A Market Transformation Strategy for Industrial Heat Pumps: An Opportunity to Reduce Industrial Greenhouse Gas Emissions by 20%

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ABSTRACT

Industrial process heat accounts for about 30% of industrial energy use and carbon emissions. Industrial heat pumps (IHP) operated on carbon-free electricity can eliminate almost half of industrial process heat emissions using currently available technologies. Advanced heat pumps now in development will be able to meet upwards of 70% process heating needs, reducing total annual industrial carbon emissions by about 20%, thereby eliminating about 300 MMT of carbon emissions each year.

Domestic installation of IHP is limited by product availability in North America; knowledge among industrial decision makers, engineers, and service providers; and economic and regulatory challenges. A multi-pronged, multi-year market transformation effort is needed to address these barriers and make IHPs common practice in the United States. Strategy elements should include:

- Supporting manufacturers to scale up domestic availability of equipment.
- Working with utilities and regulators to assist IHP uptake.
- Training engineers, technicians, and installers.
- Raising customer awareness and knowledge.
- Considering alternative finance strategies.
- Enacting federal tax incentives targeting commercial and industrial heat pumps
- Implementing a variety of DOE efforts including R&D, technical assistance, demonstrations, training, and incentives for initial projects.

These different efforts can complement each other, together helping to develop and ultimately transform the way U.S. factories produce process heat.

Introduction

In 2023, nearly 9 quadrillion Btu of energy will be used in the United States for industrial process heat, which is about 9% of total U.S. energy use and about 30% of industrial energy use (EIA 2023). Most of this process heat is supplied by burning natural gas, releasing substantial carbon dioxide and accounting for roughly 30% of the industrial sector's approximately 1400 MMT of annual carbon emissions.

An important technology to meet this process heating need is industrial heat pumps (IHPs) — vapor compression devices that transform low-grade production waste heat by increasing the temperature of air or process fluid, such as water, to meet the heating needs of agricultural, industrial, or commercial processes. When operated on carbon-free electricity, IHPs can replace a significant share of industrial fossil fuel use and substantially reduce industrial carbon emissions. Current commercial IHP systems available overseas can provide process heat up to about 160^{o} C (320^{o} F). McMillan et al. (2021) estimate that about half of industrial process heat needs are at or below this temperature. Zuhlsdorf et al. (2019) project that advanced heat pumps now in development will be able to supply process heat up to about 280° C in the near future. Based on the McMillan et al. data, such heat pumps could meet about 70% of industrial process heating needs, eliminating about 300 MMT of annual industrial carbon emissions, thereby reducing these emissions by about 20%.[1] While the rest of the developed world has decades of experience with IHP implementations, the United States has seen limited deployment of IHP and as a result has limited domestic manufacturing capacity.

To address this large opportunity for energy savings and carbon emissions reduction, we envision a series of market transformation action to rapidly increase domestic manufacturing and the implementation of currently available IHP technologies in plants over the next 5 years.

Barriers

Industrial heat pumps are currently a niche product in the United States due to a variety of market constraints. Below we summarize the major constraints that a market transformation initiative will need to address and overcome.

Limited product availability in North America: Currently, most IHPs are produced in Europe or Asia, although there are a few U.S.-produced products that cater to low-temperature applications (less than 100° C) such as lumber drying, food processing, and some commercial applications. IHPs are large products that can be expensive to ship. JCI, Mayekawa, and Nyle produce systems in the United States for these low-temperature applications. For higher-temperature applications, many of the current products come from Europe, where demand for IHP has surged, driven by tight natural gas supplies caused by the war in Ukraine. Some of these products are produced by European subsidiaries of U.S. companies, such as Frick and Sabroe (both owned by Johnson Controls) and ICS Cool Energy (owned by Trane). If a large IHP market is to grow in the United States, more products will need to be produced in North America. In our discussions, manufacturers acknowledge this but say they need assurance of sufficient market demand to justify investments in scaling up North American production of IHP, particularly when there is increasing demand for heat pumps for other markets that appears more certain.

Limited awareness and knowledge among industrial decision-makers, engineers, and installers: Most industrial decision makers are not familiar with IHPs, and even many engineering and heat pump installer firms have limited knowledge of the capabilities of available IHPs and how to design for them. Experienced engineers can optimize systems in ways that reduce system size and costs while providing important operating benefits, such as improved process control and product quality. Few industrial applications lend themselves to one-size-fits-all solutions, with many requiring tailored system designs. Most engineers presently lack this awareness, expertise, and experience.

Experience in Australia is that with good system design, the energy efficiency of industrial processes can improve by as much as 25%, achieving annual net reductions in energy consumption of between 40-75% in selected case studies (A2EP 2022b). Industrial customers and engineers have little incentive to take on the additional risks associated with modifying an existing system with a new technology unless there are well-documented examples of successful implementations.

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[1] Calculations by ACEEE using data from EIA's Annual Energy Outlook (EIA 2023) on projected future industrial heat use and emissions.

Economic challenges: The economics of IHPs depend not only on the relative costs of electricity and natural gas but also on electric rate structures (e.g., demand and interconnection charges). Site-specific timing and considerations are important; economics tend to be better at the time an existing boiler needs to be replaced or when a new facility is constructed as we are seeing with semiconductor and EV manufacturing driven by recently enacted legislation. We need strategies to focus on the applications with the best economics, provide the tools to help facilitate IHP selection and design, manage project costs, and realize the greatest non-energy benefits from process changes. Where local utilities and regulators embrace the benefits of electrifying industrial facilities, carefully designed programs can help manage some of the economic issues through technical assistance and access to expertise, financial incentives, and attractive rate structures.

Installation, service, and maintenance: Too few personnel are qualified and available to install, service, and help maintain IHP equipment. Moreover, these technicians are often not local to the plants, increasing costs for IHP implementations and risks for extended production outages. To support IHP projects in the field, more staff need to be trained and service infrastructure scaled up in parallel with growth in installations.

Equipment certification: IHPs made abroad generally have not been through Underwriters Laboratory (UL) testing and listing. Many insurance companies require that products in facilities they insure be UL listed. Also, some IHP use refrigerants that are flammable (e.g., propane, iso-butane) or potentially toxic (e.g., ammonia). Some refrigerants used in European IHP systems have been approved in the United States (e.g., R-1233), but others have not yet been approved (e.g., R-1336). There are also sometimes state or local building code restrictions to using these materials. Many states have begun to modify their building codes to permit R32, a potentially flammable refrigerant used in some residential heat pumps, but further work will be needed on best practice building codes for some of the refrigerants used in IHPs. Also, as regulations on refrigerant impact on the ozone layer and on greenhouse gas effects get tightened, some existing and even some emerging refrigerants could be restricted. Manufacturers would like some assurance that IHP products they design and commit to produce can continue to be sold for a decade or more so that they can recover their investments.

Work to Date in This Area

IHPs are not a new technology. They were developed and commercialized for industrial use in the 1980s (Linhoff March 1988) with support from DOE and electric utilities, but stalled in North America because of equipment costs and the low cost of natural gas.

Now, because of the urgency of the climate crisis, along with changing energy prices, technology improvements, and expanding technical awareness and support, IHPs are again being viewed as a critical decarbonization pathway in the United States. Most European and many Asian nations' industrial sectors are ahead of the United States in decarbonizing process heat and the use of IHPs. Significant public knowledge on the success of IHPs in foreign applications exists through resources such as the International Energy Agency's (IEA) high-temperature heat pump annexes, which have collected energy and economic data on the status of IHPs in real-world case studies (IEA 2014, IEA 2021).

In Europe, other key efforts include REPowerEU, a plan to reduce reliance on fossil fuels that includes goals such as installing 50 million heat pumps by 2030 and replacing approximately one-third of the 150 million boilers installed around the EU (EC 2023). Individual countries in Europe have also undertaken their own industrial heat pump policies and programs. The UK, for example, is aiming to support the installation of 600,000 heat pumps annually in applications across the economy (Energy Post 2022). In Denmark, the Business Pool 2022 provides subsidies to companies replacing boilers with heat pumps, covering up to 50% of project costs (IEA 2023). In the Netherlands, the Stimulation of Sustainable Energy Production and Climate Transition program has provided more than 5 billion euros of annual grants for developing and deploying technologies including electric boilers and industrial heat pumps (IEA 2023). The German think tank Agora Energiewende estimates that industrial and residential heat pumps, along with other energy efficiency measures, can reduce natural gas use in the EU by as much as 32% in 5 years (YaleE360 2023).

A2EP, the Australian Alliance for Energy Productivity, has helped popularize IHP in Australia. It has hosted summits on IHPs and thermal energy storage, published reports on opportunities for decarbonizing process heat, and developed an online heat pump cost and savings estimator (A2EP 2022a). It receives funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.

In Japan, there are financial measures for small- and medium-sized businesses, which include special interest rates for paybacks on decarbonization technologies including IHPs. The "Guidelines for Energy Management in Industry" set standards for preventing heat loss and the utilization of waste heat at large industrial facilities. IHPs can help mitigate this heat loss (IEA 2023).

The U.S. government in recent years has expressed growing interest in accessing the energy, cost, and carbon savings IHPs have been demonstrated overseas, and in expanding IHP domestic manufacturing. DOE's Industrial Heat Shot, for example, is a new initiative aiming to develop cost-competitive industrial heat decarbonization technologies with, at minimum, 85% lower carbon emissions by 2035 (DOE 2022a). DOE has also expanded its Onsite Energy Technical Assistance Partnerships (TAPs) program, which offers a network of engineering and implementation support, to reach IHPs (DOE 2022b). President Biden selected heat pumps as one of the five clean technologies to prioritize for accelerated domestic manufacturing with Defense Production Act (DPA) funds in 2022 (DOE 2022c). Several key pieces of recent legislation, such as the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA), have the potential to fund increased IHP development, manufacturing, engineering, and implementation as we discuss below. Additionally, the United States is planning on participating in IEA's latest report annex on IHPs, Annex 58.

ACEEE has been a policy and technical leader in the IHP space for several years, working to understand the landscape of policy, implementation, and economic needs and opportunities. In 2022, ACEEE published a report on IHP opportunities that found that IHPs deployed in nine key industrial processes can enable CO_2 savings of 30-43 million tons per year while creating cost savings of more than $5.6 billion per year (Rightor et al. 2022). ACEEE is currently working with the Bonneville Power Administration (BPA), Southern Company, and New York State Energy Research and Development Authority (NYSERDA) on training engineers and identifying local sites for IHP demonstration projects. ACEEE is also launching an IHP market transformation initiative (outlined below). ACEEE has developed this initiative with the National Electrical Manufacturers Association (NEMA) and the Renewable Thermal Collaborative (RTC), a global coalition for companies, institutions, and governments committed to scaling up renewable heating and cooling at their facilities, to share non-competitive knowledge, connect suppliers and end-users interested in IHP systems, and identify and publicize the policies and funding mechanisms needed to accelerate IHP market growth.

Other key leaders and stakeholders in the IHP arena include the Electric Power Research Institute (EPRI), RTC, and the national labs. EPRI published an Industrial Heat Pump Manual in 1988 (Linhoff March 1988) and a series of reports on industrial process heating over the 2010-2013 period (e.g., EPRI 2013) and is currently working with the California Energy Commission to develop from commercially available components a design that can produce steam and substitute for a typical industrial boiler (Amarnath and Vairamohan 2023). RTC has developed an industrial electrification report and a set of heat pump decision tools (RTC 2021, RTC 2023). Lawrence Berkeley National Lab released a report on electrifying U.S. industry through heat pumps (Zuberi, Hasanbeigi and Morrow 2022). Oak Ridge National Laboratory has been leading on high-temperature heat pump research and is the lead for the IEA annexes. The National Renewable Energy Laboratory helped characterize industrial process heating load, including opportunities for solar and electrification (McMillan et al. 2021).

Strategies to Initiate Market Transformation

Support Manufacturers to Scale Up Domestic Availability of Equipment

There are presently several U.S.-manufactured IHPs from companies such as JCI, Mayekawa, and Nyle that are appropriate for low-temperature applications (e.g., 140° F). For high-temperature applications, a few U.S. companies (e.g., Trane, JCI, Emerson) have IHP products available overseas, as do some foreign firms with extensive U.S. operations (e.g., Siemens). There are additional foreign firms that might consider a U.S. market presence. Currently, however, there are no suppliers in the United States whose products have heating capacity above 100° C.

For IHPs to thrive in the United States, they will need to be produced in North America due to the costs of shipping from other continent, particularly in the quantities that will be needed by U.S. industrial customers. Heat pump sales (including IHPs) are booming in Europe due to restrictions on natural gas supplies caused by the war in Ukraine (Hockenos 2023). As a result, manufacturers tell us that while a few units can be shipped from Europe for key demonstrations, those quantities will be limited for the foreseeable future.

Several manufacturers with overseas products are exploring whether to produce IHP products in the United States. Investments in onshoring production need to be compared to other potential investments, such as in the growing residential heat pump market. In addition, several new companies are entering the market. For example, AtmosZero has developed a high-temperature modular air-source heat pump system to replace a package boiler with support from DOE ARPA-E and working in partnership with Colorado State University (ARPA-E 2022). Dalrada Precision Manufacturing is starting to market its Likido One system (Dalrada 2023). Thar Energy in Pittsburgh is another U.S. firm working to bring IHPs to market. Investment decisions will be made based in part on the near-term and longer-term market potentials, and thus actions by utilities and the federal government to help support IHP markets (as discussed below) will contribute to investment decision making. DOE could decide to invest in IHP production under the Defense Production Act (DOE 2022c). Another program that could affect this calculus is the 48C tax credit included in the IRA, which provides a 30% investment tax credit for investments in facilities to manufacture clean energy technologies. This investment credit is a competitive program, and manufacturers will have to propose projects in one of several solicitation rounds (DOE 2023).

ACEEE and NEMA have started engaging with manufacturers about the opportunities for the U.S. IHP market as part of an effort to encourage IHP manufacturing in North America.

An important related effort will support work to develop, test, and approve low- and zero-Global Warming Potential (GWP) refrigerants to use in these heat pumps. Refrigerants for high-temperature applications are a particular priority.

Work with Utilities and Regulators to Assist IHP Uptake

Electric utilities can play a significant role in growing the market for IHPs. Utilities have been a primary implementor of industrial programs for more than three decades in part because of their relationships with their industrial customers. Utilities are uniquely positioned to facilitate IHP demonstration projects with some key customers to build knowledge and awareness of IHP opportunities among end-users, engineers, and technology installers, and they can help publicize IHP opportunities to other customers. ACEEE is now working with the Bonneville Power Administration, Southern Company, and NYSERDA to identify potential demonstration sites and conduct preliminary engineering assessment for those sites.

Utilities' customer service representatives are well positioned to help to identify customers with IHP opportunities and build awareness about these opportunities. Many utilities also offer industrial energy efficiency programs that could provide technical assistance and incentives for IHP systems. Because IHP systems reduce fuel use for industrial boilers while increasing electricity use, it will be important for state utility regulators to allow programs to operate fuel switching programs, which are currently prohibited in some states.

Where fuel switching is allowed, many regulators subject projects to the requirements that they save energy, reduce emissions, and save customers money. Good IHP applications should be able to meet these criteria, based on ACEEE research (Rightor, Scheihing and Hoffmeister 2022). As with other emerging technologies, utilities want assurance that IHP products are available before promoting to their customers and offering incentives.

In addition, utilities and their regulators should review the electric rates that apply to IHP installations. Most industrial customers are charged for both the energy (kWh) they use and their peak demand (kW). The impact of demand charges on IHP economics can be significant and should be considered along with measures such as smart manufacturing controls that reduce peaks (Johnson 2023). Industrial customers need to pay their fair share of required utility system upgrades, but fixed-cost recovery charges can be structured in ways that are fair and improve IHP economics. For example, chargers for electric vehicles (EV) face similar issues, and some utilities and their commissions have adopted alternative rate structures to help encourage EVs (ATE 2022).

Train Engineers, Technicians, and Installers

As noted above in the Barriers section, good system design approaches that match system sizing to actual thermal process requirements can significantly reduce equipment size and operating energy requirements for IHP applications. Engineers and system designers in the United States need to be trained in such design approaches, building on experiences of overseas designers. We also need to make technical assistance from experts available regionally to engineers and end-users. The proposed expanded scope for DOE's Onsite Energy TAP centers represents an opportunity to create such an expertise network and to facilitate training coordinated with utilities and states.

Likewise, specifiers, technicians, and installers need to be trained in proper system sizing, installation, and maintenance. Much of this training will specific to each application and vendor, so manufacturers should take the lead on these efforts in coordination with TAPs, community colleges, and other technology training programs. These installers and technicians will be vital to the success of initial demonstration projects; ensure they perform well will help build a positive reputation for IHP technologies. As IHP installations grow, the need for installers and technicians will grow as well.

Customer Awareness and Knowledge

Customer awareness and knowledge of IHPs is very limited, so building awareness among the applicable industrial customers and their trade associations, contractors, and financiers is essential. Customers need to know enough about the IHP opportunity that they ask their staff, engineers, contractors, and utilities about it. Trade associations are uniquely positioned to build awareness of IHP opportunities in their industries and connect their members with resources to allow them to consider implementing the technologies. Similarly, building awareness of IHP opportunities among banks and other financial institutions, particularly at the community level, can help reduce the perceived risks of financing the technology and in some cases have them suggest IHP applications when their customer seeks financing for thermal system upgrades or expansions.

Among larger firms, RTC has identified IHPs as an important solution pathway and will raise awareness and knowledge in conjunction with its work on other thermal energy solutions. IHP and renewable thermal energy are often complementary, with the renewable system providing a heat source and the IHP raising the temperature to create hot water or steam.

Consider Alternative Finance Strategies

Many customers can finance systems as part of their capital budgets, particularly if they are designed to replace old boiler system near their end of life and funds for replacement are part of capital plans. Other customers may seek financing from their bank or other regular capital source. Sometimes energy service companies (ESCO) can finance IHP systems and be paid back over time based on the energy savings they achieve. Currently, the use of ESCOs to help fund heat pump systems is limited primarily to residential and commercial building applications. IEA’s upcoming annex 61 on heat pumps will include investigations on the use of utilities and ESCOs for funding opportunities in building clusters and for district heating (IEA 2022). The ESCO model has been increasingly applied in practice to process heat applications in Germany, Spain, Sweden, and France (McMillan et al. 2023). As IHPs become more readily available and the technology improves, use of the ESCO model to support the electrification of industrial process heat will likely become increasingly feasible.

In addition, a variety of other alternative finance options can be used. To provide just one example, Skyven, a Texas-based energy-as-a-service company, pays for and installs clean heat-generating industrial systems, such as IHP. Skyven assumes the upfront cost and risk, billing customers for the heat consumed (Skyven 2023).

Federal Tax Incentives Targeting Commercial and Industrial Heat Pumps

There are presently both federal tax incentives and federally funded grants for residential heat pumps. There is a tax deduction–section 179d–for projects that reduce commercial building energy use by at least 20%. These projects could include large heat pumps. In the industrial sector, the 48C tax incentive includes projects with industrial heat pumps, but this is a competitive program with a finite budget. There is presently no dedicated tax incentive for commercial and industrial heat pumps.

In 2022, ACEEE developed a proposal to add commercial and industrial heat pumps to federal tax credits available under section 48A of the tax code. The present 48A credit covers 10% or 30% of the cost of new clean energy property installed in a facility, such as solar, wind, geothermal, combined heat and power, fuel cell, microturbine, and waste heat recovery systems (the amount covered by the credit varies with the type of equipment). The ACEEE proposal would add high-efficiency commercial and industrial heat pumps to this list, where high-efficiency is defined to mean ENERGY STAR certified, exceeding ASHRAE standards by at least 10%, or an IHP with a coefficient of performance of at least 2.0. This proposal has not yet been formally introduced as legislation. This or other tax credit proposals would encourage firms to buy these heat pumps and thereby help create demand that would encourage domestic production of commercial and industrial heat pumps.

DOE and State Roles

DOE can play an important role in helping to grow the IHP market. DOE's recent Industrial Decarbonization Roadmap (DOE 2022d) found that industrial heat pumps can play an important role. As noted above, DOE can:

- Provide grants to manufacturers to cover a portion of the cost of new production lines.
- Provide grants to purchasers of IHP demonstration systems.
- Fund training and technical assistance networks (such as the re-imagined TAPs program).

In addition, DOE can:

- Conduct research and development to improve IHP systems, such as systems that can achieve higher temperatures.
- Develop an assessment on key opportunities for IHP deployment and the size of a potential IHP market in the United States. We have heard from some manufacturers that such an independent assessment could aid companies considering whether to make substantial investments in U.S.-based production of IHPs.
- Support an IHP demonstration program to establish 50–100 IHP pilot projects in varied industrial sectors, with different suppliers and end-users.
- Establish a national IHP test facility to reduce the risk assumed by industry in IHP implementation.

DOE is clearly thinking about this opportunity, as reflected in the recently announced Industrial Heat Shot initiative to drastically reduce emissions from energy-intensive process heating applications (DOE 2022a).

States can assist with some of these functions. For example, the California legislature recently established the Industrial Decarbonization and Improvement of Grid Operations

(INDIGO) program. INDIGO will provide incentives for industrial projects that provide benefits to the electrical grid, reduce emissions, and reduce local air pollution. Eligible projects include those that electrify processes that use fossil fuels (CEC 2023).

Conclusion

Industrial heat pumps represent an important and immediately available element in the industrial decarbonization portfolio. IHP can supply the majority of industrial process heat, reducing total annual industrial carbon emissions by about 20%, thereby eliminating about 300 MMT of carbon emissions each year.

The IHP market is growing rapidly in Europe, with substantial activity also in Australia and Japan. Efforts to develop the U.S. IHP market have begun, but now is the time to integrate these efforts into a market transformation initiative involving multiple elements that can synergistically work together. This should include:

- Supporting manufacturers to scale up domestic availability of equipment.
- Working with utilities and regulators to assist IHP uptake.
- Training engineers, technicians, and installers.
- Raising customer awareness and knowledge.
- Considering creative financing.
- Enacting federal tax incentives.
- Implementing a variety of DOE efforts including R&D, demonstrations, training, and incentives.

Together, these actions can transform much of industrial process heating, making a major, near-term contribution to achieving the goals of industrial decarbonization while creating a robust industrial heat pump market that increases energy security and creates economic development opportunities and jobs.

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