




## Defining an industrial heat pump: A review & synthesis<sup>☆</sup>

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### ABSTRACT

Clear and understandable definitions of advanced energy technologies are not common and often confuse those who are not experts. This review paper addresses a critical issue in the field of heat pumps: the ambiguity surrounding the term “industrial heat pump.” The term, as discussed in various literature and media, often leads to misconceptions about the capabilities and applications of heat pumps, particularly in industrial contexts. This review paper seeks to refine and unify the definition of industrial heat pumps by analyzing existing academic and commercial literature, industry reports, and classifications. Unique identifiers explored for the definition of an industrial heat pump include the use of waste heat, operating temperature ranges, size specifications, and specific end-use applications. The study reveals differences in how industrial heat pumps are defined in academic and commercial contexts, highlighting the need for a standardized definition to facilitate better communication among manufacturers, policymakers, and end users. This is especially important considering recent legislative efforts such as the HEAT Act, which seeks to promote industrial heat pump adoption. The proposed definition aims to provide clarity while supporting the effective deployment of industrial heat pumps. With proper adoption, the definition will help promote the role of industrial heat pumps in achieving energy efficiency goals in the industrial sector. The intended impact is for the definition to serve as a foundational reference for future research and policy development.

### 1. Introduction

Language is of paramount importance in communicating ideas effectively. In the field of engineering, plain language ensures audiences achieve sufficient understanding to enable their use of today’s engineering advances. Throughout history, use of the wrong language or words has inhibited the progress of scientific discovery and technological advancement. One such situation might be happening currently in the field of heat pumps. In 2023, the *Washington Post* published an article praising heat pumps as a breakthrough but criticizing their nomenclature as a pitfall to societal acceptance as a whole [1]. The article outlined a public sentiment that the word “heat” falsely denotes the ability of a heat pump to provide only heating to spaces and that the word “pump” can denote large, cumbersome equipment not typically present in residential spaces. Though these notions are false, various blog posts,

unofficial opinion articles, and open internet forums have expressed the same confusion stemming from the widely accepted term.

In the energy sector, the definition of a heat pump is generally not disputed. Heat pumps are mechanical devices that perform work, using energy in the form of electrical, chemical, or thermal energy, to transfer heat from a relatively cold area to a relatively hot area. Electrically driven heat pumps are typically vapor compression systems where a compressor driven by an electric motor compresses low-pressure, low-temperature vapor stream to a higher-pressure, higher-temperature vapor. Thermally driven heat pumps use thermal energy from steam or waste heat to do the work. As an added complication, both vapor compression and thermal systems can be further classified into different types [2] with variations in heat sources and working fluid mechanisms (i.e., open, semi-open, and closed). This paper primarily addresses heat pumps within the temperature ranges typically associated with

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mechanical vapor compression (MVC) systems because these are the most common. Generally, an unspecified designation in the type of heat pump usually alludes to an MVC system. In these systems, the majority of the heat is not generated by a heat pump but merely is relocated or “pumped,” as the name implies. Electrical, thermal, or chemical energy is used in the process to upgrade and move heat energy in a refrigeration cycle. Heat pumps used for heating are typically appropriately referred to as heat pumps, whereas heat pumps used for cooling are sometimes commonly referred to as refrigerators. In either case, heat pumps cool a source and heat up a sink. But as the previously mentioned *Washington Post* article suggests, this definition is not intuitive for all [1].

Even the intuition of informed engineers can break down when language specificity is added. Clear definitions understood in the energy sector begin to “muddy” when qualifiers are added to heat pumps. For example, residential heat pumps are typically used in single-family homes or single units of multifamily residential buildings for HVAC purposes. But when a heat pump is used for home refrigeration purposes in a residential setting, it may not be considered a residential heat pump. Many professionals would probably not even classify a home refrigerator as a heat pump. One of the most interesting and arguably confusing qualifiers of heat pumps is the designation of “industrial.” The use of the word industrial to describe certain types of heat pumps is becoming more common as the push to electrify the industrial sector escalates in importance. Clarifications regarding the definition of an industrial heat pump would provide a stable language baseline and dispel confusion among the entities trying to transform energy use in the industrial sector.

In May 2023, representatives from the 118th Congress of the United States presented legislation in the US Senate for the Heat Pump Energy Assistance and Training Act, commonly known as the HEAT Act. The legislation proposed to require the US Secretary of Agriculture to formulate a program for supporting the use of industrial heat pumps, specifically identifying them by name [3]. Legislation like the HEAT Act and the prospect of future legislation concerning industrial heat pumps necessitate clarification of the definition of industrial heat pumps by academics and experts familiar with the operation, deployment, and use of the technology. Thus, the immediate need for this review is established to clarify and unify the definition of industrial heat pumps. No currently existing work has tried to synthesize such a cohesive and comprehensive definition. Though past publications, academic and otherwise, have used industrial heat pumps as main points of study, a unifying definition has not been included or attempted in any other publication.

A unifying definition can provide clarity and specificity for potential end users of industrial heat pumps, current and future manufacturers of heat pumps, and lawmakers seeking a definition to use in future legislation for rebates, incentives, or other policies intended to promote energy efficient technologies. The main objectives addressed in this research are the following: (1) Review the spectrum of definitions of industrial heat pumps in published literature (from both academic and manufacturing sources). (2) Categorize unique identifiers and qualifications for industrial heat pumps in the reviewed definitions and provide analysis of those characteristics. (3) Synthesize a substantial and specific definition of industrial heat pumps based on the most common identifiers.

## 2. Methodology

Existing publications offer two types of definitions of industrial heat pumps: explicit and implicit. Explicit definitions are statements made within a publication that clearly state what an industrial heat pump is or has the mechanical ability to do. These definitions are typically direct, short, and found near the beginning of publications about industrial heat pumps to establish a baseline for the rest of the content. Implicit definitions are not plainly written but rather are general ideas and characteristics of industrial heat pumps that must be synthesized by a reader

after reading the complete article. These implied definitions work from the assumption that the reader already has some level of background knowledge before diving into the publication’s overall content. The result of this review paper is the development of an explicit definition of industrial heat pumps. In formulating that definition, both explicit and implicit definitions were used from existing literature. Findings from these two types of definitions in literature are included in the results section. Fig. 1 presents the methodology followed to collect data and synthesize the final definition of an industrial heat pump. The process includes a literature review for sources pertaining to industrial heat pumps followed by a literature classification into one of the two types of definitions, explicit or implicit. For each identified definition, specific traits and identifiers were extracted and then categorized. Common categorizations were then grouped into defining identifiers for industrial heat pumps with input from industry experts. These common identifiers were then analyzed for underlying reasons for including the identifiers in the extracted definitions with the analysis being the foundation for the synthesis of a formal definition.

The articles used in this work come from various sources: academic journals, government publications, websites, official documents, and manufacturers’ informational sources (e.g., websites, brochures, and fact sheets). Though information on heat pumps in general is available from those same sources, this work uses only definitions that include the specific qualifier “industrial.”

## 3. Results

The initial literature search for the definition of an industrial heat pump yielded four classification characteristics that many publications use within their industrial heat pump designations. The first is if an industrial heat pump is required to use only waste heat sources from an industrial setup as opposed to air, water, and ground source heat pumps. The second is if a temperature range is specified in which an industrial heat pump operates. Likewise, the third is if a size criterion is specified that an industrial heat pump must meet. And fourth is, in terms of end-use, if the upgraded heat from an industrial heat pump must be utilized in a specified location. At least one of these classifiers is included in some form in almost every existing definition of an industrial heat pump.

Perhaps the most illuminating definition of an industrial heat pump

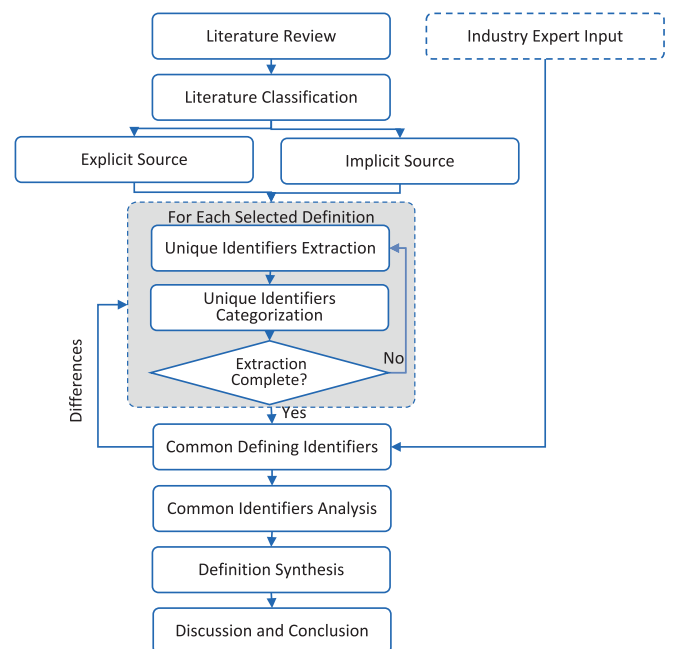


Fig. 1. Flow chart of the review methodology of industrial heat pump definitions.

was given in a 1990 article in the scientific publication *Hydrocarbon Processing*. In the article, authors Ranade and Chao refer to the industrial heat pump as an enigma [4]. They describe that although there is familiarity with what makes up a heat pump, both a lack of information and abundant misinformation exist concerning industrial heat pumps. Acknowledging that the article is outdated, those who are less informed concerning industrial heat pumps than heat pump industry engineers and technicians now consider them less of an enigma and more of a muddled conglomerate of definitions needing clarification and organization.

### 3.1. Specified utilization of industrial waste heat

Heat pumps inherently do not produce heat; instead, they upgrade heat from a low-grade heat source to an upgraded heat sink with the use of electric work or thermal energy. In industrial heat pumps, many definitions specify that the heat source needs to be industrial waste heat for the heat pump to be considered a true industrial heat pump. The specific wording from explicit definitions listed in academic articles is shown in Table 1. The qualifiers for the type of heat source tend to include low-grade or low-temperature heat that would be required for the upgrade to usable heat. These can be important differentiators for definitions of industrial heat pumps. In general, waste heat can be recovered and used via conventional heat exchangers, which are typically passive devices that need no energy input and that require less maintenance and control than that of a heat pump. Under these specified qualifiers, industrial heat pumps take low-grade or low-temperature heat that cannot be effectively captured or utilized by a heat exchanger to provide practical and beneficial outcomes, and upgrade that heat to a usable temperature. The New York State Energy Research and Development Authority defines industrial heat pumps as no more than electrically powered heat recovery devices [5]. Though the definition is simple, it does little to differentiate the technology from other active heat recovery devices.

The use of waste heat as the heat source for industrial heat pumps is a relatively uncomplicated way to integrate a heat pump directly into an industrial process. No matter what the heat sink is, since the source is recovered process waste heat, some definitions would agree with the designation of an industrial heat pump versus a generic heat pump because the former touches part of an industrial process. This designation is like the specification of the end-use of heat on the sink side of an industrial heat pump.

### 3.2. Specified temperature range

Specified temperature ranges in heat pumps were found to be less common in published academic literature and more common from commercial industrial heat pump suppliers. Two temperature values, supplied temperature and temperature lift, are sometimes used in describing heat pump operating characteristics. Various published works in academic literature have specified quantitative ranges for these two temperatures. Two sources specified a heat sink temperature of up

**Table 1**

Explicit definitions of industrial heat pumps and their wording concerning the use of waste heat.

Definition Wording	Year	Reference
“Recover the waste heat from industrial processes”	2016	[6]
“A waste heat source”	2021	[7]
“Supplied with low temperature waste heat”	2019	[8]
“The heat source is generally waste heat from an industrial process”	2022	[9]
“Of a waste-heat stream”	2003	[10]
“Transforms low-grade waste heat”	2023	[3]
“Raise the temperature of waste heat in an industrial process”	2020	[11]
“Technologies upgrading the waste heat”	2010	[12]

to 150 °C (302 °F), implying no lower bound to the supply temperature [8,13]. One of those same articles specified that temperature lifts for industrial heat pumps would be between 30 °C and 50 °C (54 °F–90 °F) [8]. Another older article specified the same ceiling of about 150 °C (302 °F) but noted that innovation has been pushing that ceiling [14]. One conference article from Purdue University’s well-known International Refrigeration and Air Conditioning Conference noted that the typical working temperature range of industrial heat pumps is 18 °C (65 °F) to 82 °C (180 °F) with typical lifts of 31 °C (56 °F) [15]. The International Energy Agency (IEA) published a short fact sheet that defined industrial heat pumps as heat pumps that could reach up to 200 °C (392 °F), though it is unclear if that value is because of technological limits at the time or from a boundary set in the definition [11].

The results of a survey of advertised temperature ranges for commercial suppliers of industrial heat pumps are shown in Fig. 2. This survey included only major suppliers that used the specific wording “industrial heat pump” and not variations of those terms. Every surveyed specification included deliverable temperatures between 50 °C and 100 °C (122 °F and 212 °F) with some extending the upper bound much higher up to 300 °C for mechanical vapor recompression technology.

Though the ranges differ greatly between manufacturers, the inclusion of temperatures that are higher than those of common heat pumps, for example those used for residential HVAC, is a repeated characteristic. Typical residential heat pumps operate at a maximum of 75 °C (176 °F), depending on the type of heating system, and more commonly operate at temperatures below 35 °C (95 °F) [27]. Demonstrating that an industrial heat pump can achieve temperatures required in industrial end uses is important for vendors to show that their product can meet increased demands of industrial applications.

### 3.3. Specified size range

Within academic publications, size specifications for industrial heat pumps are sparse. One article used the vague qualifier of “very large” in a listed definition of industrial heat pumps [28]. Another specified that industrial heat pumps are those in the medium- and high-power ranges but did not give quantitative qualifiers [29]. A 1994 article stated that industrial heat pumps differ from residential and commercial heat pumps mainly with thermal levels and capacities [14]. The IEA has one of the few quantitative definitions of industrial heat pumps in relation to size, that being from <100 kW<sub>th</sub> to 150 MW<sub>th</sub> [11]. That range is quite wide and does little to define the boundaries of the definition. A definition published by the Electric Power Research Institute in 1988 stated that one of the main criteria is that the heat pump must be large enough to be of industrial scale, specifying that usually means over 250,000 Btu/h (~75 kW<sub>th</sub>) of heat delivered [30].

Like the survey completed for temperature ranges from various industrial heat pump manufacturers, a search was conducted for size specifications. The results are shown in Fig. 3 with the size measured in MW<sub>th</sub>. The figure shows two main groupings of industrial heat pumps from manufacturers. The first is smaller industrial heat pumps that have a range of 0–2 MW<sub>th</sub> in size. The other is much larger, ranging from 10 to 90 MW<sub>th</sub>, with very little overlap between the two groupings. These differences could imply separate customer bases between the manufacturers or different anticipated end uses with varied brands.

Though not a manufacturer of heat pumps, the international consulting firm McKinsey & Company used size as the only qualifier for its definition of an industrial heat pump, stating that they are heat pumps larger than 200 kW<sub>th</sub> [31]. The specification of size seems to be a designation used more for advertising and sales than for a definition. Suppliers need to specify the size ranges their products can reach so industrial facilities can know if those products will fit their needs. In these cases, the industrial qualifier could be used by suppliers to deter individuals searching for heat pumps that are commonly sized for residential usage and attract potential customers looking for heat pump

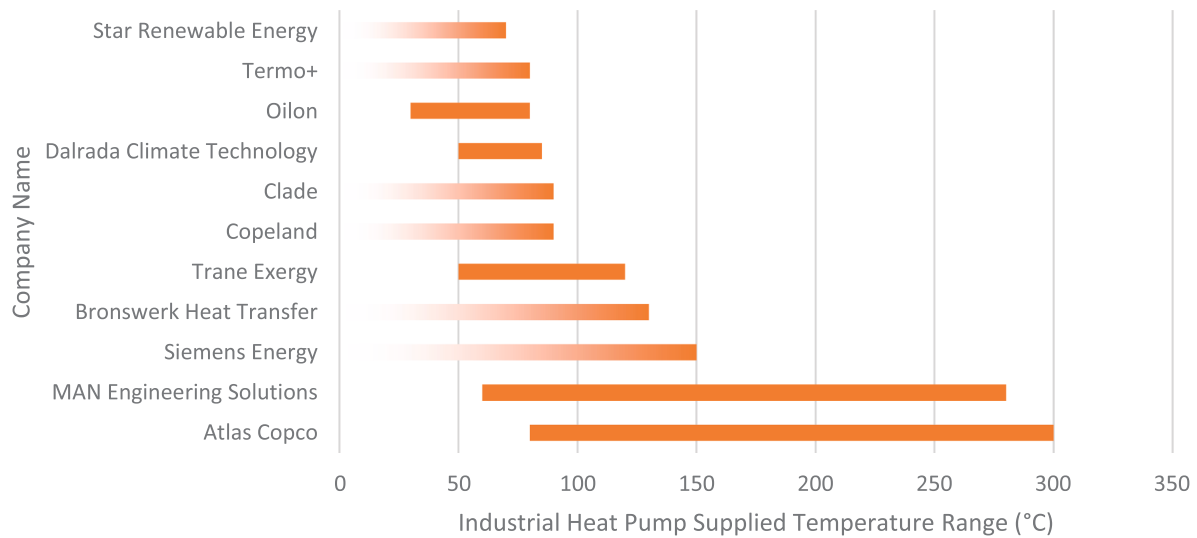


Fig. 2. Advertised temperature ranges of the supplied fluid from manufacturers who specified their products as “industrial heat pumps.” The fading bars represent companies that specified a maximum achievable temperature but not a minimum. Data taken from [16–26].

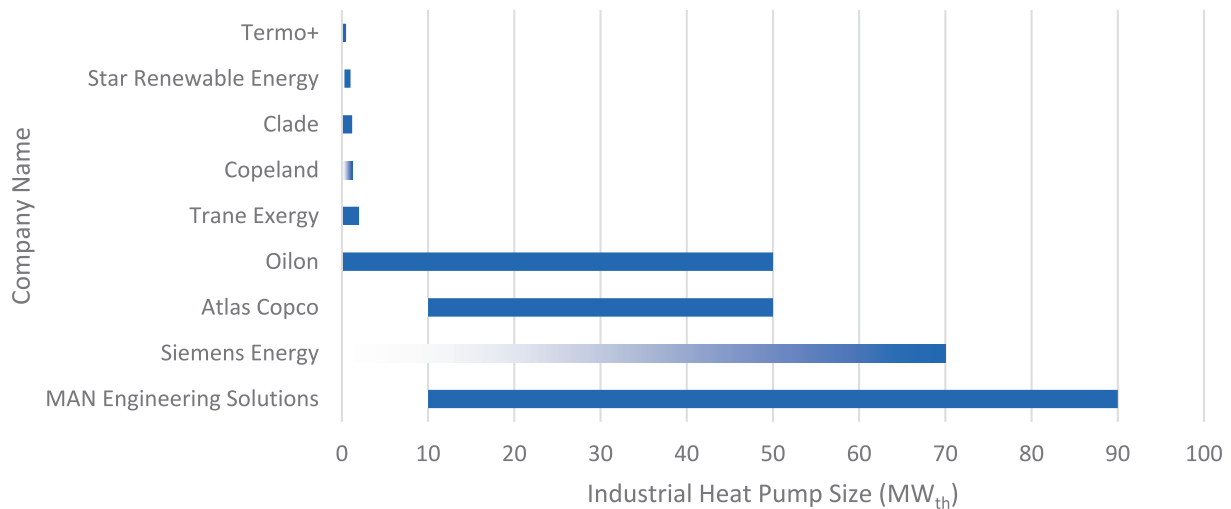


Fig. 3. Advertised size ranges from manufacturers who specified their products as “industrial heat pumps.” The fading bars represent manufacturers that specified a maximum size available but not a minimum. Data taken from [16–19,21–25].

solutions with larger capacities. Though not explicitly stated, suppliers may intend to specify a size characteristic when using residential, commercial, or industrial as a qualifier, but more specific language may be necessary to meet heating and cooling loads within different applications. Thus, when considering a broad definition of industrial heat pumps, size specification may be a secondary qualifier to include.

### 3.4. Specified end use requirements

Wording in published definitions of industrial heat pump requirements for end use is possibly the vaguest of the four classification characteristics. Specific wordings from explicit definitions in literature are shown in Table 2. The definitions given here can be split into two distinct groups. The first is those that specify that industrial heat pumps must be used for industrial processes. The second is a broader definition that includes industrial processes but also can include large commercial and residential applications.

Various papers interchange the term “industrial heat pump” with the term “heat pumps in industry,” implying where the end use of the heat pumps is specified. One older paper was even more broadening,

conflating industrial heat pumps with heat pumps in industrial processes to suggest that any heat pump used as part of an industrial process would fit within the definition [36]. A study by the American Council for an Energy-Efficient Economy noted that, by nature, industrial heat pumps are more complicated than those used in homes, buildings, or common refrigerators [34]. Another journal article proposed that industrial heat pumps used for industrial heat recovery and temperature elevation fundamentally differ from basic refrigeration and air conditioning [37]. A publication on industrial heat pumps from the IEA similarly indicated that the heat would be used in the same industrial process that it originated from or in another adjacent process or heat demand [11]. These definitions point out that limiting the definition of industrial heat pumps to those that only touch industrial processes could be important. Though similar equipment could be used in commercial and agricultural spaces, limiting the industrial qualifier would correctly target the electrification and energy efficiency goals of the industrial sector.

### 3.5. Governmental definitions of industrial heat pumps

The gathered definitions of industrial heat pumps carry various

**Table 2**

Explicit definitions of industrial heat pumps and their wording concerning the specific end use requirements of heat as part of the formal definition.

Definition Wording	Year	Reference
"Applied in many industrial processes"	2016	[6]
"To produce process heat"	2021	[7]
"Used for process optimization of industrial plants"	2015	[28]
"For a specific industrial process application"	2013	[32]
"The heat sink is a higher-temperature input heat stream for another, or the same industrial process"	2022	[9]
"In industrial processes"	2020	[33]
"For heat recovery and upgrading in industrial processes, but also for heating, cooling and air conditioning in commercial and industrial buildings"	2018	[13]
"Used for industrial processes and in industrial, commercial and multi-family residential buildings as well as district heating"	2010	[29]
"To meet the heating needs of agricultural, industrial, or commercial processes"	2023	[3]
"Tailored to meet the diverse needs of industrial processes"	2022	[34]
"Must involve an industrial process stream as either the heat source or as the heat sink"	1988	[30]
"Integration... .. in a process"	2014	[35]

influential weights based on the publishing entity. This section highlights definitions from governing bodies, whether or not the definition is officially stated or included in an official publication.

In May 2022, the European Union released its RePowerEU plan, which outlines specific efforts to accelerate the adoption of heat pumps in industry. It refers to the use of heat pumps in industry with phrases such as "large-scale," those which "exploit industrial heat" [38], or those that can supply "high temperature" heat [39]. Explicit definitions for industrial heat pumps are lacking in European Union-supported legislation and resources. One European Commission report from 2020 outlined many innovations for upcoming technologies and labeled industrial heat pumps as those with heat sinks greater than 100 °C (212 °F) [40]. Other documents from the European commission indicate a continuation of that definition [41]. Industrial heat pumps are even excluded from the scope of the European Union Clean Energy Technology Observatory's 2022 Report on the status of heat pumps in the European Union, citing that the current number of installations is low compared with that of the market potential, but demand is increasing [42]. The report emphasizes that improved communication strategies are crucial to raise awareness of industrial heat pump feasibility. Establishing a sector-wide consensus on the definition of industrial heat pumps could be a starting point for such efforts. Germany has demonstrated particular emphasis on utilizing heat pumps to transform their heating infrastructure, including in the industrial sector. Various sources refer to those systems as large-scale heat pumps for industry but not always industrial heat pumps [43]. In 2024, Germany announced that there were plans to construct the largest heat pump in existence, calling it an industrial heat pump because it would serve industrial heating loads [44]. The Netherlands Organisation for Applied Scientific Research or TNO released a report in 2020 that identified industrial heat pumps as technology that upgrades waste heat for re-integration into an industrial process [45].

New Zealand's Energy Efficiency and Conservation Authority published an extensive website and documentation in 2023 outlining and defining industrial heat pumps. Its definition of industrial heat pumps includes upgrading heat to useful temperatures that can meet required industrial loads and using larger, more robust systems designed to output high amounts of heat reliably [46]. Definitions from United States government entities have also been sparse, with two main contributions from the previously cited legislative bill [3] and a 2003 report from the US Department of Energy's Office of Energy Efficiency and Renewable Energy [10]. Similar to the definitions from the European Union, improvement of these definitions would help limit and define the use of industrial heat pumps in the future.

#### 4. Formal definition and discussion

In line with the goals of this paper, the synthesis and formal definition of industrial heat pumps is presented in this section.

Heat pumps are mechanical devices that use electric, chemical, or thermal energy to perform work to upgrade heat from a lower temperature to a higher temperature. A heat pump is an industrial heat pump if at least one of the following criteria are met:

- Gains most of the required heat to be upgraded from a source within an industrial process.
- Delivers most of the upgraded heat to a sink within an industrial process.

A flow chart outlining this definition of industrial heat pumps is shown in Fig. 4. In the context of this definition, industrial processes refer to the combined use of actions, procedures, and equipment to produce or transform raw materials into products or provide industrial services. Under this definition, no size or temperature range restricts what an industrial heat pump can or cannot be. Most industrial heat pump applications are dependent on the needs of the process itself and on the heating requirements and temperature ranges needed to fulfill process or product requirements. Instances of utilizing industrial waste heat and specifying end use of heat in an industrial process both would qualify as industrial heat pumps per this given definition. With this definition, the major considerations found in literature are captured allowing for flexibility on both the size and temperature ranges, and including waste heat integration and end-use specifications within industrial process.

Industrial heat pumps often have the following associated traits:

- Reliability—Industrial heat pumps will typically be used in processes that dictate high heat availability where a sufficient analysis was completed before installation. Because this equipment will often replace heating using natural gas or other conventional fuels, which are viewed as very reliable, industrial heat pumps must be reliable to demonstrate virtually uninterrupted availability (low/no downtime) and operate under process conditions without failure or excessive maintenance.
- Continuous use—Industrial heat pumps will typically be used in instances where they can provide heat to a continuous process or be able to operate continuously to feed batch processes with storage integration or part-load capability, though seasonal and intermittent applications are expanding. Most will operate at high capacity factors, supplying heat to the sink side for over 80 % of the calendar year.
- High delivered sink temperature—Industrial heat pumps will typically operate at temperatures much higher than those of conventional (residential and commercial) types of heat pumps. The most common industrial heat pump applications occur above 50 °C (122 °F).
- Process integration—Industrial heat pumps will typically not be stand-alone units or systems but rather will be integrated into the process. This could include utilization of process fluids and working fluids within the heat pump loop or building an industrial heat pump with special materials to be resilient to strains to the equipment caused by the specific process.
- Temperature lift—Industrial heat pumps will typically be used in instances where the temperature lift from a heat source to a heat sink is greater than 28 °C (50 °F).

Though these listed traits are common and can be used to help identify opportunities for future deployment of industrial heat pumps, they are not included in the formal definition.

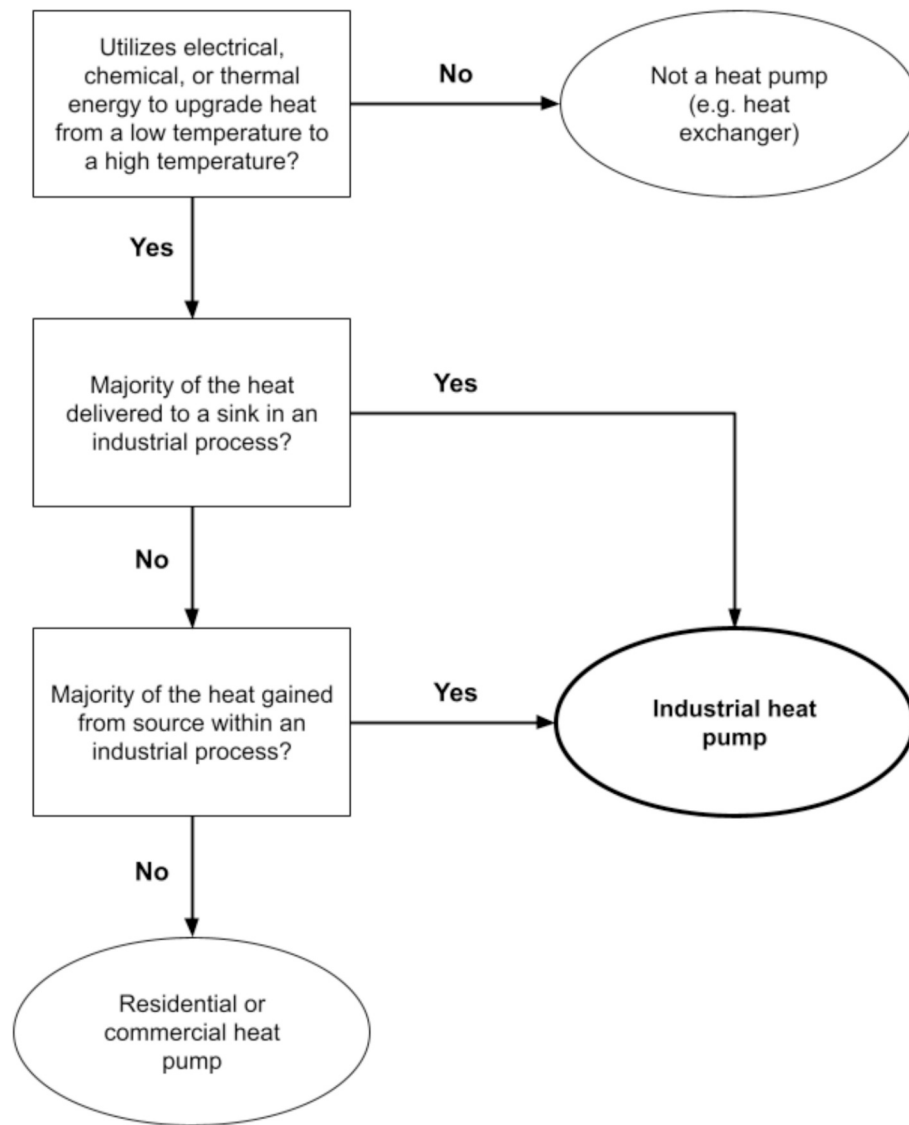


Fig. 4. A flow chart for the formal definition of industrial heat pumps.

## 5. Conclusion

As the world continues to transition to a more efficient industrial sector, rising technologies that change how process heat is delivered will continue to grow. Heat pumps are a promising technology that has historically had a lower deployment rate in the industrial sector. Defining the boundaries of what constitutes an industrial heat pump can help lawmakers, vendors, researchers, and end users understand and promote the potential that heat pumps can have in the industrial sector. As the global industrial sector continues to move toward resilience goals, industrial heat pumps are poised to play a key role in the provision of heat to fill process needs that have traditionally been filled by constrained fuels. Industrial heat pumps provide an electrified solution to use waste heat, increase overall energy efficiencies, and provide useful heating resources to industrial processes across many different sectors.

To achieve increased clarity and simplicity in the final definition, many aspects and characteristics of heat pumps are not considered or discussed in this work. Considerations such as simultaneous heating and cooling applications or specific heat pump types and classifications were not addressed and therefore can be considered a limitation of this work. Future work in this space could consider these unaddressed characteristics. Other avenues of future work include sourced-based or end-use-

based classification of industrial heat pumps, comparison with traditional heat pump nomenclature, or time-dependent evolution of definitions based on technology deployment and innovation. Each of these can bring clarity and background to the emerging space. The formal definition in this work outlines specific boundaries to unify the use of “industrial” as a qualifier to heat pumps. As industrial heat pump deployment grows and as opportunities arise for entities to incentivize heat pump deployment in industrial processes and facilities, this definition can stand as the baseline to categorize and differentiate industrial heat pumps from all other heat pumps.

## CRedit authorship contribution statement

**Blake W. Billings:** Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kalie Miera:** Writing – review & editing, Writing – original draft, Project administration, Formal analysis, Data curation. **Subodh Chaudhari:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sen-thil Sundaramoorthy:** Writing – review & editing, Methodology, Conceptualization. **Kiran Thirumaran:** Writing – review & editing,

Methodology, Conceptualization. **Riyaz Papar:** Writing – review & editing, Supervision, Conceptualization.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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