goals. IHP workshops may present the best opportunity to reach technical and organizational parties. This would involve convening candidates as an iteration of or in the style of the Department of Energy funded IHP bootcamp put on by RTC and IHP Alliance, described further in the education and promotion section. Since early projects are unlikely to pay back on economics alone, candidates will be motivated by factors like greenhouse gas reduction and the qualitative benefits of early adoption. Once interested candidates are identified, the screening and design tools described in the Heat Pump Screening Guide section can be used for a high-level evaluation of technical and economic feasibility.

[2] https://www.pca.state.mn.us/news-and-stories/climate-smart-food-systems-grants-update accessed October 7, 2025.

Projects can be constructed and commissioned based on either design-build or design-bid-build project structures, pending stakeholder preference.

Two Minnesota utilities are currently pursuing IHP demonstration projects through the recently established NGIA. CenterPoint Energy is launching a pilot program to help industrial customers switch from fossil fuels to electric heat pump technologies for low- to medium-temperature processes (CPE 2023). The program will be carried out in three phases — first, a study to assess the technical potential of heat pumps and identify suitable pilot sites; second, installation of heat pumps at three selected facilities; and third, measurement and verification of system performance. CenterPoint will cover the full cost of equipment and installation, up to $1.5 million per site. The pilot is available to customers in specific rate classes, including Small Volume Dual Fuel B, Large Volume Dual Fuel, Commercial/Industrial Firm C, and Large Volume Firm. By supporting these installations, CenterPoint aims to demonstrate the feasibility and benefits of IHP adoption.

Xcel Energy is offering a pilot program to support non-residential customers interested in strategic electrification projects that reduce greenhouse gas emissions (Xcel 2023). These projects may not qualify for incentives under the company’s standard ECO programs if they don’t result in source BTU energy savings. To fill this gap, the pilot provides both technical analysis and financial incentives to help customers move forward with electrification efforts that deliver environmental benefits. Eligible participants include industrial and corporate customers whose projects reduce emissions but fall outside traditional incentive criteria. The total incentive pool for the pilot is $1.1 million, with funding amounts based on projected energy savings. Incentives are calculated using a value of $30 per ton of avoided carbon dioxide emissions, applied to the expected reductions in natural gas use.

These Minnesota plant case studies can be written in parallel with design and development activities for both Minnesota demonstration sites and the few dozen identified projects in the U.S. (Hoffmelster, Omotesho, and Chen 2025), so the market can update recommendations around ideal applications and best practices for screening tools and develop better feasibility testing tools to accelerate candidate projects.

Utility Program Services

Programs funded by utilities, like ECO, Minnesota's Efficient Technology Accelerator, and CARD, help lower the resistance to optimization at varying economic and temporal scales. The industrial market presents a challenge — it has more decision-making inertia and more diverse interests than the residential and commercial customers served by utility programs.

Minnesota utilities have begun supporting industrial electrification and heat recovery, primarily through custom programs. All four utilities on this project’s advisory group currently rebate industrial electric heat improvements against an electric resistance baseline, and the ECO Act has created a framework for rebating efficient fuel-switching projects that deliver higher net benefits. NGIA has also opened the door for targeted studies and pilot projects, with utilities developing screening criteria to identify promising sites.

Each utility is taking a distinct approach. Xcel Energy is focused on leveraging its Process and Commercial Efficiency programs and consultant networks, while downplaying prescriptive rebates as a near-term driver. Their participation is tied to the scope of their NGIA plan, under review by the Department of Commerce at the time of interview. CenterPoint Energy is moving ahead with the state's largest NGIA plan. Otter Tail Power has shown flexibility in launching prescriptive rebates quickly, though none are under consideration for heat pumps. Their PUC-level pilots on rate design, tested with an ethanol plant in South Dakota, highlight another avenue for influence. Minnesota Power continues to use custom programs, noting increased customer motivation to reduce emissions but persistent cost barriers.

Expanding adoption will require utilities to refine metrics, rates, and program structures. Current practice tracks savings in first-year kWh or Dth, which limits recognition of long-term or source-energy benefits. Developing subregional or customer-level source-energy and emissions factors would improve screening potential and strengthen cost-effectiveness cases for electrification.

Rate design is equally important. Beyond on-site controls and optimization, most industrial customers will need bill engineering to close the spark gap. Potential mechanisms include demand management products that stabilize unit demand costs, predictive rate pilots that limit demand charges, or pricing structures indexed to natural gas costs. These levers can make projects cost-neutral and reduce barriers to adoption.

Program design can also evolve. Bundling passive energy recovery with large heat pump projects raises cost-effectiveness, while integrating electrification into established efficiency programs simplifies implementation. On the customer services side, utilities can increase uptake by funding audits, feasibility studies, and design incentives. Encouraging advanced methods such as pinch or energy analysis will help target thermal optima, and RFPs that reference these approaches will attract stronger proposals.

Together, these steps — refined metrics, rate innovation, program bundling, and enhanced customer services — create a pathway for utilities to accelerate industrial electrification. With careful alignment, they can reduce cost barriers while building confidence and replicability across the market.

Industry Education and Promotion

Industry education and promotion aim to connect agents with relevant skills to plants and plant managers with operations to which those skills can be applied, supporting plants and plant managers as they increase their ability to spot optimization opportunities internally.

Some efforts to this effect are in progress. For example, DOE has funded the IHP Alliance (consisting of RTC, National Electrical Manufacturers Association (NEMA), and consulting firm DGA) to run workshops. This is a good model, though it segregates the buy side and supply side. Plant managers engaging in peer-to-peer collaborative conversations, rather than suppliers driving a conversation toward the purchase of equipment, is a distinct benefit. Parties interested in optimal applications without a sales drive (like utility demand side management engineers) are selected to facilitate these bootcamp conversations. The question remains whether key decision-makers are likely to attend these bootcamps, and if so, whether the content of the workshop presentations brings them closer to identifying projects.

One historical example of an initiative that changed the status quo at industrial plants for an energy-consuming system is the DOE's Compressed Air Challenge, which began in 1997 and still operates. The program provided industry education in pursuit of a simple objective; rather than increase the supply pressure to achieve required discharge CFM, system owners should turn their attention to the demand side of the compressed air system, study it for leaks, and stage their supply side to appropriately match the improved demand side. As a result, utilities have been able to support leak detection studies and claim associated savings, while also supporting supply-side improvements.

While the status quo for operation and maintenance was motivated to a new and better equilibrium, compressed air did not require convening the key corporate decision-makers responsible for significant and long-term investments.

There is a clear parallel to this in the required approach for IHPs. Rather than focusing on fixing leaks before increasing pressure, plants can focus on fixing heat leaks before increasing prime heat. Importantly, the scope of these improvements is complex enough that fixing heat leaks requires substantial integrated intelligence between plant engineers, design engineers, and decision-makers. For industrial customers, as repeatedly emphasized in our plant manager interviews, investments in production always outweigh investments in energy. Convening decision-makers, plant engineers, and experts in source energy optimization can provide substantive insights to drive thermal optimization projects, going beyond the typical industry education goal of familiarity with the relevant technical terminology. DOE's Better Plants platform is a mass-communication approach to this, but local or regional implementations will be more likely to drive collaboration.

Regulatory guidance and financial support through typical energy avenues is most likely to catch the attention of sustainability staff, but influencing decision-making requires attention across practice areas. For example, integrating source energy intensities into the Food and Drug Administration's Current Good Manufacturing Practices or related avenues would drive data collection and reporting and bring attention to these opportunities at the decision-maker level.

Conclusions

Industrial heat pump characteristics

The IHP product market can be dissected in a few ways. One categorization is packaged vs. custom units. There is a recent increase in the prevalence of packaged units with a variety of sizes and temperatures available in the U.S. Some select applications and particularly high capacities still require custom component selection. A second categorization is the source/sink fluid and temperatures. Current products are either air or water source, and either water or steam output. Typically, the minimum source temperature is near 68°F (20°C) for water source products, and 14°F (-10°C) for air source products. The working fluid type plays a critical role in performance and sink (i.e., output) temperature capability. Both natural and synthetic refrigerants are used, with tradeoffs between global warming potential, ozone depletion potential, safety, and performance. Ammonia and synthetic refrigerants (R1000 series mixtures of traditional HCFC/HFC hydrofluoroolefins) systems can reach high output temperatures, with common industrial applications delivering heat up to 185°F (85°C) and some reaching 190-203°F (88-95°C) or more, depending on compressor capabilities and system design. Carbon dioxide (R744) is used in transcritical cycle units that are capable of up to 190°F (88°C) output water. Units with supply temperatures from 212°F (100°C) to 300°F (149°C) are also offered by most industrial manufacturers possessing multiple stages of compression to manage the larger lifts. For applications requiring temperatures above 300°F, booster steam compressors are added to overcome refrigerant limitations.

Stakeholder interest is growing, but plant manager awareness and experience are limited

Interviews with plant managers, industrial designers, manufacturers, and utility representatives revealed growing interest in IHPs, particularly driven by corporate sustainability goals and greenhouse gas reduction targets. While plant managers were generally unfamiliar with IHP technologies, especially for high-temperature applications, they expressed strong willingness to explore pilot projects when aging equipment or sustainability initiatives were present. Manufacturers and consultants were well-informed and noted increasing market traction, particularly in Europe, with investments in packaged IHP systems. Utilities are beginning to support industrial electrification through custom programs and demonstration funding, though there was no consensus on whether prescriptive or custom rebates would be most effective. The ECO Act and NGIA have opened new pathways for funding and technical support, with demonstration projects underway. Overall, stakeholder feedback highlighted both the promise and the challenges of IHP adoption—while technical capabilities and funding mechanisms are improving, economic viability and operational constraints remain key barriers.

Economic viability is limited by Minnesota's spark gap

Six industrial sites were selected for evaluation of heat pump applications, representing a range of sectors including food and beverage and pharmaceuticals/cosmetics. The surveyed facilities included diverse thermal processes such as cooking, pasteurization, refrigeration, and cleanroom air treatment, with varying heating and cooling demands. Each site provided input to identify feasible heat recovery opportunities, and field surveys were conducted to assess process characteristics, space constraints, and potential for heat pump integration. IHP feasibility was evaluated using pinch analysis to identify viable source-sink pairings and estimate temperature lift requirements. HWHPs and SHPs were assessed based on their ability to meet heating needs and recover available waste heat.

For heat pump applications to be financially viable, the COP_h must exceed the spark gap. For the IHP applications considered for the six sites the IHP COP_h was always lower than the spark gap. For each site, the HWHP applications provided better economics than SHPs. However, in all cases, both types of IHPs had higher energy costs than the current gas systems that they would replace. This illustrates why Minnesota's relatively high spark gap presents a major barrier to cost-effective IHP adoption. Based on EIA reported 2023 industrial energy costs (IEA 2025), Minnesota had a spark gap of 4.62 which ranked 41st of the 50 U.S. states. However, excluding electric demand charges from the spark gap calculation improves the economics of heat pump applications. In some cases, this adjustment brings COP_h above the spark gap, suggesting that thermal storage, demand management strategies, or modified rate structures could make certain installations financially viable.

Industrial heat pumps show strong technical potential in Minnesota

IHPs have the potential to replace up to 32% of Minnesota's industrial natural gas consumption for thermal processes, equivalent to approximately 12.6 million Dth annually. This technical potential is concentrated in sectors with suitable temperature ranges for heat pump operation. Food processing, pulp and paper drying, and chemical manufacturing emerged as the most promising sectors, with food processing alone accounting for nearly half the total technical potential. However, when economic factors are considered, the potential drops significantly. With current Minnesota industrial gas and electric rates, only 4.7% of industrial gas use is economically viable for heat pump replacement, and just 2.4% is considered maximum achievable under current market and policy conditions.

A roadmap for adoption requires coordinated action and includes demonstration projects

The report outlines a five-step roadmap to accelerate IHP adoption:

1. Identify high-potential sectors and processes, especially in food and pulp/paper industries.
2. Develop screening tools and design guides to simplify feasibility assessments.
3. Implement and publicize demonstration projects to build market confidence.
4. Expand utility program services, including identification of best opportunities, incentives, and rate design innovations.
5. Educate stakeholders and promote IHPs through workshops, peer learning, and targeted outreach.

Successful implementation will require collaboration among utilities, manufacturers, plant managers, and policymakers. Improved screening tools, adjustments to rate structures, and broader education efforts are essential to overcome current barriers and unlock the full potential of IHPs in Minnesota. Demonstration projects will be key to building confidence and showcasing successful applications. Demonstration sites should ideally be widely applicable, economically viable, and capable of replacing a significant portion of heating loads. Lower-impact but replicable installations (e.g., recovering heat from cooling towers for hot water) are good candidates for utility support. Two utility-led pilots, CenterPoint Energy's NGIA Industrial Electrification Pilot and Xcel Energy's Strategic Electrification Incentive

Program, have been approved. These projects will provide full or partial funding for heat pump installations and performance verification, addressing economic and technical uncertainties.

References

CalNEXT Industrial Heat Pump Market Study. 2023. *https://calnext.com/wp-content/uploads/2023/12/ET23SWE0036_Industrial-Heat-Pump-Market-Study_Final-Report.pdf*

CenterPoint Energy. CenterPoint Energy Natural Gas Innovation Act Plan: Industrial Electrification Incentives Pilot Project. Exhibit D. Pages 36 – 38. 2023. https://www.edockets.state.mn.us/documents/%7B90EE0389-0000-CE1C-AA01-7EC7812FB55E%7D/download?contentSequence=0&rowIndex=109

Chen, Hellen, Neal Elliott, and Andrew Hoffmeister. *Stop the Waste: Using Industrial Heat Pumps to Rethink Thermal Loads*. Washington, DC: American Council for an Energy-Efficient Economy. 2024. https://www.aceee.org/topic-brief/2024/02/stop-waste-use-industrial-heat-pumps-rethink-thermal-loads

Department of Energy. Industrial Decarbonization Roadmap. DOE/EE-2635, September 2022. https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf

Energy Information Administration. *State Energy Price and Expenditure Estimates: 1970 Through 2023*. DOE/EIA-0376(2023), June 2025. https://www.eia.gov/state/seds/archive/seper2023.pdf

EPRI. Heat Pump Manual. EM-4110-SR Special Report. 1989. https://www.epri.com/research/products/em-4110-sr

Hoffmelster, Andrew, Fikayo Omotesho, and Hellen Chen. "New Map Shows Industrial Electrification Gaining Momentum in U.S. 2025. https://www.aceee.org/blog-post/2025/02/new-map-shows-industrial-electrification-gaining-momentum-us

IEA Annex 58. 2024. *https://heatpumpingtechnologies.org/annex58/*

MnTAP Energy Conservation Market Analysis. 2010. *http://www.mntap.umn.edu/wp-content/uploads/simple-file-list/Publications/Source/MnTAP-Energy-Conservation-Market-Analysis.pdf*

Nelson, Carl, Jon Blaufuss, Christopher Plum, et al. *Minnesota Energy Efficiency Potential Study: 2020–2029*. Conservation Applied Research and Development Report No. 121430. Minnesota Department of Commerce, 2018.

Rightor, Ed, Paul Scheihing, Andrew Hoffmeister, and Riyaz Papar. 2022. Industrial Heat Pumps: Electrifying Industry's Process Heat Supply. Washington, DC: American Council for an Energy-Efficient Economy. aceee.org/research-report/ie2201.

Xcel Energy. *Xcel Energy Natural Innovation Act Plan: Pilot 11: Custom Projects for Large Customers. Exhibit B.* Pages 60 – 63. 2023. https://www.edockets.state.mn.us/documents/%7BE0546F8C-0000-C21D-A0FE-E788DD21EAD5%7D/download?contentSequence=0&rowIndex=120

Bibliography

Ahrens, Marcel Ulrich, Sverre Stefanussen Foslie, Ole Marius Moen, Michael Bantle, and Trygve Magne Eikevik. "Integrated High Temperature Heat Pumps and Thermal Storage Tanks for Combined Heating and Cooling in the Industry." *Applied Thermal Engineering* 189 (May 2021): 116731. https://doi.org/10.1016/j.applthermaleng.2021.116731.

Amarnath, Ammi, Baskar Vairamohan, Sreenidhi Krishnamoorthy, and Keirstan Field. *Opportunities for Demonstrating Industrial Heat Pumps in the United States*. EPRI Technical Update No. 3002031135. Electric Power Research Institute, 2024.

Amarnath, Ammi, Baskar Vairamohan, and Pradeep Vitta. "High-Temperature Heat Pumps Unleashed: Cracking the Code on Waste Heat Recovery in Industry and Overcoming Commercialization Hurdles." *ECEEE Summer Study Proceedings*, 2024.

American Council for an Energy-Efficient Economy. *State Policies and Rules to Enable Beneficial Electrification in Buildings through Fuel Switching*. Policy Brief. State Fuel-Switching Policies and Rules. American Council for an Energy-Efficient Economy, 2022. https://www.aceee.org/sites/default/files/pdfs/state_fuel-switching_policies_and_rules_7-21-22.pdf.

Arpagaus, Cordin, Frédéric Bless, Michael Uhlmann, Jürg Schiffmann, and Stefan S. Bertsch. "High Temperature Heat Pumps: Market Overview, State of the Art, Research Status, Refrigerants, and Application Potentials." *Energy* 152 (June 2018): 985–1010. https://doi.org/10.1016/j.energy.2018.03.166.

California Energy Commission. *Report on Expenditures and Status of Clean Energy Programs*. 2024.

Chen, Hellen, Neal Elliott, and Andrew Hoffmeister. *Stop the Waste: Using Industrial Heat Pumps to Rethink Thermal Loads*. Topic Brief. IHP Design Principles. American Council for an Energy-Efficient Economy, 2024.

Cresko, Joe, Edward Rightor, Alberta Carpenter, et al. *U.S. Department of Energy's Industrial Decarbonization Roadmap*. DOE/EE--2635, 1961393. Department of Energy, 2022. https://doi.org/10.2172/1961393.

Department of Energy. *Industrial Heat Pumps for Steam and Fuel Savings*. DOE/GO-102003-1735. Department of Energy, 2003.

DeWahl, Karl, Krysta Larson, Jeff Becker, et al. *Energy Conservation Market Analysis*. Minnesota Technical Assistance Program, 2010.

Edward Rightor, Paul Scheihing, Andrew Hoffmeister, and Riyaz Papar. *Industrial Heat Pumps: Electrifying Industry's Process Heat Supply*. Industrial Heat Pumps. American Council for an Energy-Efficient Economy, 2022. https://www.aceee.org/sites/default/files/pdfs/ie2201%20final.pdf.

Esram, Nora, Anna Johnson, and Neal Elliott. *How to Decarbonize Industrial Process Heat While Building American Manufacturing Competitiveness*. Policy Brief. Industrial Electrification. American Council for an Energy-Efficient Economy, 2024.

Gao, Harry, Matthew Stevens, Glen LaPalme, and Marian Goebes. *Craft Brewery IHP Screening Tool*. ET23SWE0062. CalNEXT, 2024.

Hoffmeister, Andrew, Hellen Chen, and Neal Elliott. *Consistent Refrigerant Policy Is Essential for Investment in Industrial Heat Pump Market Transformation*. Topic Brief. Refrigerants Overview. American Council for an Energy-Efficient Economy, 2024.

Hoffmeister, Andrew, Hellen Chen, and Fikayo Omotesho. *Effective State and Utility Programs to Accelerate Industrial Electrification*. Topic Brief. IHP Program Best Practices. American Council for an Energy-Efficient Economy, 2025. https://www.aceee.org/sites/default/files/pdfs/effective_state_and_utility_programs_to_accelerate_industrial_electrification.pdf.

Kanwal, Maria, Muhammad Ali Qamar, Kurt Kornbluth, and John Kelly Kissock. *Spatial life cycle assessment and technoeconomic analysis of industrial heat pumps in the United States*, Cleaner Environmental Systems, Volume 18, 100315, ISSN 2666-7894, 2025. https://doi.org/10.1016/j.cesys.2025.100315.

Landry, Russ, Jon Blaufuss, Cody Meschke, et al. *Commercial and Industrial Refrigeration Market Assessment*. Conservation Applied Research and Development Report No. 158225. Minnesota Department of Commerce, 2021.

Lee, Colin, Derick Baroi, and Akane Karasawa. *Industrial Heat Pump Market Study*. ET23SWE0036. CalNEXT, 2023.

Members of Annex 35/13. *Application of Industrial Heat Pumps*. IEA Industrial Energy-related Systems and Technologies, 2020.

Synapse Energy Economics and World Wildlife Fund. *Utility Engagement Playbook for Industrial Customers: Addressing Power Sector Barriers to Electrification*. Renewable Thermal Collaborative, 2024. https://www.renewablethermal.org/wp-content/uploads/2018/06/Utility-Engagement-Playbook-for-Industrial-Customers.pdf.

Zhang, Jing, Hong-Hu Zhang, Ya-Ling He, and Wen-Quan Tao. "A Comprehensive Review on Advances and Applications of Industrial Heat Pumps Based on the Practices in China." *Applied Energy* 178 (September 2016): 800–825. https://doi.org/10.1016/j.apenergy.2016.06.049.

Zuberi, M Jibran S, Ali Hasanbeigi, and William R Morrow. *Electrification of U.S. Manufacturing with Industrial Heat Pumps*. LBNL-2001478. Berkeley Lab, 2022.

Zühlsdorf, Benjamin. *High-Temperature Heat Pumps*. Task Report HPT-AN58-2. IEA Technology Collaboration Programme, 2023.

Appendix A: Interview Instrument

Interview Protocol for Plant Managers

Hello! My name is ______ and I'm calling from CEE, and nonprofit based in Minnesota. We are hoping to talk with you about your industrial processes and energy use. We are conducting a project funded by the state of Minnesota Conservation Applied Research and Development program that is designed to help utilities meet their energy savings goals. Your insights are incredibly valuable and will help us shape programs that can help businesses like yours to save energy and money. I will ask questions about different heat process applications in your facility, decision making in your operation, and some questions around energy efficiency and goals. The conversation should take about an hour, and to say thank you for your time, we are offering a $50 Amazon e-gift card. We are also offering a follow-up site visit where we can help identify areas for heat recovery opportunities.

Just a couple of things to note before we dive in:

- Your participation is voluntary, and your responses are confidential.
- We will not attach your name or company to any responses for public reporting; however, we would like to note your industry segment and role.
- The final report will include summaries of quantitative responses grouped by stakeholder category (e.g., plant manager or manufacturer rep). We may include key comments but would not attribute those to an individual.
- Finally, is it ok if I record the interview for notetaking purposes? *Record if allowed.*

<u>Business characteristics and loads/processes</u>

1. First, can you start off by telling me about the types of products or business you have at this location?
2. Do your process operations require heating or cooling, not including space heating or cooling? (if yes, continue, if no, not eligible)

a. What are the processes that use the most heating?

i. [Probe if not specifically stated:] What about hot water?

b. What are the processes that require cooling?

i. [Probe if not specifically stated:] What about cooling water?

c. What are the critical temperatures for heating and cooling?

i. What is the critical temperature for hot water? [greater than 150°F, less than 150°F, don't know]

ii. What is the critical temperature for process cooling? [greater than 85°F, less than 85°F, don't know]

3. What systems use the most energy within your facility?

a. Are there any systems that you feel use more energy than they should, or that you feel are bad performers?

4. Have you done or considered doing an energy optimization study to reduce heat demand at your facility?

a. If yes, what were some key findings?

Heat pump awareness

5. Have you considered using heat recovery for any of your process load applications? If so, what loads?

6. What barriers exist to implementing heat recovery in your facility?

a. *[probe for technical barriers e.g., thermal elements vs other considerations]*

7. How familiar are you with industrial heat pumps? Would you say…

a. Very familiar,

b. somewhat familiar,

c. or not familiar? *[If not familiar, skip to Q9]*

8. *[If very or somewhat familiar, continue]* Have you considered using an industrial heat pump for any of your heat process load applications? If so, what loads?

9. *[If very or somewhat familiar, continue]* What barriers exist to implementing industrial heat pumps in your facility?

a. *[probe for technical barriers e.g. thermal elements vs other considerations]*

b. What would make you more likely to implement industrial heat pumps in your facility?

i. Would having successful pilot sites or case studies help make implementation at your facility easier? (probe about local vs international sites)

Decision making processes

Switching gears a little bit, I'd like to talk a bit more about your decision-making processes and equipment purchasing.

10. How are decisions made around purchasing new equipment?

d. [*if needed]:* Who makes major purchasing decisions?

e. Is there an equipment replacement schedule?

f. Is there a payback threshold for major equipment or other budgetary requirements?

11. For equipment design, selection, installation, and maintenance, are there key vendors or service providers you consistently work with? If so, who are those providers?

Energy efficiency, sustainability, and support

12. Does your company have any energy efficiency or sustainability goals that you consider when purchasing equipment or more broadly in your work? If so, please describe the goals. [if no, skip to Q14]

g. [if yes] Are these goals a part of a regulatory program or mandate?

h. [if needed] Are there specific timeframes associated with these goals?

13. What, if any, energy efficiency or sustainability or decarbonization initiatives or purchases has your organization already undertaken?

14. Who is responsible for making sure your organization meets its goals?

i. [if needed] Is there a specific role or team?

15. How familiar are you with rebates and incentives available from utility programs around industrial energy efficiency? Would you say…

j. Very familiar,

k. Somewhat familiar,

l. Or not familiar?

16. How can utilities best support you in decarbonization or sustainability goals?

17. Have you participated in any energy utility programs in the past? If so, which programs or what were they for?

<u>Wrap up</u>

18. Those are all my questions! Is there anything else you'd like to tell us?

19. We are also doing on-site surveys of heating processes. Would you be interested in having us come out to better understand your processes and which ones might be appropriate to have a heat pump?

20. We will be doing some pilots around industrial heat pump use in the next year. Would you be at all interested in participating in a pilot?

m. If yes, further describe and collect contact info

21. Finally, to say thank you for your time, we'd like to offer you a $50 Amazon e-gift card. Are you able to accept a gift card, and if so, where should we send it to?

a. Email

Interview Protocol for Others

Stakeholders include industrial energy professionals, industrial process designers, manufacturers' representatives, and utility staff who support industrial customers.

Introduction. See above for cold call options and items to note.

<u>Business characteristics and loads/processes</u>

1. First, can you start off by telling me about the types of products or industries you tend to work with?
2. What processes do you see in industrial settings that tend to use the most heating?
   a. What processes tend to require cooling?
   b. What are the critical temperatures for heating and cooling?
3. What industrial systems use the most energy?
   a. Are there any systems that you feel use more energy than they should, or that you feel are bad performers?

<u>Heat pump awareness</u>

4. Do you work at all with industrial heat recovery processes? If so, what loads do you work with?
5. What barriers do you commonly see with implementing heat recovery?
   a. *[probe for technical barriers e.g. thermal elements vs other considerations]*
6. How familiar are you with industrial heat pumps? Would you say…
   n. Very familiar,
   o. somewhat familiar,
   p. or not familiar? *[If not familiar, skip to Q9]*
7. *[If very or somewhat familiar, continue]* Have you considered recommending an industrial heat pump for any of your heat process load applications? If so, what loads?
   a. Have any of your customers expressed interest in industrial heat pumps?
   b. Are you seeing industrial heat pumps gaining any momentum in your circles?
8. *[If very or somewhat familiar, continue]* What barriers do you commonly see with implementing industrial heat pumps?
   a. *[probe for technical barriers e.g. thermal elements vs other considerations]*
9. What would make businesses more likely to implement industrial heat pumps in their facility?
   a. Would having successful pilot sites or case studies help make implementation easier? (probe about local vs international sites)

<u>Decision making processes and sustainability efforts</u>

Switching gears a little bit, I'd like to talk a bit more about how decisions are made and sustainability efforts you see.

10. Who do you most commonly work with in equipment purchasing processes?
    a. [Probe around roles, decision making, replacement processes, etc.]
    b. Does replacement typically follow a schedule or specific process?
    c. Who are the key points of influence in implementing more industrial heat pumps?

11. How often do you see businesses considering energy efficiency or sustainability goals when purchasing equipment or more broadly in your work? Would you say:

a. Very often

b. Sometimes

c. Not very often

i. *[If very often or sometimes]* How do you see them implementing these goals? (e.g. what types of equipment are they purchasing, are they actively acting on them, etc.)

12. How big of a factor do you think energy efficiency or sustainability goals are in purchasing decisions overall? Would you say:

a. A big factor

b. A small factor

c. Not a factor

13. How else do you see energy efficiency, sustainability, or decarbonization playing a role for industrial entities right now?

Additional Questions Tailored to Respondent Category

INDUSTRIAL PROCESS DESIGNERS AND ENERGY PROFESSIONALS:

18. What factors tend to motivate a customer to change a process design?

d. [Probe if needed] What about new plant design or large-scale process redesign, plant capacity expansion, or equipment replacement?

e. Are customers motivated to make changes after an assessment study is done?

f. How much motivation is energy efficiency?

19. After generating recommendations, what measures are most often implemented?

g. What measures are not often implemented?

h. Are there particular considerations that drive or hinder implementation? (E.g. capital cost or complexity)

Wrap up

20. Those are all my questions! Is there anything else you'd like to tell us?

21. We will be doing some pilots around industrial heat pump use in the next year. Are there any companies located in Minnesota you know that you think would be interested in participating in a pilot?

q. If yes, further describe and collect contact info

MANUFACTURER REP ONLY

16. What industrial heat pump products do you have in the market, if any?

a. What temperature range could these products accommodate?

b. How helpful would utility rebates or programs be in getting more of these products installed?

17. What are the current lead times for industrial heat pumps or relevant components? (Relevant components include large compressors, heat exchangers, large expansion valves, etc.)

c. Are any components particularly challenging to obtain right now?

UTILITY ONLY

14. What industrial rebates or programs, if any, do you have available?

a. [If they have rebates or programs and if need] Can you tell me more about the program/rebate like the incentive amount, savings allocated, or measure life?

15. What information is needed or helpful for you to create or adjust programs for industrial processes or equipment?

Appendix B: Heat Pump Evaluation Tools

The most useful tool in evaluating a heat pump application will be transparent in its assumptions, and it will guide the user to not only screen an application and select equipment appropriate to identified heat sink/source temperatures, but also to understand what the best potential process sink and source streams are at a plant. We are not aware of a tool to identify the best potential process sink and source streams. This compilation of existing tools focuses on the selection of equipment for identified sink and source temperatures.

Existing tools vary in their resolution and complexity. This section reviews techniques including:

- Renewable Thermal Collaborative's "Tool 1" and "Tool 2" spreadsheets
- A simple web tool called heatpumpestimator.com
- An approach presented by Electric Power Resource Institute (EPRI) in a recent publication
- A manufacturer's selection tool

Each tool is reviewed within the input-computation-output structure here.

Computation methods for estimating system COP vary between approaches. The COP for a process is limited first by its absolute temperature conditions. Methods for calculating ideal theoretical COP include simple Carnot efficiency and the more complex Lorenz efficiency. Lorenz efficiency is most relevant for systems with non-zero glide, where the refrigerant side of the condenser and evaporator heat exchangers do not operate at a constant temperature. This is the case for systems with zeotropic refrigerants, which, as the name suggests, change temperature during boiling because they are made up of a mixture of refrigerants with different boiling points. Non-zero glide is also the case for trans-critical condensers, which contain supercritical fluids, displaying a mix of sensible and latent heat transfer, though these aren't as common for higher-temperature applications. After calculating an ideal theoretical COP, that COP must be discounted to include inefficiencies. Real world equipment can operate at some fraction of the cycle's thermodynamic ideal efficiency. Different sources choose different fractions, dubbed second law efficiencies, ranging from 40% to 70%, and employ varying approaches to produce a conservative estimate of required temperatures.

Renewable Thermal Collaborative Tools

Both spreadsheet tools, available for free download, were developed by Verco Advisory Services in the United Kingdom. RTC Tool 1 is a ~250 row database of documented applications, with parameter sorting to determine which rows of the database domain match the user's input parameters. Parameters include source and sink unit process, fluid medium and temperature, and low-GWP/ODP refrigerant toggles.

Outputs take two forms. Output table 1 provides a list of relevant available technologies by category, such as TVR, MVR, MVC, MVC-multistage, and Absorption. Output table 2 provides matching case study results, with additional return parameters beyond the sort parameters, including capacity, COP range, and links to further details.

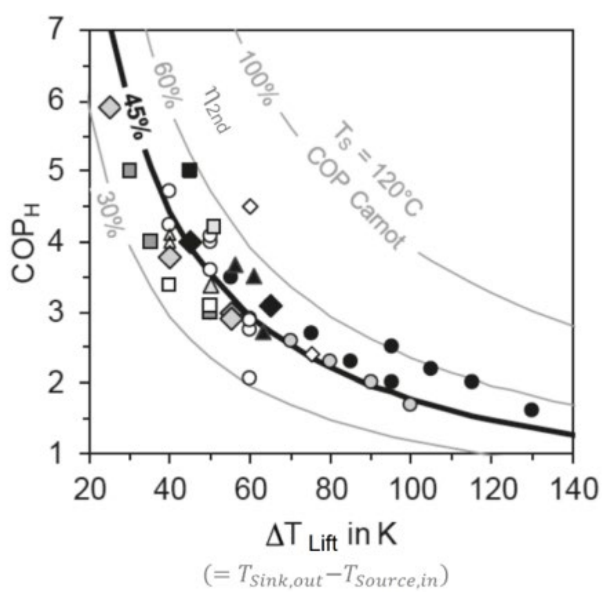
Since several variables cannot be modified or are out of the feasibility range (such as equipment COP and utility cost), more information is required to provide system and process specific outputs. The tool may also provide a false negative when the potential application is not represented by the database, but newer equipment is available for the process.

RTC Tool 2 builds from Tool 1 in each element of the input-computation-output structure. The tool allows more detailed technical and financial inputs. Technical inputs include properties of both source and sink streams, including entering and leaving temperatures, fluid medium, and presence of phase change. The tool also has a detailed analysis toggle, which allows additional inputs.

The tools computations use a binary second law efficiency assumption of 40% for lifts greater than 108°F and 45% for lifts less than 108°F. This represents a generalization of the meta-analysis performed by Arpagaus et al. (see The tool also makes assumptions about thermal storage performance and its impact on the system COP, in cases where thermal storage is required due to non-synchronicity of source-sink loads (as indicated by the tool).

The tool also makes assumptions about thermal storage performance and its impact on the system COP, in cases where thermal storage is required due to non-synchronicity of source-sink loads (as indicated by the tool).

Figure 20: Second Law Efficiencies



Note, lift is given in terms of the more neutral temperature for both process temperatures — full scale compressor lift is greater for all applications of indirect heat exchange.

The tool outputs are detailed, including carbon reduction, energy cost impacts, and payback period. The accuracy of outputs may be inflated, since the analysis includes a default method for determining the equipment COP. There isn't an option to assign an equipment COP if it is known for a particular manufacturer at a particular operating state. In the same vein, energy costs vs. demand costs aren't site-specific, i.e., tabulating or entering demand impact of the new system is not a feature of the tool. RTC Tool 2 does not readily allow for iteration or calculation of required input parameters to achieve desired breakeven output parameters, so its usefulness is limited to applications where the high-level details of the proposed system are already known.

There also exists an RTC tool, called Tool 3, which is an international supplier matching database similar in form factor to Tool 1. The tool is not particularly detailed or complete for North America. Since the U.S. market is rapidly evolving, other avenues for equipment sourcing are necessary.

Other Tools

First, Heatpumpestimator.com is sponsored by the Australia Alliance for Energy Productivity (A2EP), and has a similar array of inputs, including a toggle for whether thermal storage is required.[3] There is no information about its calculations (i.e., they are a black box). The tool recently underwent an update to add some supportive features which will allow plant personnel to better evaluate heat pump potential.

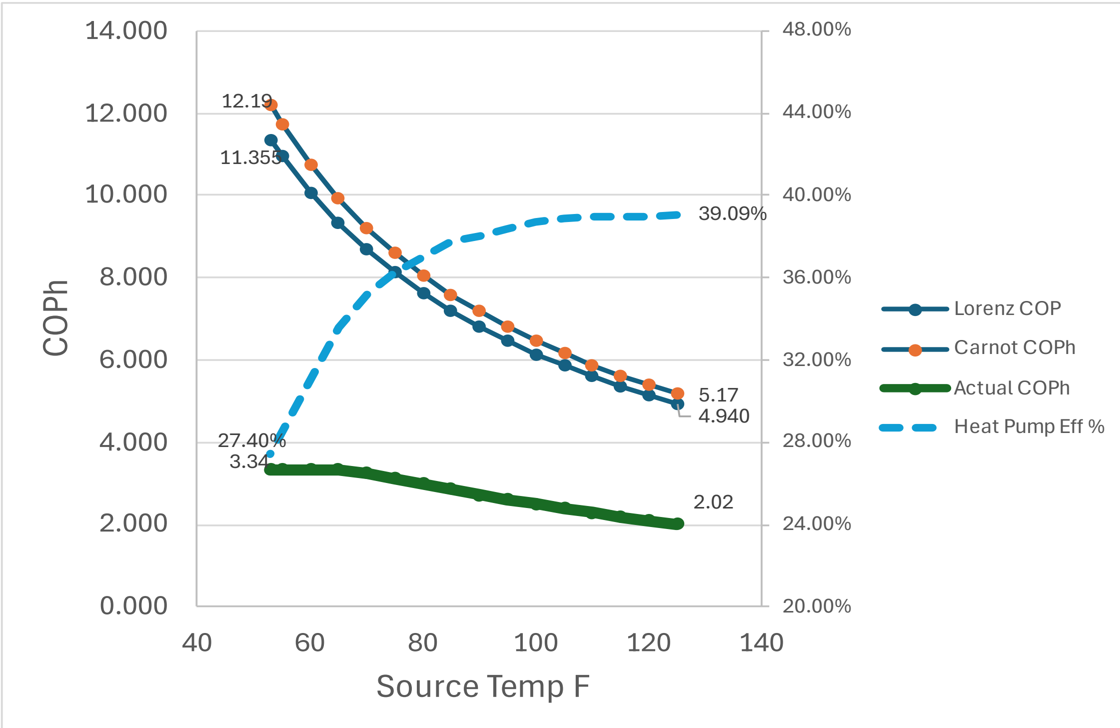
Second, EPRI has a simple spreadsheet tool targeted at food and beverage sectors that is accurate for other facilities and processes. The tool is currently held by EPRI for internal use and is not available to the public. The paper that describes the tool also includes a compiled average of normalized equipment capital cost, which is useful for the applicability step in this report's proposed approach. Full report text is freely available, and discussion of the analysis tool begins on page 50 (EPRI Report 3002031135).

The EPRI tool uses Lorenz ideal efficiency rather than Carnot efficiency. The key difference between the two values is that the Lorenz efficiency captures temperature variation in the evaporator and condenser heat exchangers. Carnot efficiency is always higher than the Lorenz efficiency, because it assumes an ideal heat exchanger with an infinite surface area such that the process fluid delta T is negligible, and the refrigerant temperature is equal to the process fluid temperature. The EPRI tool uses Lorenz efficiency to increase the accuracy of the efficiency estimate and applies a constant second law efficiency of 50%.

Third, the Oilon equipment selection program produces an empirical COP that is a negative-linear function of lift (see Figure 21). Rather than generalizing a 2nd law efficiency to apply to the Carnot/Lorenz efficiency, characterizing efficiency vs. stream temperatures is accomplished by using independent variables like compressor type, refrigerant, and working pressures. More benchmarking of equipment design and performance of other manufacturers is required to generalize the relationship.

[3] At the time of writing this interim report, the website indicates that a new version (V2) is coming, and the tool is unavailable for access. More detailed benchmarking of outputs will be provided here when the V2 website is published.

Figure 21: Comparison of COP with Carnot and Lorenz Efficiencies: Oilon HP Selection Program



Appendix C: Heat Pump Evaluations for Six Sites

The following sections provide details of the heat pump evaluations for each of the six sites. The plant staff described the typical operating mode used to estimate stream heating needs. This is adequate for gauging heat pump feasibility. Additional investigation is needed to define more detailed implementation concepts and configuration.

The results for typical operating mode streams are displayed in a sources and sinks table, a pinch analysis composite curve, and grand composite curve. The table is provided for the first four sites and the curve charts for the first three sites. The pinch analysis composite curve includes a green arrow and circles that show the potential for a heat pump to transfer energy from the available sources to the appropriate sinks. The heat pump would take that energy rejected at lower temperature and deliver it at a higher temperature to meet process hot water or steam needs. A better understanding of process thermal needs is visualized using a grand composite curve. The grand composite curve shows the heat pump lift needed (temperature difference between the source and sink application), available source energy, and amount of heat recovery that can be achieved at different temperature levels.

Site 1 Food and Beverage / Canned Products

Overview

Site 1 is a 500,000 sq. ft. food and beverage facility that produces canned products. It has an annual electricity use of about 15 GWH and gas use of 300,000 Dth. The process includes blanching, cooking, sauce making, and canning. Current process design includes integrated heat recovery to preheat hot water and minimize the need for heating and cooling utilities. Key opportunities for application of heat recovery heat pumps were to provide hot water for soaking, blanching, and pick-heaters. Prime sources of heat were tower water, compressed air, and boiler stack. Site 1 decision-making criteria required a strong ROI and minimization of risk and reliability as the top two considerations.

Heat Pump Opportunity Evaluation

The typical operating mode streams are summarized in Table 14 and were used for the pinch analysis shown in Figure 22 and Figure 23. The green arrow in the pinch analysis composite curve shows the opportunity to recover heat from cooling tower water to heat water for the pick-heaters or blanching. An HWHP could transfer heat from a temperature of 74°F from the tower water to 161°F for providing process hot water for a temperature lift of 87°F. About 15% of the total heating requirement could be met by an HWHP. As shown by the blue vertical arrows in the grand composite curve, an SHP would require a lift of 132°F and could provide up to 67% of the heating.

Table 14: Site 1 Heat Sources and Sinks

				Temperature Range, F			
Process / Streams	Thermal Energy	Sink	Source	Tin	Tout	Mcp	Comments
Kitchen/Sauce Making/ Blanching	Sensible	1		55	132	249.0	Hot water heat recovery used
Sauce Cooking	Sensible	1		180	200	143.2	130 psig steam jackets (10% of process hot water total)
Cooking	Sensible	1		180	200	1100.0	Uses heat recovery
Continuous Cooker	Sensible	1		180	200	481.3	Uses heat recovery
Pick Heaters	Sensible	1		132	170	249.0	Go from 132F to 170F
Boiler Feed Water Heating	Sensible	1		50	220	7.0	Boiler Feed Water - 240 gpm max RO
Boiler Stack	Sensible		1	320	250	31.1	5% stack loss (80% design efficiency)
Compressed Air Cooling	Sensible		1	85	95	25.6	Plant air - est 80% design 125 hp operating and 75% waste heat
Product Cooling	Sensible		1	86	55	506.5	Tower Water
Process Zone 1 Cooling	Sensible		1	159	87	172.5	Can zones cooling
Process Zone 2 Cooling	Sensible		1	99	86	506.5	Can zones cooling

Figure 22: Site 1 Pinch Analysis Composite Curve

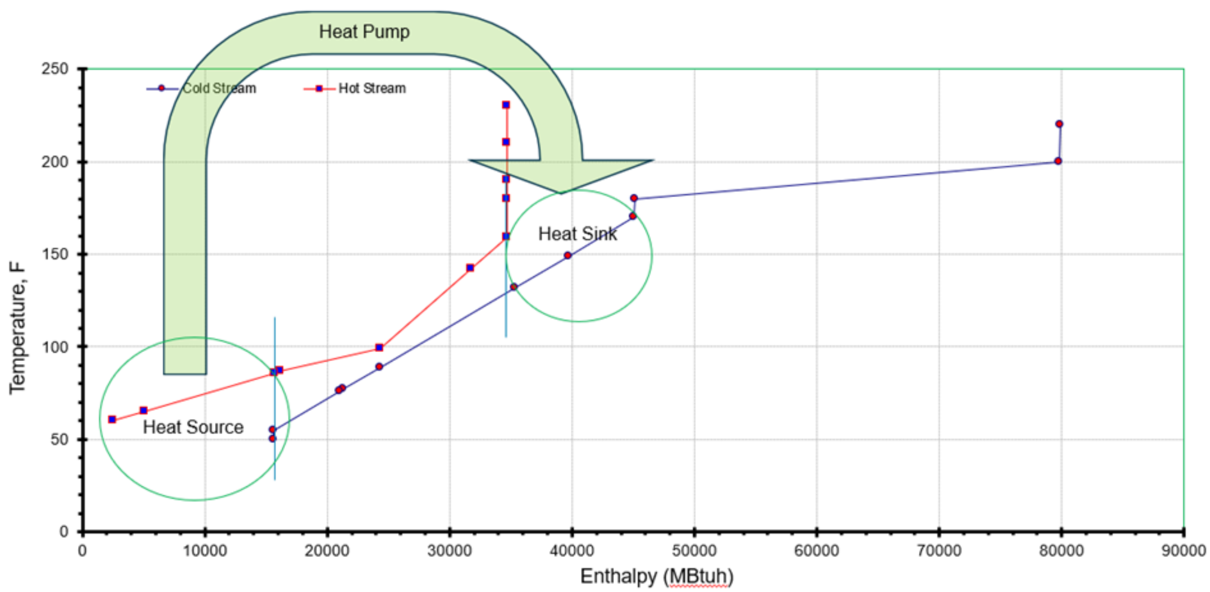
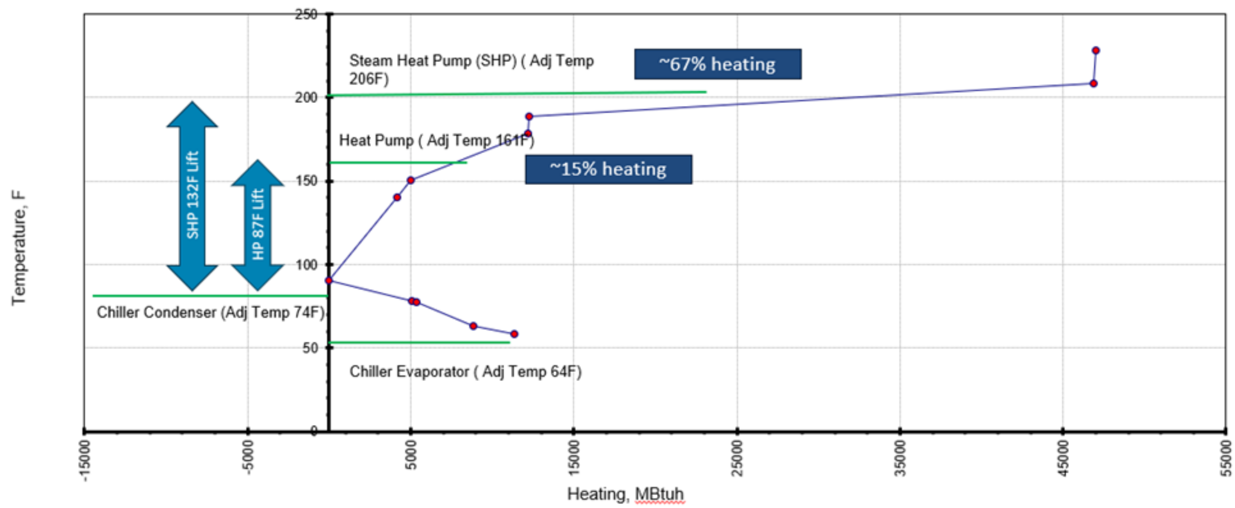


Figure 23: Site 1 Pinch Analysis Grand Composite Curve



Factors for Adoption

Based on the temperature lifts the estimated COP_h for the HWHP is 3.8 and the COP_h for the SHP is 2.8. The spark gap for the site is 4.6. Since the spark gap is greater than COP_h for both heat pumps, the energy cost per unit would increase by 11% for the HWHP and by more than 50% for the SHP. There is no beneficial ROI for this site.

Further evaluation to get to a feasible concept for a pilot project would require addressing the following concerns:

- Risk / reliability
- Maintainability / equipment Life
- Food and Drug Administration requirements
- Codes / standards

Implementation of the heat pump at this site with an acceptable ROI would not be possible for the current spark gap. The best application would be to fine-tune the HP options for hot water, by maximizing source temperature and reducing lift to recover less than the 15% target possible for hot water. While this could reduce the cost penalty for application of heat pumps, the ROI is still expected to be poor or non-existent.

Site 2 Food and Beverage / Egg Products

Overview

Site 2 is a 150,000 sq. ft. food and beverage site producing egg products. It has an annual electricity use of about 30 GWH and gas use of 30,000 Dth. The process includes cooking, pasteurization, and toasting. Current process design includes steam/gas ovens for cooking, hot oil for toasting, and an ammonia refrigeration system. Key opportunities for application of heat recovery heat pumps were to provide hot water for CIP and cleaning and process steam at 12 psig. The main sources of heat were oven exhausts, boiler stack, and refrigeration system heat rejection. Site 2 decision-making criteria required a strong ROI and ability to fit in a limited space.

Heat Pump Opportunity Evaluation

The typical operating mode streams are summarized in Table 15 and were used for the pinch analysis shown in Figure 24 and Figure 25. The green arrow in the pinch analysis composite curve shows the opportunity to recover heat from refrigeration to hot water. An HWHP with a temperature lift of about 75°F would recover heat from refrigeration condenser to heat hot water for process loads. About 46% of the total heating requirement could be met by an HWHP. An SHP would require a lift of 155°F and could provide up to 79% of the heating.

Table 15: Site 2 Heat Sources and Sinks

Process Application				Temperature Range, F			Confidential
Row Labels	**Thermal Energy**	**Sink**	**Source**	**Tin**	**Tout**	**MCP est**	**Comments**
Cooking	Latent	1		80	270	33	Steam 12 psig
Process Application	Sensible	1		100	300	13	
Process Application	Sensible	1		100	300	13	
Hot water / cip	Sensible	1		55	140	0.27	
Hot water - washing	Sensible	1		55	120	0.36	
Hot water	Sensible	1		100	145	47	Product heated to 145F
Hot water	Sensible	1		100	120	1	Keeps tank at 80F
Hot Oil	Sensible	1		100	380	4	
Waste heat 1	Sensible		1	300	200	6	Assume 25% to stack
Waste heat 2	Sensible		1	300	200	6	Assume 25% to stack
Waste heat 1 Stm	Sensible		1	300	150	4	Assume 25% to stack
Boiler Stack	Sensible		1	350	200	4	Assume 10% to stack
Refrigeration	Latent			95	85	983	

Figure 24: Site 2 Pinch Analysis Composite Curve

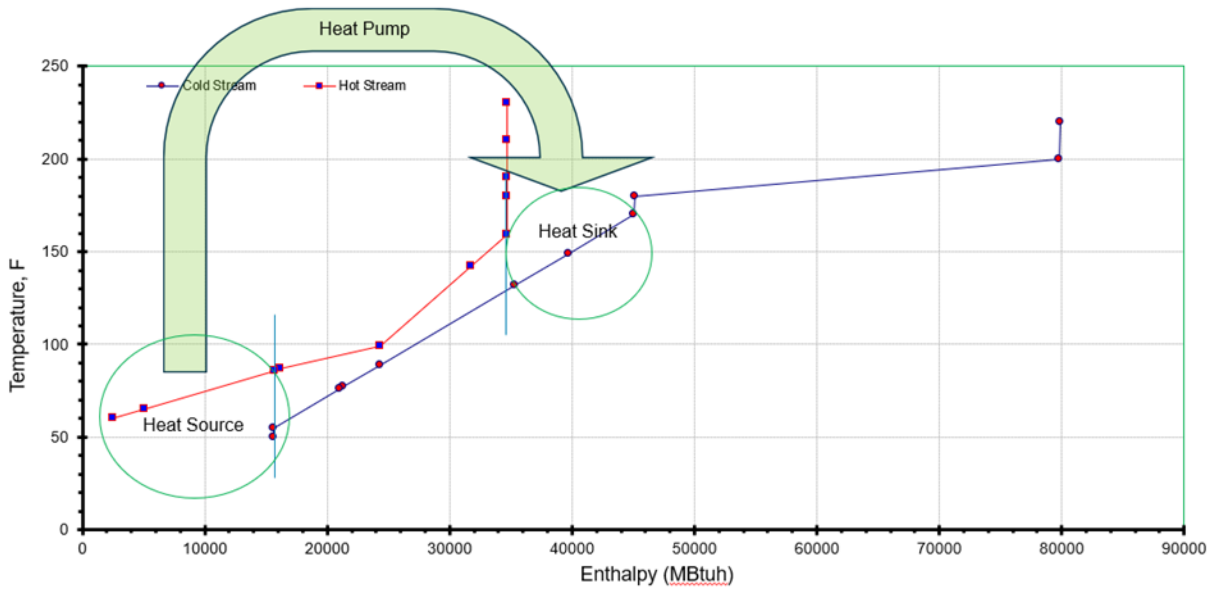
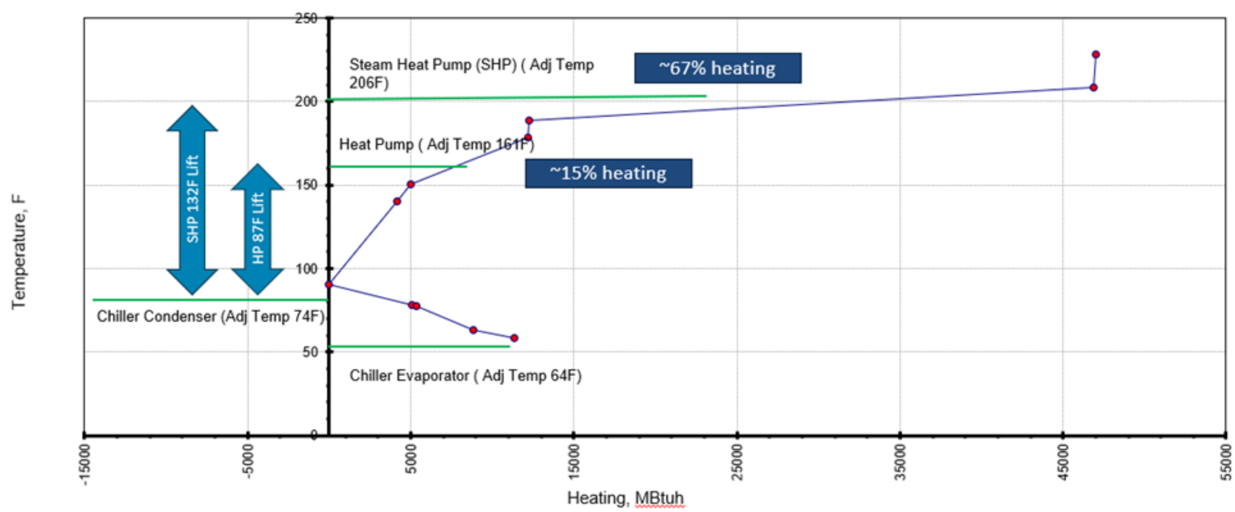


Figure 25: Site 2 Pinch Analysis Grand Composite Curve



Factors for Adoption

Based on the temperature lifts the estimated COP_h for the HWHP is 4.3 and the COP_h for the SHP is 2.5. The spark gap for the site is 5.05. Since the spark gap is greater than COP_h for both heat pumps, the energy cost per unit would increase by 17% for the HWHP and by more than 105% for the SHP. There is no beneficial ROI for this site.

Further evaluation to get to a feasible concept for a pilot project would require addressing the following concerns for this site:

- Space
- Maintainability
- Complexity

Implementation of the heat pump at this site with an acceptable ROI would be challenging at the current spark gap. Due to aging equipment, the site is looking to replace the boilers. There is also an interest in additional heat recovery and cogeneration. Heat pumps could be considered as an option to address the replacement of aging equipment with similar equipment. Site space constraints are a significant challenge.

Site 3 Pharmaceuticals / Cosmetics

Overview

Site 3 is a 180,000 sq. ft. food pharmaceuticals and cosmetics facility. It has an annual electric use of about 8 GWH and gas use of 6,000 Dth. The process includes mixers, reactors, and other vessels that require batch heating and cooling. Key opportunities for application of heat recovery heat pumps, were to provide hot water for Clean-In-Place and process steam at 12 psig. Prime sources of heat were process heat rejection, boiler stack and compressed air cooling. Site 3 decision making criteria are driven by sustainability goals for reduction in greenhouse gas emissions.

Heat Pump Opportunity Evaluation

The typical operating mode streams are summarized in Table 16 and were used for the pinch analysis shown in Figure 26 and Figure 27. The green arrow in the pinch analysis composite curve shows the opportunity to recover heat from cooling tower water to hot water for process batch heating. An HWHP with a temperature lift of about 90°F, would recover heat from chiller evaporator to heat hot water. About 58% of the total heating requirement could be met by a hot water heat pump. An SHP would require a lift of 125°F and could provide up to 100% of the heating.

Table 16: Site 3 Heat Sources and Sinks

Process Application				Temperature Range, F			
	Thermal Energy	Sink	Source	Tin	Tout	Mcp	Comments
Hot water / cip	Sensible	1		130	180	21.51	Steam 12 psig
Process heating	Sensible	1		130	180	43.03	Steam 12 psig
Boiler Stack	Sensible/Latent		1	220	180	12.33	Stack heat from boiler
Compressed air cooling	Sensible		1	170	85	9.98	Tower water cooled
Process cooling	Sensible		1	95	85	218.30	Tower water cooled

Figure 26: Site 3 Pinch Analysis Composite Curve

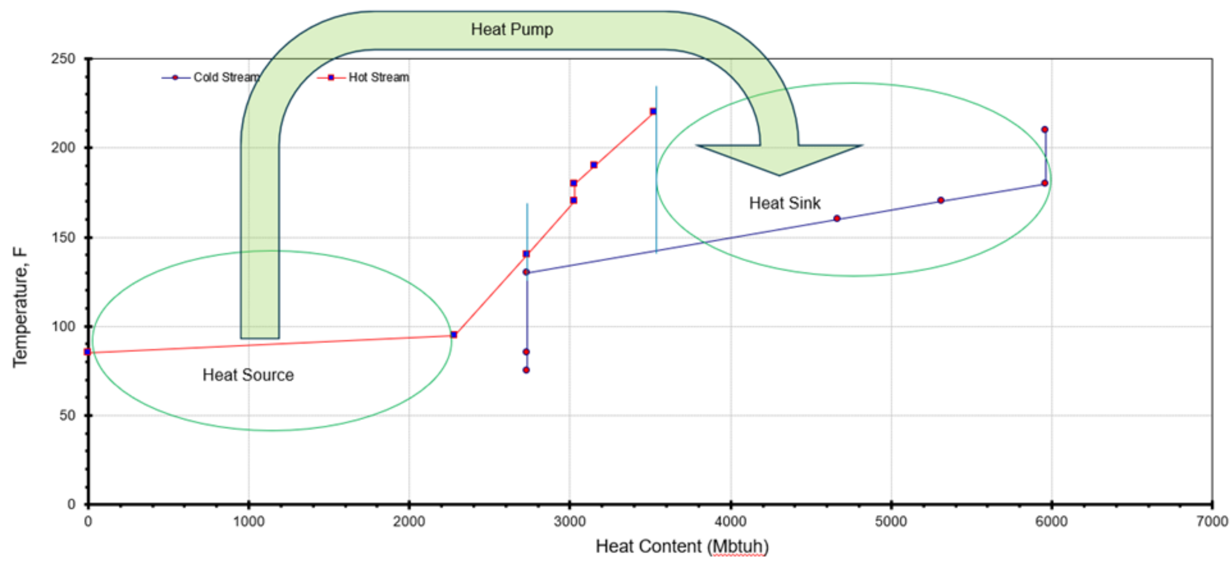
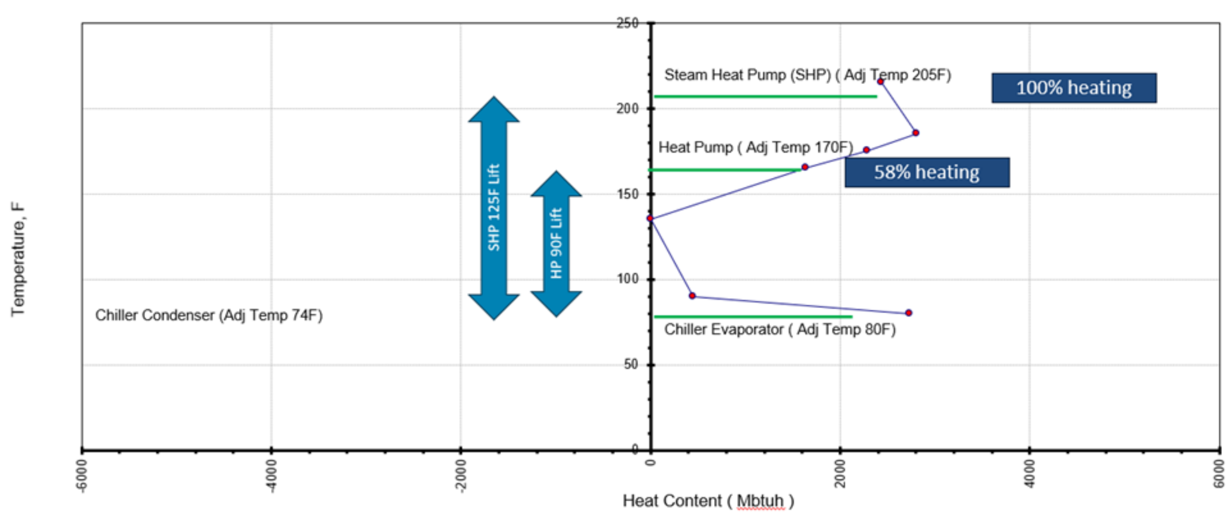


Figure 27: Site 3 Pinch Analysis Grand Composite Curve



Factors for Adoption

Based on the temperature lifts the heat pump efficiency COP_h estimated for the HWHP is 3.7 and the COP_h for the SHP would be 2.9. The spark gap for the site is at present 3.98. Since the spark gap is greater than COP_h for both heat pumps, the energy cost per unit would increase by 6% for the hot water heat pump and by 37% for the SHP. There is no ROI for this project from energy cost savings.

Further evaluation to get to a feasible concept for a pilot project would require addressing the following concerns for this site:

- Sustainability scope 1 reduction
- Space
- Maintainability
- Service life

Implementing the heat pump at this site is driven by sustainability goals for scope 1 emissions. This site has potential to be a candidate for a pilot heat pump project. Thermal storage will be required because of batch operations.

Site 4 Food and Beverage Dairy

Overview

Site 4 is a 105,000 sq. ft. food and beverage dairy facility. It has an annual electricity use of about 12 GWH and gas use of 90,000 Dth. The process includes pasteurization and hot water. The prime sources of heat are for pasteurization and hot water. Site 4 decision-making criteria is driven by sustainability goals for reduction in greenhouse gas emissions.

Heat Pump Opportunity Evaluation

The typical operating mode streams are summarized in Table 17 and were used for the pinch analysis. This site has incorporated significant amounts of heat recovery from the high-temperature pasteurization units and has very limited opportunities for heat pump applications.

Table 17: Site 4 Heat Sources and Sinks

Process Application				Temperature Range, F			
	Thermal Energy	Sink	Source	Tin	Tout	Mcp	Comments
Pasteurisation	Sensible	1		125	290	5.7	100 psig steam (80%)
Hot water	Sensible	1		150	180	6.9	CIP for liines and tank (50%)
Pasteurisation	Sensible	1		156.6	180	10.0	Steam (20%)
Process cooling			1	250	35	4.4	Assume 70% rejection

Site 5 Food and Beverage Egg Processing

Overview

Site 5 is a 323,000 sq. ft. food and beverage site producing egg products. It has an annual electricity use of about 30 GWH and gas use of 130,000 Dth. The processes include gas and steam ovens, ammonia refrigeration, and hot water for process heat and clean-in-place. Key opportunities for heat pump applications were to provide hot water for clean-in-place and process steam at 10 psig. Prime sources of heat were oven exhaust, boiler stack, and compressed air cooling. Site 5 decision-making criteria is strictly driven by aggressive ROI requirements.

Heat Pump Opportunity Evaluation

The only appropriate opportunity was the use of heat rejection from the ammonia refrigeration system for process hot water at 180°F or the production of low-pressure steam. An HWHP with a temperature lift of about 75°F would recover heat from the ammonia refrigeration condenser for hot water. About 25% of the total heating requirement could be met by a hot water heat pump. An SHP would require a lift of 145°F and could provide up to 100% of the low-pressure steam heating.

Factors for Adoption

Based on the temperature lifts the heat pump efficiency COP_h estimated for the HWHP is 4.3 and the COP_h for the SHP would be 2.6. The spark gap for the site is at present 5.16. Since the spark gap is greater than COP_h for both heat pumps, the energy cost per unit would increase by 20% for the hot water heat pump and by 99% for the SHP. There is no positive ROI for this project from energy cost savings and an HP installation would not be considered at this time.

Site 6 Food and Beverage Brewing

Overview

Site 6 is a 41,800 sq. ft. food and beverage site producing egg products. This plant did not provide electric and gas use information. The processes include steam and hot water. The plant has air-cooled chillers for process cooling.

Heat Pump Opportunity Evaluation

The plant is relatively new and was constructed with optimal process heat recovery. About 80% hot water is produced by heat recovery. There is an opportunity for recovering heat from the refrigerant condensers to produce low pressure steam. An SHP would require a lift of 145°F and could provide up to 100% of the low-pressure steam heating.

Factors for Adoption

Based on the temperature lifts the heat pump efficiency COP_h for the SHP would be 2.6. The spark gap for the site is at present 5.16. Since the spark gap is greater than COP_h for the SHP, the energy cost per unit would increase by 99% for the SHP. There is no positive ROI for this project from energy cost savings and an HP installation would not be considered at this time.