

High-Temperature Heat Pumps: From Pilot to Process Strategy

Introduction

Industrial manufacturing is entering a period of significant transformation. As facilities strive to improve energy efficiency, reduce operating costs, strengthen resilience and prepare for an evolving energy landscape, the way process heat is generated and managed is changing.

For decades, industrial thermal systems have been designed around the reliable combustion of fossil fuels to produce steam, hot water and process heat. While these systems continue to play an important role across many industries, advances in electrification technologies are creating new opportunities to recover, upgrade and reuse thermal energy that was previously considered waste.

Among these emerging technologies, **High-temperature heat pumps (HTHPs)** have become one of the most promising solutions for industrial process heating. Improvements in compressor technology, refrigerants, controls and system design have expanded their operating capabilities into temperature ranges suitable for a growing number of industrial applications. **As a result, HTHPs are moving beyond demonstration projects and becoming commercially viable solutions for process manufacturing.**

However, successful implementation requires more than selecting the appropriate equipment. Achieving meaningful improvements in energy efficiency, operating performance and lifecycle value depends on understanding the manufacturing process as a whole and integrating HTHPs into a coordinated thermal strategy.

This white paper examines the evolving role of HTHPs in industrial process manufacturing, drawing on insights from the 2025 High-Temperature Heat Pump Symposium in Denmark, current industry developments and The Haskell Company's experience integrating complex industrial utility systems.

Rather than promoting a single technology solution, this paper presents an engineering framework for evaluating where High-temperature heat pumps provide the greatest value, how they should be integrated into industrial process facilities and how they can complement other technologies—including mechanical vapor recompression (MVR), conventional steam systems, heat recovery and thermal storage—to improve overall plant performance.

The objective is not to identify a single technology solution, but to engineer an integrated thermal system that applies the appropriate combination of technologies to maximize efficiency, reliability, operational flexibility and long-term value. HTHPs are one of the most important technologies enabling that objective.

As an engineering, procurement and construction (EPC) company with extensive experience in industrial process facilities, **Haskell is uniquely positioned to help clients evaluate, design and integrate these technologies into practical, reliable and economically sound solutions.** The intent of this paper is to provide engineers, facility owners and industry leaders with a practical understanding of HTHPs and the engineering considerations that determine successful implementation.

1. The Changing Landscape of Industrial Heat

Industrial process heat is entering one of the most significant transitions since steam power became the foundation of modern manufacturing. For more than a century, industrial facilities have relied on the combustion of fossil fuels to generate the thermal energy required for production. Steam boilers fueled by coal, fuel oil and more recently, natural gas, have provided a reliable and

economical means of delivering process heat across nearly every industrial sector.

Today, however, the environment in which industrial facilities operate is changing. While safety, reliability, production capacity and product quality remain the primary drivers of engineering decisions, facility owners are increasingly evaluating energy systems through a broader lifecycle perspective that includes operating costs, energy efficiency, resiliency and long-term flexibility. These factors are reshaping how industrial thermal

systems are designed and creating new opportunities for technologies capable of delivering process heat more efficiently.

One of the primary drivers of this transition is the continued electrification of industrial energy systems.

As electrical grids evolve and incorporate a more diverse mix of generation resources—including natural gas, nuclear, hydroelectric, solar, wind and other renewable energy sources—electricity is becoming an increasingly attractive energy source for industrial applications. Electrification also provides facility owners with greater flexibility as energy markets, utility infrastructure and environmental regulations continue to evolve.

At the same time, manufacturers are placing greater emphasis on reducing overall energy consumption rather than simply changing fuel sources. Every industrial process contains thermal energy that is transferred, rejected or lost during production. Historically, much of this energy has been discharged to the atmosphere through cooling towers, condensers, refrigeration systems or wastewater streams because it could not be economically recovered or reused. Advances in heat recovery technologies are changing that approach by allowing facilities to capture, upgrade and reuse thermal energy that was previously considered waste.

Economic considerations are also accelerating this transition. **Energy remains one of the largest operating expenses for many industrial facilities**, particularly those requiring continuous process heating, steam generation, refrigeration or hot water production. Improving thermal efficiency reduces operating costs while improving competitiveness and reducing exposure to future energy price volatility. Increasingly, facility owners are evaluating projects based on lifecycle operating costs rather than first cost alone.

Corporate sustainability initiatives and evolving environmental regulations are further influencing investment decisions. Many manufacturers have established long-term goals to reduce greenhouse gas emissions while maintaining operational performance and product quality. Although regulatory requirements vary by region, industrial facilities are increasingly expected to improve energy efficiency and reduce direct emissions without compromising production.

These market drivers are changing the way engineers approach industrial utility systems. Historically, heating and cooling systems have often been designed independently. Boilers generated steam, refrigeration systems rejected heat, cooling towers removed excess thermal energy and each utility system was optimized individually. Today, engineers are increasingly evaluating these systems as interconnected components of a single thermal process in which energy can be recovered, upgraded, redistributed and reused to improve overall plant performance.

High-temperature heat pumps (HTHPs) have emerged as one of the most promising technologies supporting this transition. Unlike conventional boilers that generate heat through combustion, HTHPs recover thermal energy from existing process streams and upgrade it to temperatures suitable for process heating, hot water production and, in many applications, steam generation. This capability enables facilities to recover valuable energy that would otherwise be rejected while reducing overall energy consumption and improving system efficiency (see figure 1).

The rapid advancement of HTHP technology was evident throughout the 2025 High-Temperature Heat Pump Symposium in Denmark. A consistent message emerged from equipment manufacturers, researchers, utilities and industrial end users: **High-temperature heat pumps have reached a level of technical maturity where the primary challenge is no longer proving that the technology works.** The challenge is determining where it creates the greatest value and how it should be integrated into industrial processes.

For Haskell, this represents a significant opportunity. Successfully implementing HTHPs requires far more than selecting the appropriate equipment. It requires understanding manufacturing processes, identifying available heat sources and heat sinks, optimizing process temperatures, integrating utility systems and evaluating lifecycle economics. These are multidisciplinary engineering challenges that align directly with Haskell's expertise in process engineering, industrial utilities, refrigeration, controls and facility design.

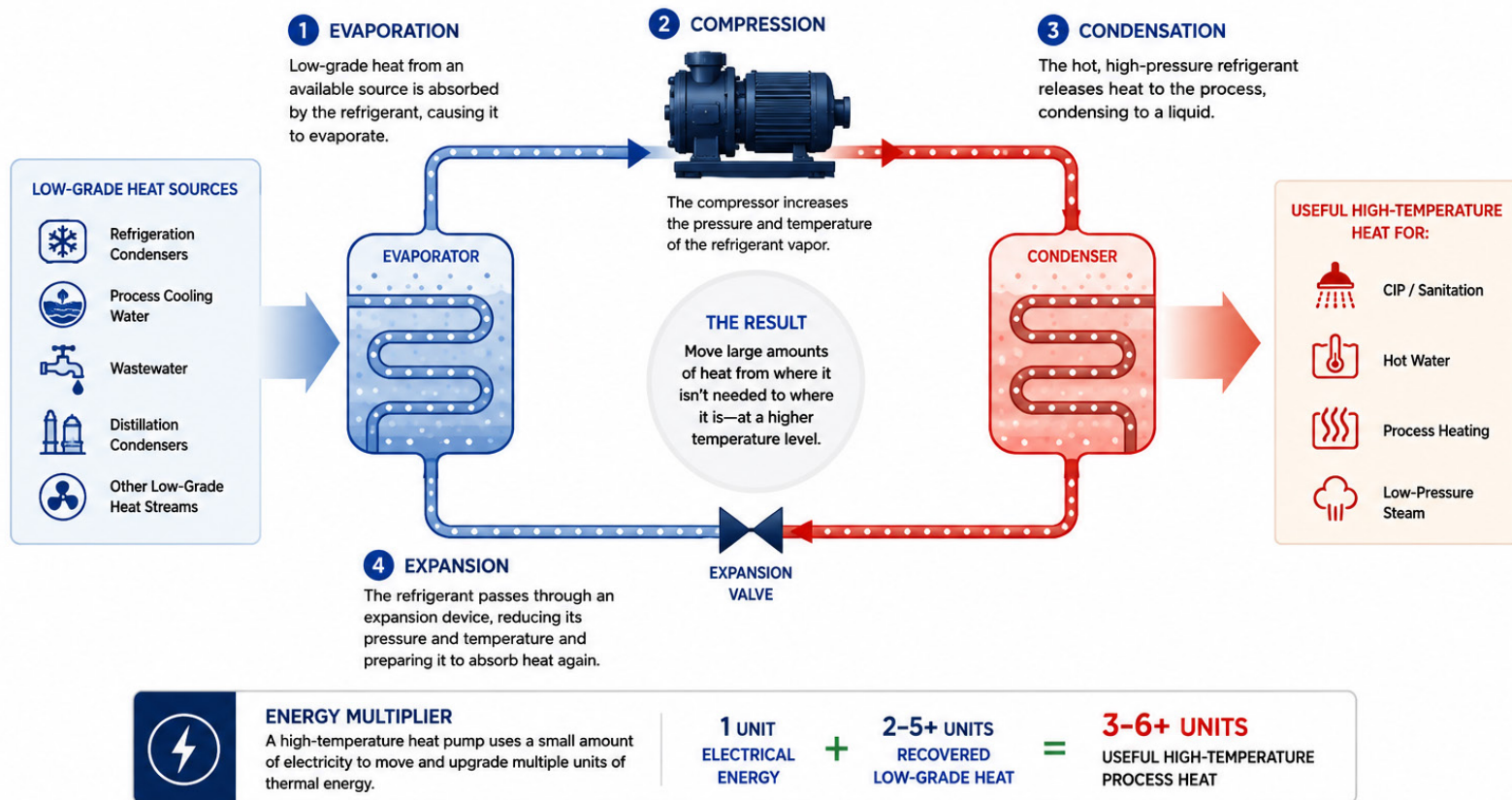
The objective is not to identify a single technology solution, but to engineer an integrated thermal system that applies the appropriate combination of technologies to maximize efficiency, reliability, operational flexibility and long-term value. HTHPs are one of the most important technologies enabling that objective. When properly integrated into industrial process facilities, they have the potential to improve energy efficiency, reduce operating costs and help prepare manufacturing operations for the ongoing energy transition.

2. Understanding High-Temperature Heat Pumps

High-temperature heat pumps (HTHPs) have emerged as one of the most significant advancements in industrial process heating in recent decades. While heat pump technology has long been used in residential and commercial heating applications, recent advances in compressor technology, refrigerants, heat exchangers and control systems have expanded their capabilities into temperature ranges suitable for industrial process heating. Today, commercially available HTHPs are capable of producing hot water and process heat **exceeding 120°C (248°F)**, with several manufacturers demonstrating

FIGURE 1. HOW A HIGH-TEMPERATURE HEAT PUMP WORKS

Basic operating cycle of a High-Temperature Heat Pump, showing how low-grade heat is absorbed, compressed and delivered as useful process heat.



Note: Actual performance (COP) varies based on temperature lift, refrigerant, system design, and operating conditions.

systems capable of temperatures approaching **200°C (392°F)** for select applications.

Unlike conventional boilers, which generate heat by burning fuel, HTHPs transfer existing thermal energy from one location to another while increasing its temperature to a useful level. This distinction is fundamental to understanding their value. Rather than creating heat through combustion, HTHPs recover thermal energy that already exists within an industrial facility and upgrade it for productive use elsewhere in the process.

Every manufacturing facility contains recoverable thermal energy. Refrigeration systems reject heat through condensers, process cooling systems remove heat from equipment, wastewater leaves the process carrying thermal energy and steam systems reject heat through condensate and flash steam. Historically, much of this energy has been discharged to the atmosphere because its temperature was too low to be economically reused.

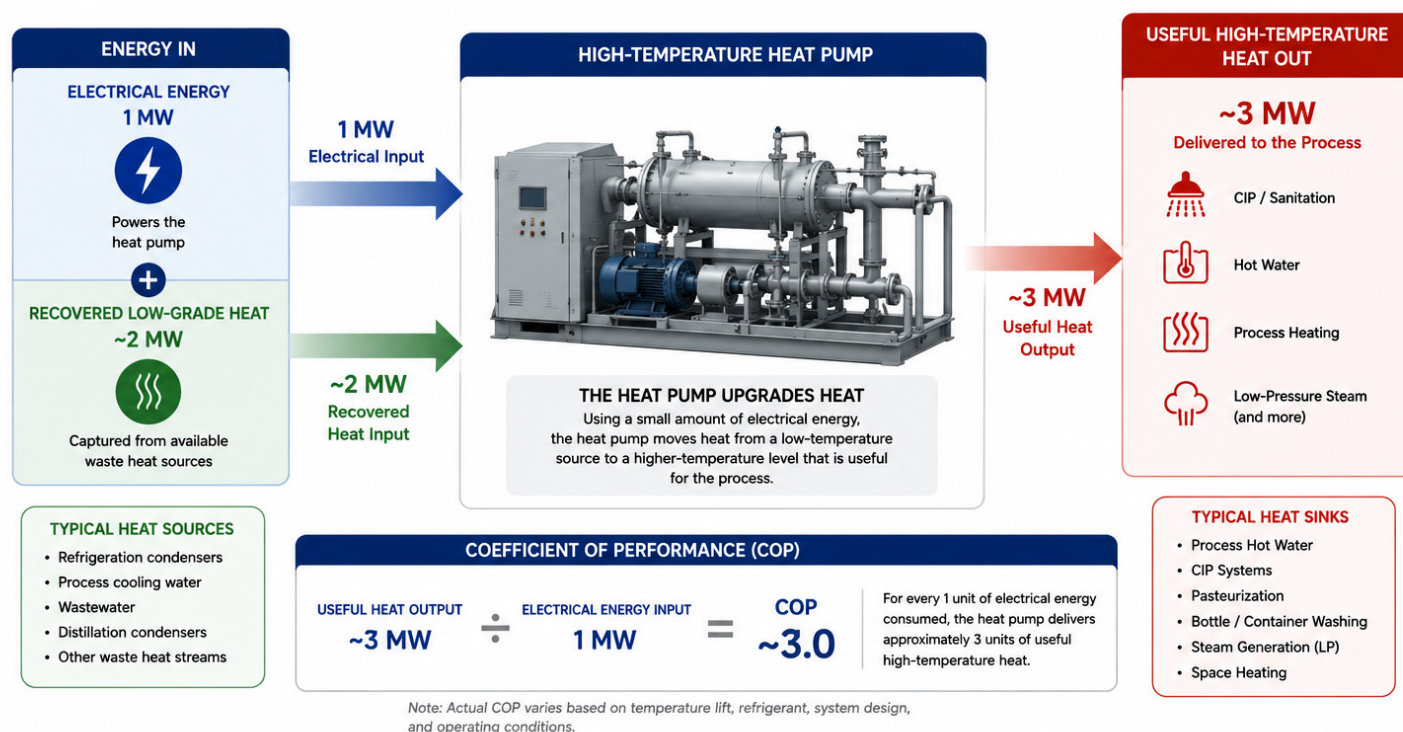
HTHPs make it possible to recover this low-grade heat and upgrade it to temperatures suitable for processing hot water, cleaning systems, preheating applications and, in many cases, generating steam.

The performance of an HTHP is measured by its **coefficient of performance (COP)**. COP is defined as the ratio of useful thermal energy delivered by the heat pump to the electrical energy required to operate it. For example, an HTHP operating with a COP of 4.0 delivers four units of useful thermal energy for every unit of electrical energy consumed. Unlike boiler efficiency, which is limited by the conversion of fuel into heat, the COP of a heat pump depends primarily on the relationship between the available heat source and the required process heating temperature (**see figure 2**).

One of the most important factors affecting HTHP performance is **"temperature lift."** Temperature lift is the difference between the temperature of the available heat source and the required process heating temperature. As temperature lift increases, the heat pump must perform more work to raise the temperature of the recovered heat, resulting in lower efficiency and increased electrical consumption. Conversely, reducing temperature lift improves system performance and operating economics. This principle reinforces the importance of evaluating process temperatures early in project development rather than simply selecting equipment after process conditions have been established.

FIGURE 2. THE HEAT PUMP EFFECT: COP

Illustration of the energy balance and Coefficient of Performance of a typical High-Temperature Heat Pump



KEY TAKEAWAY

By recovering and upgrading waste heat, high-temperature heat pumps can deliver 2–6+ units of useful heat for every 1 unit of electrical energy. This is the fundamental reason heat pumps can dramatically reduce energy consumption and operating costs.

Successful HTHP projects also depend on identifying appropriate “heat sources” and “heat sinks.” **Heat sources are locations within the manufacturing process where recoverable thermal energy is available.** Common examples include refrigeration condensers, compressor cooling water, wastewater streams, evaporator condensate, process cooling loops and other waste heat streams. **Heat sinks are the locations where upgraded thermal energy can be beneficially utilized,** such as process hot water systems, Clean-in-Place (CIP) systems, bottle washing, process heating, makeup water preheating, space heating and steam generation. The effectiveness of an HTHP depends on successfully matching available heat sources with appropriate heat sinks.

The continued development of natural refrigerants has also contributed significantly to the commercial maturity of HTHPs. Refrigerants such as ammonia (R-717), carbon dioxide (R-744), propane (R-290) and water (R-718) are increasingly being utilized in industrial systems due to their excellent thermodynamic performance and alignment with evolving environmental regulations. Combined with advances in compressor design and control systems, these refrigerants have expanded the

range of industrial applications that can be economically served by HTHPs.

One of the recurring themes throughout the 2025 High-Temperature Heat Pump Symposium was that **HTHPs should no longer be viewed as experimental technologies.** Equipment manufacturers, industrial end users and researchers consistently presented commercially operating systems across multiple industries, demonstrating that the technology has reached a level of maturity suitable for a growing number of industrial process applications. The discussion has shifted from whether HTHPs work to where they provide the greatest technical and economic value.

For engineering firms like Haskell, the value of HTHPs extends beyond the equipment itself. The greatest opportunity lies in integrating HTHPs into the overall manufacturing process. Successful implementation requires understanding process temperatures, thermal loads, utility infrastructure, operating schedules, refrigeration systems and future facility requirements. Evaluating these factors **during conceptual design** allows HTHPs to become part of an integrated thermal strategy rather than simply replacing an existing boiler or water heater.

It is also important to recognize that HTHPs are **not intended to replace every conventional heating technology**. Many industrial facilities will continue to rely on conventional boilers, mechanical vapor recompression (MVR), thermal storage systems and other process heating technologies. In many applications, the greatest technical and economic benefit is **achieved by combining these technologies into an integrated thermal system**. For example, MVR can efficiently recover energy from process vapor streams while HTHPs simultaneously recover lower-grade waste heat from refrigeration systems and cooling processes. Working together, these complementary technologies maximize overall heat recovery, reduce utility demand and improve plant-wide energy efficiency.

As industrial facilities continue to pursue improved efficiency, lower operating costs and greater operational flexibility, HTHPs have become an increasingly important engineering tool. Their greatest value is realized not as standalone equipment, but as part of a **comprehensive process integration strategy that optimizes thermal energy across the entire manufacturing facility**.

3. Technology Maturity and Market Readiness

High-temperature heat pumps have reached a significant point in their evolution. Over the past decade, advances in compressor technology, refrigerants, heat exchanger design, system controls and manufacturing have transformed HTHPs from promising research projects into commercially available solutions capable of supporting a growing range of industrial process applications.

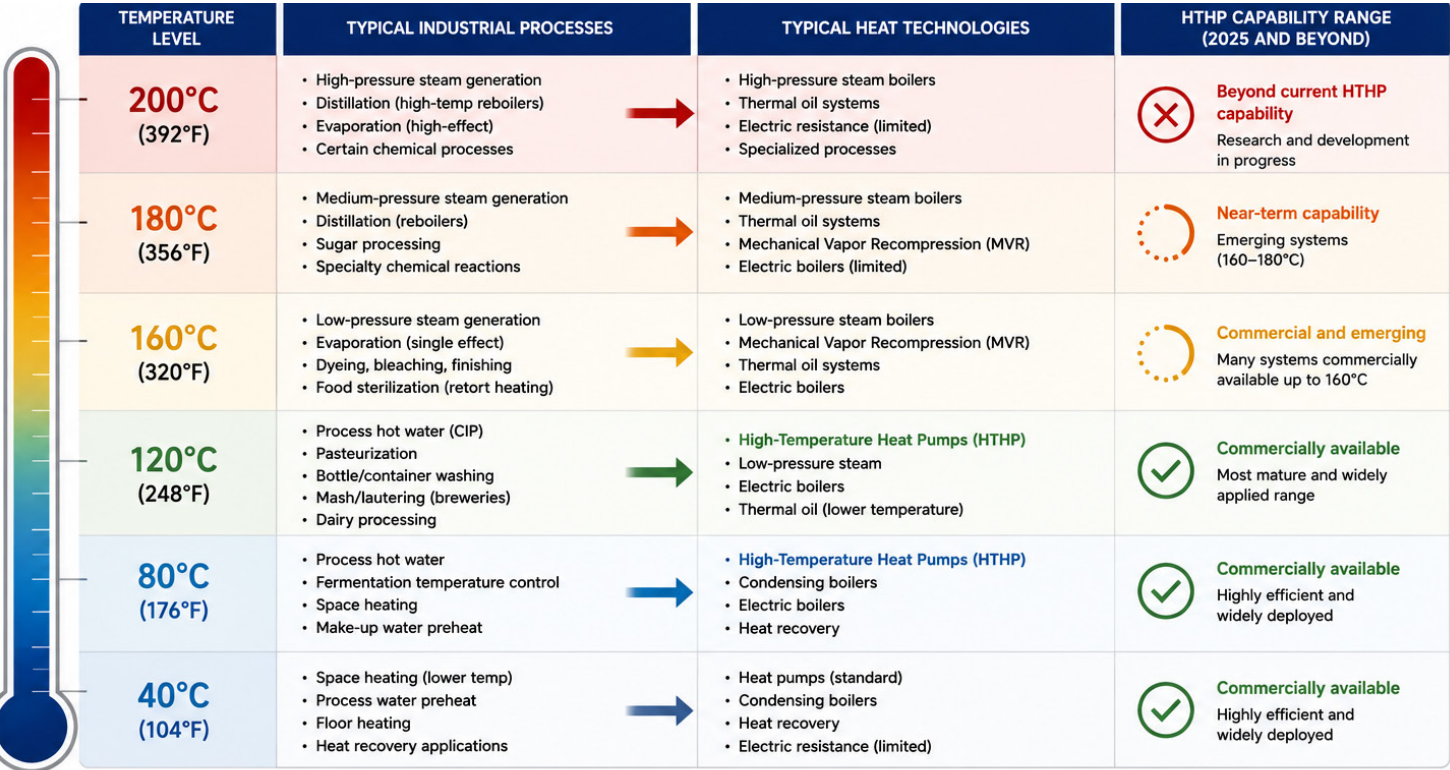
This transition was a recurring theme throughout the 2025 High-Temperature Heat Pump Symposium. Presentations from equipment manufacturers, research organizations, utilities and industrial end users consistently demonstrated that the industry's focus has shifted from proving the technology to deploying it. Discussions were no longer centered on whether HTHPs could achieve industrial process temperatures, but rather on how they can be effectively integrated into manufacturing facilities to maximize technical and economic performance.

COMMERCIAL MATURITY

Today's HTHPs are available in a wide range of capacities and operating temperatures suitable for many industrial processes. Commercial systems are now capable of producing hot water and process heating temperatures exceeding

FIGURE 3. INDUSTRIAL HEAT LADDER

Typical industrial process temperatures, heating technologies and the current and emerging capability range of High-Temperature Heat Pumps.



KEY POINT

High-Temperature Heat Pumps are ideal for medium-temperature process heating (typically 60–160°C / 140–320°F), where they can deliver high efficiency and significant energy savings.

CAPABILITY KEY

Commercially Available

Emerging Capability

Beyond Current Capability

120°C (248°F), while several manufacturers have demonstrated systems capable of producing temperatures approaching or exceeding 160°C (320°F). Research and demonstration projects presented during the symposium also highlighted ongoing development toward temperatures approaching 200°C (392°F), further expanding potential industrial applications **(see figure 3)**.

This increase in operating temperature significantly broadens the industries and processes that can benefit from HTHPs, including **food and beverage manufacturing, brewing and distilling, dairy processing, pharmaceuticals, chemical manufacturing, pulp and paper, district energy systems** and numerous other industrial applications requiring medium-temperature process heat.

ADVANCES DRIVING TECHNOLOGY DEVELOPMENT

Several technological advancements have contributed to the rapid maturation of HTHPs.

Modern compressor designs have significantly expanded operating envelopes while improving efficiency, reliability and equipment life. Improvements in **heat exchanger** technology have enhanced thermal performance while reducing equipment size and improving heat transfer efficiency. **Advanced control systems** now allow HTHPs to respond dynamically to changing process conditions, improving both performance and operational flexibility.

Refrigerant development has also accelerated technology adoption. Natural refrigerants—including ammonia (R-717), carbon dioxide (R-744), propane (R-290) and water (R-718)—are increasingly being incorporated into industrial HTHP designs due to their favorable thermodynamic properties and alignment with evolving environmental regulations. Manufacturers continue to develop refrigerant cycles capable of achieving higher discharge temperatures while maintaining system efficiency and long-term reliability.

Collectively, these advancements have expanded both the technical capabilities and commercial viability of industrial HTHPs.

MANUFACTURING SCALE AND STANDARDIZATION

Another important theme emerging from the symposium was the continued transition from custom-engineered systems toward standardized commercial products.

As manufacturing volumes increase, equipment suppliers are reducing engineering complexity, improving equipment availability, shortening delivery schedules and lowering installed costs. Standardized product platforms are replacing many first-generation demonstration systems, providing industrial owners with greater confidence in long-term equipment support, serviceability and reliability.

This trend reflects a technology entering commercial maturity rather than remaining in the research and demonstration phase.

ECONOMICS CONTINUE TO IMPROVE

While technical performance is essential, successful HTHP projects are ultimately driven by economics.

Presentations throughout the symposium emphasized how project success depends on evaluating the complete thermal system rather than focusing solely on equipment efficiency. Factors such as electricity pricing, available waste heat, operating hours, process temperatures, utility rates and overall system integration have a greater influence on project economics than any single equipment specification.

As manufacturing capacity increases and equipment becomes more standardized, installed costs continue to improve. At the same time, higher system efficiencies and improved reliability contribute to reduced lifecycle operating costs, making HTHPs increasingly attractive for facilities with significant heating demands and available waste heat sources.

THE ENGINEERING CHALLENGE HAS CHANGED

One of the strongest messages from the symposium was **that the industry's greatest challenge is no longer equipment development.**

The engineering challenge has shifted toward process integration.

Successful HTHP projects require identifying suitable heat sources, matching them with appropriate process heat demands, minimizing temperature lift, integrating utility systems and evaluating overall facility energy flows. These engineering decisions have a greater influence on project success than selecting a particular equipment manufacturer.

This evolution presents a significant opportunity for engineering firms capable of evaluating industrial processes as complete thermal systems rather than independent utility components.

4. Engineering Process Integration: Maximizing the Value of High-Temperature Heat Pumps

As High-temperature heat pumps (HTHPs) become increasingly common in industrial process applications, the engineering discussion is shifting from equipment capability to system integration. Advances in compressors, refrigerants and controls have demonstrated that HTHPs are capable of supplying useful industrial process heat across a growing range of temperatures and capacities. The question facing facility owners is no longer whether the technology works, but where it creates the greatest value and how it should be integrated into the manufacturing process.

Every manufacturing facility has unique thermal characteristics that influence the suitability of HTHPs. Process temperatures, operating schedules, utility systems, production requirements and available waste heat all influence project performance. Before evaluating equipment, engineers must first understand how thermal energy enters, moves through and ultimately leaves the facility.

UNDERSTAND THE PROCESS

The first step in evaluating an opportunity for HTHPs is developing a clear understanding of the manufacturing process and its thermal requirements.

This evaluation should identify:

- » Process heating requirements
- » Operating temperatures
- » Utility loads
- » Batch versus continuous operation
- » Production schedules
- » Seasonal operating variations
- » Future production capacity

Understanding these process characteristics establishes the **foundation for all subsequent engineering decisions.**

IDENTIFY HEAT SOURCES AND HEAT SINKS

Once the process has been evaluated, engineers can begin mapping thermal energy throughout the facility.

Common industrial examples of heat sources include:

- » Refrigeration condenser heat
- » Compressor cooling systems
- » Process cooling water
- » Wastewater streams
- » Distillation condensers
- » Evaporator condensate
- » Air compressor aftercoolers
- » Process exhaust streams

A “heat sink” is any process requiring useful thermal energy, including:

- » Process hot water
- » Clean-in-place (CIP) systems
- » Bottle washing
- » Mash heating
- » Fermentation temperature control
- » Pasteurization
- » Makeup water preheating
- » Space heating
- » Steam generation

Successful projects depend on effectively matching heat sources with heat sinks while minimizing unnecessary energy losses (**see figure 4**).

EVALUATE TEMPERATURE LIFT

After heat sources and heat sinks have been identified, the next step is evaluating temperature lift, which is one of the most important factors influencing HTHP performance.

The smaller the difference between the available heat source temperature and the required process temperature, the higher the expected system efficiency and coefficient of performance (COP).

FIGURE 4. HEAT SOURCES AND HEAT SINKS

Common industrial Heat Sources and Heat Sinks that can be connected through a High-Temperature Heat Pump.

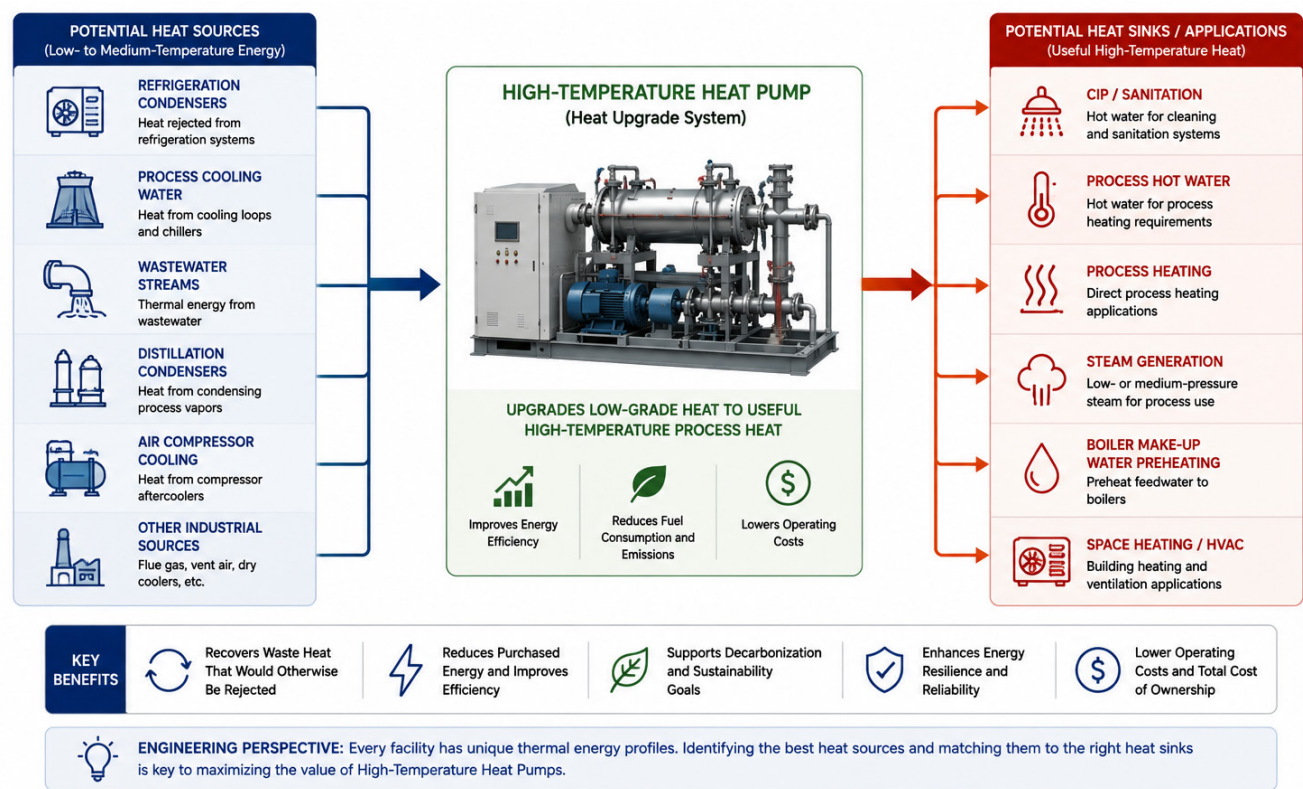
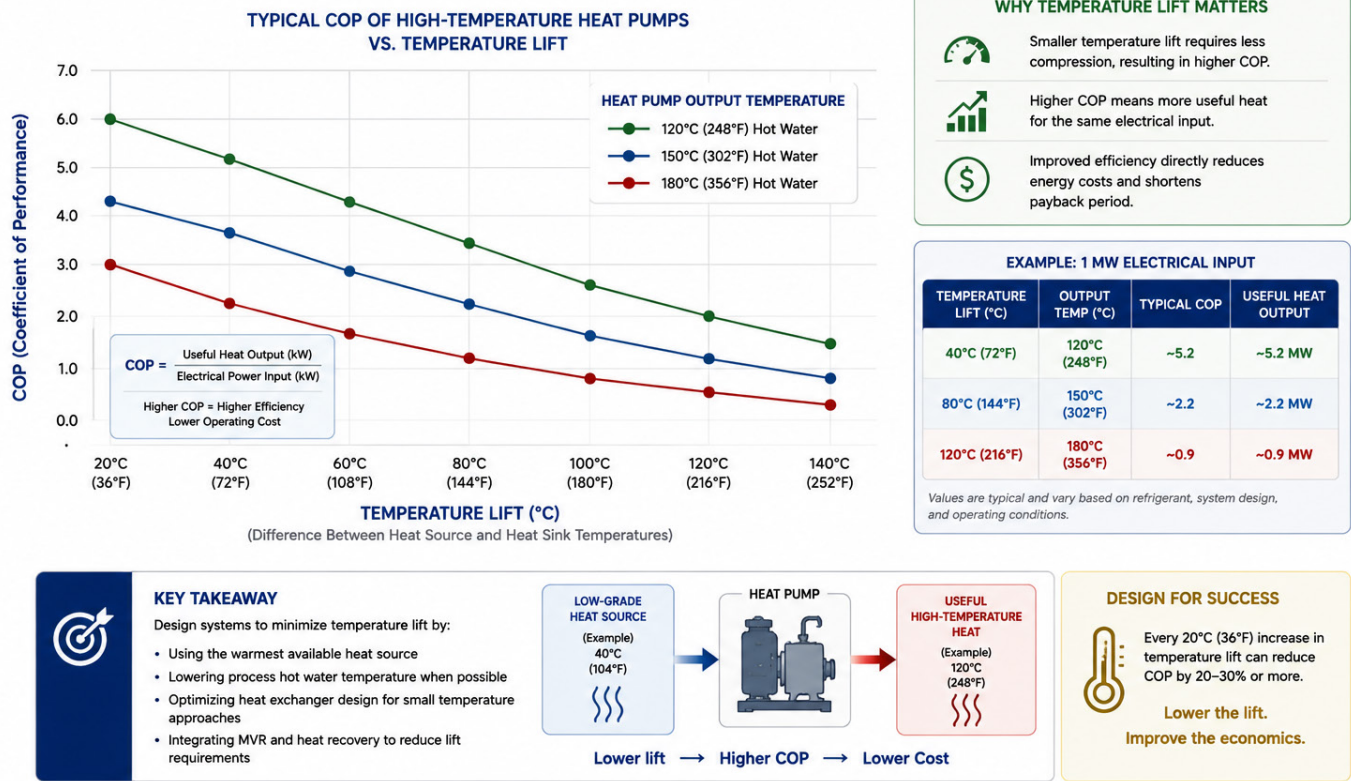


FIGURE 5. COP VS. TEMPERATURE LIFT

Relationship between temperature lift and typical High-Temperature Heat Pump Coefficient of Performance.



For this reason, process engineers should evaluate opportunities to reduce required process temperatures before selecting equipment. In many facilities, relatively minor process modifications can significantly improve HTHP performance while reducing operating costs throughout the life of the facility.

Evaluating temperature lift early during conceptual design often provides greater value than selecting a larger or more sophisticated heat pump later in the project (see figure 5).

INTEGRATE UTILITY SYSTEMS

HTHPs **should not be evaluated independently** of the facility's utility systems.

Steam, hot water, refrigeration, chilled water, condensate recovery, compressed air, electrical distribution and process controls all influence overall system performance.

In many facilities, the greatest value is achieved through **hybrid utility systems** where HTHPs operate alongside conventional boilers and other thermal technologies.

Rather than replacing existing infrastructure, HTHPs frequently reduce boiler loading, improve heat recovery, increase operational flexibility and lower overall energy consumption (see figure 6).

The objective is to optimize the performance of the entire thermal system rather than maximizing the utilization of any individual piece of equipment.

MECHANICAL VAPOR RECOMPRESSION AND HIGH-TEMPERATURE HEAT PUMPS

Mechanical vapor recompression (MVR) and HTHPs should be viewed as **complementary technologies** rather than competing solutions.

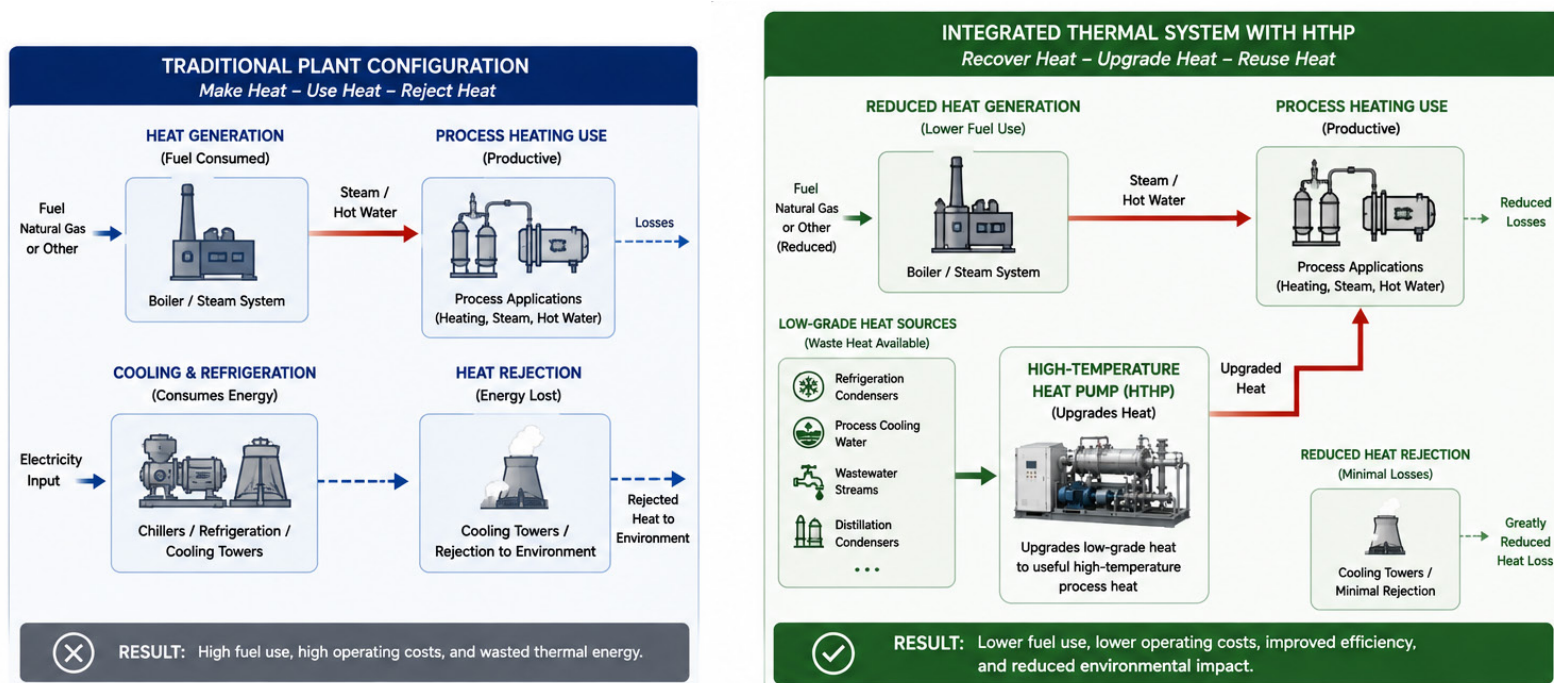
MVR is highly effective at recovering and reusing energy contained within process vapor streams, particularly in evaporation and distillation applications. HTHPs are well suited for recovering lower-grade thermal energy from refrigeration systems, condensers, cooling water and other waste heat sources (see figure 7).

When designed together as part of an integrated thermal strategy, **MVR and HTHPs allow multiple levels of thermal energy to be recovered and reused throughout the process.** MVR recovers high-value vapor energy while HTHPs upgrade lower-temperature waste heat, reducing the overall demand for new energy input.

For many industrial applications—including distilling, brewing, food processing, dairy manufacturing and chemical processing—the combination of MVR and HTHPs often provides the highest overall system efficiency.

FIGURE 6. TRADITIONAL PLANT VS. INTEGRATED THERMAL SYSTEM

Comparison of a traditional industrial thermal system with an integrated system that recovers, upgrades and reuses waste heat.

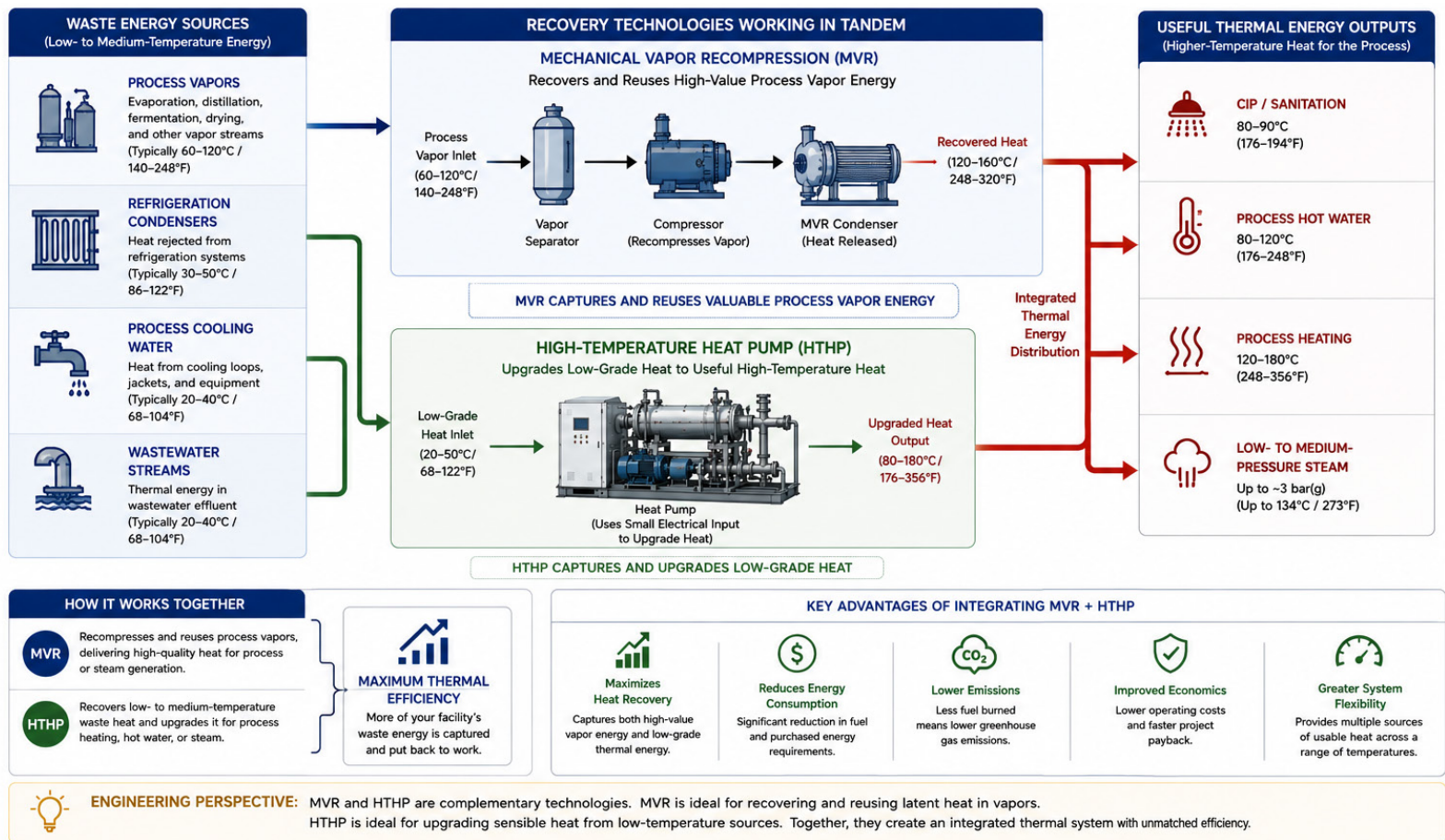


KEY BENEFITS OF INTEGRATED THERMAL SYSTEMS

- Lower Operating Costs**
Significant reduction in fuel and purchased energy.
- Improved Energy Efficiency**
Higher overall plant efficiency through heat recovery.
- Reduced Emissions**
Lower fuel consumption reduces greenhouse gas emissions.
- Greater Energy Resilience**
Less dependence on volatile fuel markets.
- Stronger Economics**
Better payback, lower lifecycle cost, higher ROI.

FIGURE 7. HTHP + MVR WORKING IN TANDEM

Complementary roles of Mechanical Vapor Recompression and High-Temperature Heat Pumps in an integrated thermal recovery strategy.



The objective should not be to determine which technology is better, but rather to determine how these complementary technologies can work together to maximize thermal recovery, improve process efficiency and reduce lifecycle operating costs.

EVALUATE LIFECYCLE PERFORMANCE

Successful HTHP projects should always be evaluated using **lifecycle performance** rather than first cost alone.

Engineering evaluations should consider:

- » Annual operating hours
- » Utility rates
- » Electrical infrastructure
- » Fuel costs
- » Maintenance requirements
- » Reliability
- » Operational flexibility
- » Future production expansion
- » Carbon reduction objectives
- » Lifecycle operating costs

Projects that appear marginal when evaluated solely on initial capital cost often become highly attractive when long-term operating performance is considered.

5. Applications Across Various Markets

High-temperature heat pumps are not a universal replacement for conventional heating systems. Their value depends on the thermal characteristics of the manufacturing process, the availability of recoverable waste heat, operating temperatures, utility infrastructure and overall project economics.

The following examples illustrate how HTHPs can be integrated into a variety of manufacturing processes to improve thermal efficiency, reduce operating costs and support long-term facility electrification.

DISTILLED SPIRITS

Breweries and distilleries represent some of the strongest opportunities for HTHP integration because they contain both **significant heating and cooling demands** operating simultaneously.

Potential heat sources include:

- » Refrigeration condenser heat

- » Distillation condensers
- » Process cooling water
- » Air compressor cooling
- » Wastewater streams
- » Potential heat sinks include:
- » Mash water heating
- » Process hot water
- » Clean-in-Place (CIP) systems
- » Fermentation temperature control
- » Bottle washing
- » Boiler makeup water preheating
- » Steam generation for selected applications

These facilities also present opportunities to integrate HTHPs with mechanical vapor recompression (MVR). When engineered together, **these complementary technologies maximize overall heat recovery** and significantly improve plant-wide thermal efficiency (**see figure 8**).

FOOD AND BEVERAGE

Food processing facilities often operate continuously and **require large quantities of** hot water, steam, refrigeration and process heating.

Typical applications include:

- » Pasteurization
- » Cooking
- » CIP systems
- » Bottle and container washing
- » Ingredient preheating
- » Hot water generation
- » Boiler load reduction

Many food processing facilities also contain large refrigeration systems operating year-round, providing excellent opportunities for recovering condenser heat and upgrading it using HTHPs.

DAIRY PROCESSING

Dairy facilities require significant thermal energy for **pasteurization, cleaning, product heating, refrigeration and hot water production**.

HTHPs can recover waste heat from refrigeration systems while supplying:

- » Pasteurization water
- » CIP hot water
- » Process heating
- » Boiler makeup water
- » Building heating

Because heating and refrigeration operate simultaneously throughout much of the production cycle, dairy facilities are particularly well suited for integrated thermal system design.

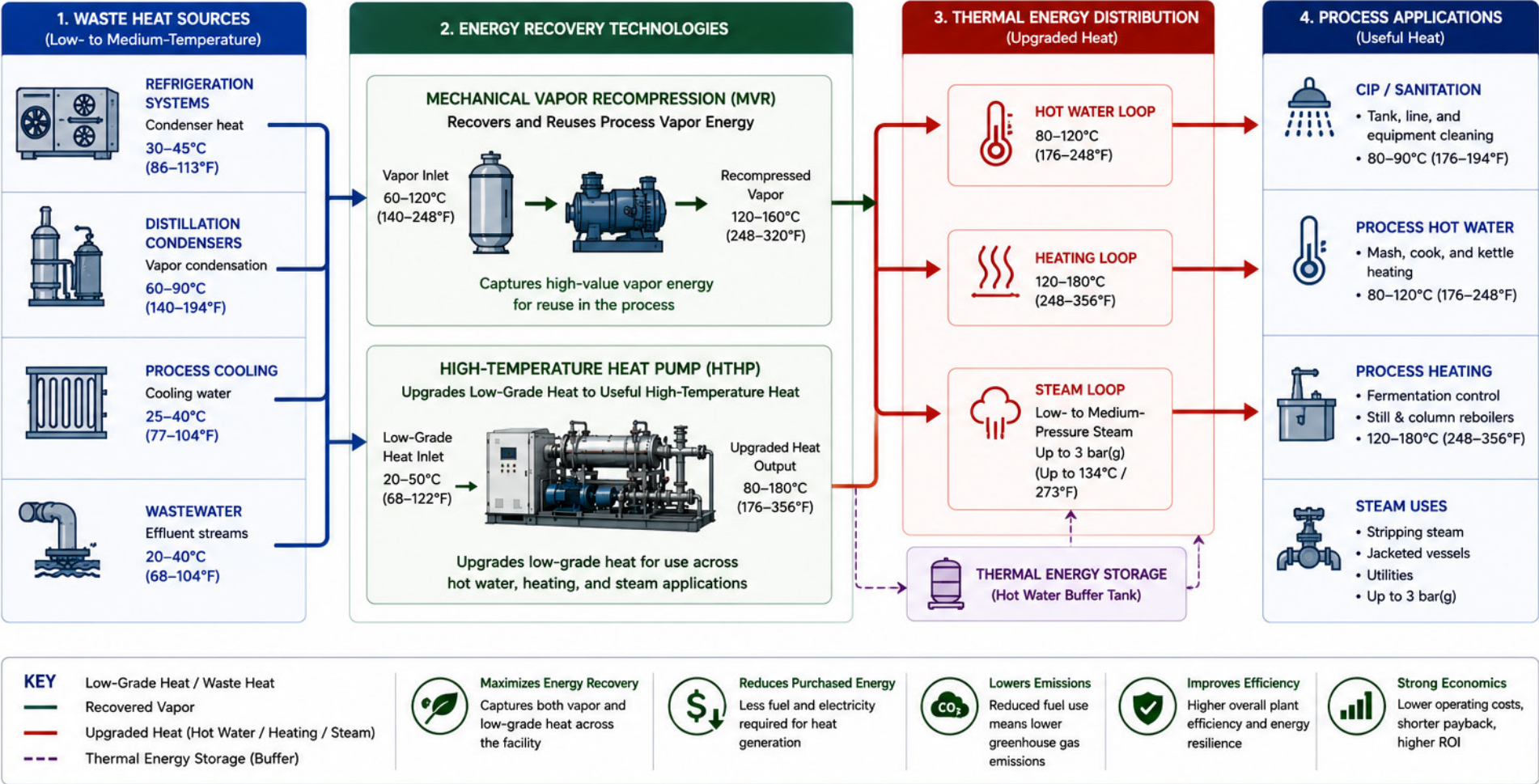
Advanced Manufacturing

Many advanced manufacturing facilities have simultaneous heating and cooling demands associated with production equipment, environmental control and process utilities:

- » Process water heating
- » HVAC integration

FIGURE 8. DISTILLERY/BREWERY THERMAL INTEGRATION

Example of integrated thermal energy recovery and distribution in a brewery or distillery using High-temperature heat pumps, mechanical vapor recompression and thermal storage.



ENGINEERING PERSPECTIVE

By integrating MVR and HTHP technologies, distilleries and breweries can transform waste heat into valuable thermal energy for hot water, process heating, and steam—driving down costs while improving sustainability and competitiveness.

- » Heat recovery from manufacturing equipment
- » Utility optimization
- » Building heating

As these facilities continue to electrify, HTHPs provide an opportunity to improve overall utility efficiency while reducing dependence on combustion-based heating.

DISTRICT ENERGY

District energy systems represent one of the fastest-growing applications for large-scale HTHPs worldwide.

These systems recover heat from:

- » Wastewater treatment facilities
- » Rivers and lakes
- » Industrial waste heat
- » Data centers
- » District cooling systems

Recovered energy is upgraded and distributed through centralized hot water or district heating networks serving multiple facilities.

While district energy projects are more common in Europe today, they **represent an emerging opportunity as North American communities** pursue decarbonization and energy resilience initiatives.

SELECTING THE RIGHT APPLICATIONS

The successful application of High-temperature heat pumps depends less on industry type than on process characteristics.

Facilities are generally well suited for HTHP integration when they have:

- » Continuous or high annual operating hours
- » Simultaneous heating and cooling demands
- » Recoverable waste heat sources
- » Medium-temperature heating requirements
- » Opportunities for process heat recovery
- » Long-term ownership horizons
- » High energy consumption
- » Interest in reducing lifecycle operating costs

Conversely, facilities with intermittent operation, limited waste heat availability or extremely high process temperatures may require alternative or hybrid heating strategies.

For this reason, every project **should begin with a comprehensive engineering** evaluation rather than an equipment selection exercise.

6. Economics and Project Evaluation

While the technical capabilities of high-temperature heat pumps continue to advance, successful implementation ultimately depends on project economics. Like any major capital investment, HTHPs should be **evaluated based on their ability to improve overall facility performance** while delivering measurable long-term value.

Unlike conventional heating equipment, the economic performance of an HTHP is influenced by the manufacturing process itself. The availability of recoverable waste heat, operating schedules, utility costs, process temperatures and system integration all have a direct impact on project financing. As a result, evaluating an HTHP requires a broader engineering and financial assessment than simply comparing equipment efficiencies (**see figure 9**).

LOOKING BEYOND EQUIPMENT EFFICIENCY

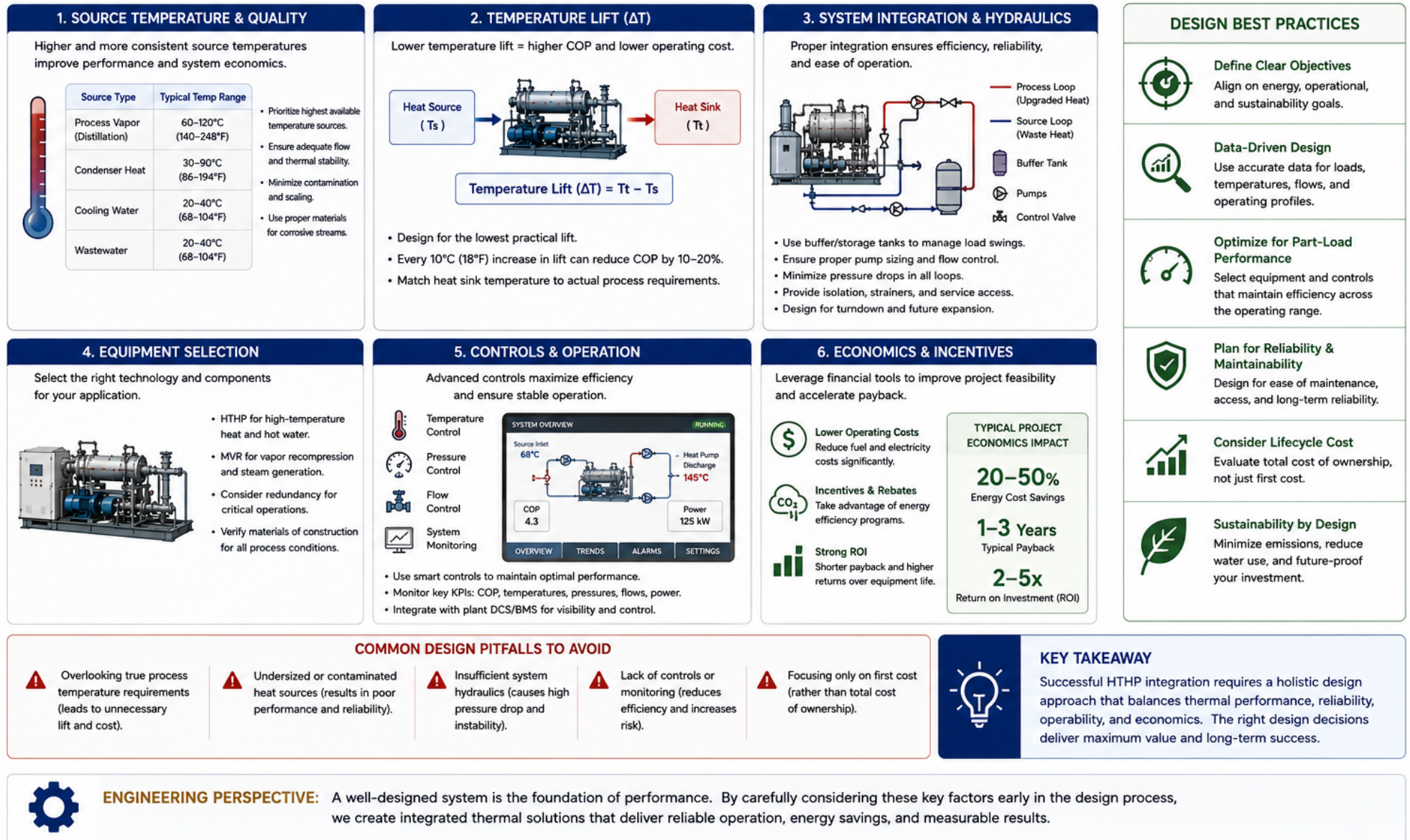
While COP is an important indicator of system efficiency, it should not be viewed in isolation. A high COP does not necessarily result in the best project, just as a lower COP does not automatically indicate poor economics.

Successful projects are developed by evaluating the complete thermal system, including:

- » Available heat sources

FIGURE 9. DESIGN CONSIDERATIONS FOR SUCCESSFUL HTHP INTEGRATION

Principal design considerations, best practices and common pitfalls associated with successful High-Temperature Heat Pump integration.



- » Required heat sinks
- » Temperature lift
- » Annual operating hours
- » Utility rates
- » Existing infrastructure
- » Process integration opportunities

Understanding how these factors interact provides a much more accurate assessment of long-term project value than equipment performance alone.

THE IMPORTANCE OF OPERATING HOURS

High-temperature heat pumps typically provide the greatest economic return in **facilities that operate continuously or for extended periods throughout the year.**

Facilities operating **24 hours per day, seven days per week** often recover their investment more quickly because the equipment operates at a higher annual utilization rate.

Industries such as food processing, brewing, distilling, dairy manufacturing, chemical processing and district energy systems frequently operate under these conditions, making them well suited for HTHP applications.

Conversely, facilities with highly seasonal or intermittent heating demands may require a different economic evaluation.

UTILITY COSTS DRIVE ECONOMICS

One of the primary factors influencing HTHP economics is the relationship between electricity prices and conventional fuel costs.

Because high-temperature heat pumps consume electricity while reducing the consumption of natural gas, fuel oil or other heating fuels, the relative cost of these energy sources has a significant impact on project economics.

Electric utility rate structures—including demand charges, time-of-use pricing and available incentive programs—should also be considered during project evaluation.

Rather than comparing equipment efficiencies alone, engineers should evaluate the anticipated annual operating cost of the complete thermal system.

RECOVERING EXISTING ENERGY

Perhaps the greatest economic advantage of an HTHP is its **ability to recover energy that has already been paid for.**

Facilities continuously reject valuable thermal energy through refrigeration systems, condensers, cooling water, wastewater and numerous other process streams.

Recovering and upgrading this energy reduces the amount of new energy that must be purchased to satisfy process heating demands.

The greater the quantity of recoverable waste heat available, the greater the opportunity to improve project economics.

LIFECYCLE COST EVALUATION

Successful projects should be evaluated over the expected life of the facility rather than on initial capital cost alone.

A comprehensive lifecycle analysis should consider:

- » Initial capital investment
- » Equipment life expectancy
- » Annual energy savings
- » Maintenance requirements
- » Utility cost escalation
- » Production reliability
- » Operational flexibility
- » Future expansion opportunities
- » Carbon reduction objectives
- » Potential incentive programs

Evaluating these factors provides a more complete understanding of long-term project value.

HYBRID THERMAL SYSTEMS

In many industrial facilities, the most economical solution is not an all-electric facility or an overhaul of existing boilers.

Instead, HTHPs often perform best as part of a hybrid thermal system.

Conventional boilers continue to provide high-temperature process heating and backup capacity while HTHPs recover waste heat and satisfy appropriate medium-temperature heating demands.

Mechanical vapor recompression (MVR), thermal storage, waste heat recovery and advanced process controls can further improve overall system performance.

Selecting the appropriate combination of technologies often provides greater value than maximizing the use of any single technology.

THE VALUE OF EARLY ENGINEERING

Evaluating HTHPs early allows engineers to optimize process temperatures, reduce temperature lift, identify heat sources and heat sinks and integrate utility systems before major equipment selections have been finalized.

These early engineering decisions frequently have a greater impact on lifecycle economics than equipment selection alone.

7. Preparing Clients for the Energy Transition

The transition toward electrified industrial heat is already underway. High-temperature heat pumps (HTHPs) are becoming an increasingly practical solution

for a growing number of industrial applications, but successful implementation requires careful planning, sound engineering and a thorough understanding of each facility's unique process requirements.

For many facility owners, **the first step** is not selecting equipment. It is **understanding how thermal energy is currently generated, distributed, utilized and ultimately rejected** throughout the manufacturing process. Facilities that understand their thermal energy flows are significantly better positioned to identify opportunities for heat recovery, process optimization and future electrification (**see figure 10**).

BEGIN WITH THE PROCESS

Before evaluating equipment, owners and engineering teams should clearly define:

- » Process heating requirements
- » Operating temperatures
- » Annual operating hours
- » Production schedules
- » Utility demands
- » Future production growth
- » Reliability requirements
- » Available heat sources and heat sinks

Developing this understanding early allows engineering teams to identify opportunities that may not be apparent after utility systems have already been designed.

EVALUATE THERMAL ENERGY AS A RESOURCE

Historically, industrial facilities have viewed waste heat as something to reject.

The next generation of industrial facilities will increasingly view thermal energy as a valuable resource that can be recovered, upgraded and reused.

Understanding where energy enters the process, where it is consumed and where it leaves the facility provides the foundation for evaluating High-temperature heat pumps and other heat recovery technologies.

Facilities with significant refrigeration systems, process cooling, wastewater heat or continuous heating demands often present the strongest opportunities for thermal energy recovery.

PLAN DURING CONCEPTUAL DESIGN

The greatest opportunity to improve project performance occurs during conceptual design.

Evaluating HTHPs early in project development allows engineering teams to:

- » Optimize process temperatures
- » Reduce temperature lift
- » Improve utility integration

- » Reduce future infrastructure modifications
- » Improve lifecycle economics
- » Increase operational flexibility

Waiting until detailed design or construction limits the number of available options and may reduce the overall value of the project.

THINK BEYOND TODAY'S ENERGY MARKET

Industrial facilities are long-term investments.

Many manufacturing plants operate for decades, often with multiple production expansions and utility upgrades throughout their life.

As energy markets continue to evolve, facilities designed with flexibility will be better positioned to adapt to changing utility costs, emerging technologies, future regulations and evolving sustainability objectives.

QUESTIONS OWNERS SHOULD ASK

As facilities evaluate HTHPs, several questions can help guide the engineering process:

- » Where is thermal energy currently being rejected?
- » Which process heating loads operate continuously?
- » Can process temperatures be reduced without affecting production?
- » Are heating and cooling occurring simultaneously?
- » Where can waste heat be recovered and reused?
- » How can HTHPs complement existing utility systems?
- » Should MVR, thermal storage or other technologies also be considered?
- » How will today's engineering decisions support the facility over the next 20 to 30 years?

Answering these questions early creates the foundation for informed investment decisions and successful project implementation.

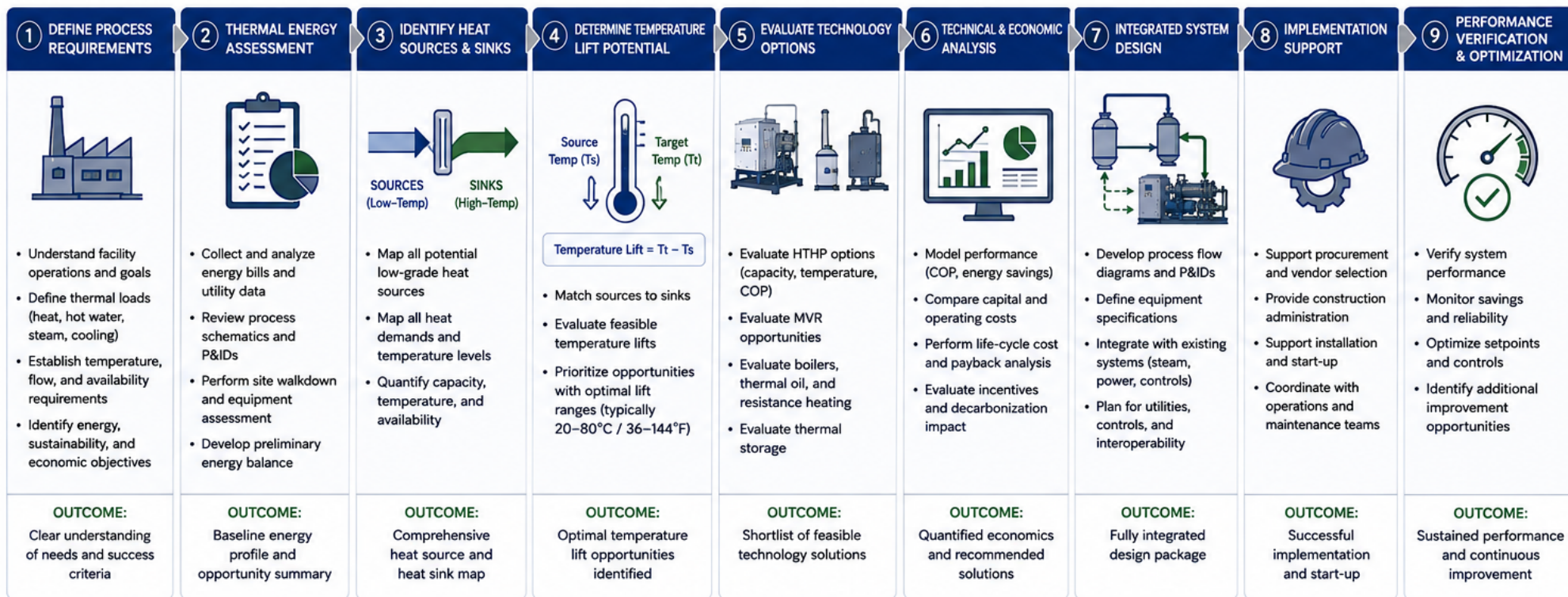
8. Conclusion

Industrial process heating is entering a period of **significant transformation**. Advances in electrification, heat recovery and process integration are changing how facilities generate, distribute and utilize thermal energy. **High-temperature heat pumps (HTHPs) have emerged as one of the most promising technologies supporting this transition**, providing industrial facilities with new opportunities to recover waste heat, improve energy efficiency, reduce operating costs and increase long-term operational flexibility.

As demonstrated throughout this paper, the **continued advancement of compressor technology, natural refrigerants, controls and system design** has moved HTHPs beyond the demonstration phase and into commercial industrial applications. The discussions

FIGURE 10. HASKELL HTHP INTEGRATION METHODOLOGY

Haskell's process-driven methodology for evaluating, designing, implementing and optimizing integrated High-Temperature Heat Pump systems.



ENGINEERING PRINCIPLES THAT GUIDE EVERY PROJECT





OUR COMMITMENT: Haskell delivers integrated thermal solutions that are technically sound, economically compelling, and built to perform—helping our clients achieve their energy, operational, and sustainability goals.

presented during the **2025 High-Temperature Heat Pump Symposium** reinforced that the industry is no longer asking whether HTHPs work. Instead, the focus has shifted toward identifying where they create the greatest value and how to successfully integrate them into industrial manufacturing processes.

The greatest opportunities for HTHPs are realized when they are evaluated as part of an integrated thermal strategy rather than as standalone equipment replacements. Recovering and upgrading waste heat, optimizing process temperatures, integrating refrigeration and steam systems and coordinating complementary technologies such as mechanical vapor recompression (MVR), thermal storage and advanced controls allow facilities to maximize overall thermal efficiency while improving long-term performance.

Successful implementation **begins with understanding the manufacturing process**. Every facility has unique conditions, utility infrastructure, production requirements and thermal energy flows. Identifying available **heat sources and heat sinks, minimizing temperature lift, evaluating lifecycle economics and integrating utility systems** are all critical engineering decisions that ultimately determine project success.

For facility owners, the decision to implement HTHPs should **not be based solely on equipment efficiency or first cost**. Instead, projects should be evaluated through

the broader lens of lifecycle performance, operational flexibility, energy resilience and the manufacturing facility's long-term objectives. Facilities that begin evaluating these opportunities **during conceptual design** will be best positioned to realize the full technical and economic benefits of the technology.

For Haskell, HTHPs represent more than another utility system. They represent an opportunity to help clients **rethink how thermal energy is managed throughout the manufacturing process**. By combining process engineering, industrial utilities, refrigeration, controls, heat recovery, MVR, steam systems and advanced process integration, **Haskell can help clients develop thermal strategies to improve plant performance and prepare facilities for future energy challenges**.

The transition toward electrified industrial heat will **not be defined by a single technology**. It will be driven by thoughtful engineering, sound process integration and the intelligent application of technologies that improve overall manufacturing performance.

HTHPs are one of the most important technologies enabling the next generation of integrated industrial thermal systems. **Haskell's role is to help clients determine where, when and how they should be applied to deliver the greatest technical and economic value**.