Do Heat Pumps Work for Process Heat? Yes and Maybe!

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ABSTRACT

Heat pumps can efficiently electrify certain kinds of industrial process heat. Despite intense interest in industrial electrification via heat pump technologies, there are few U.S. studies that address their real-world performance. To begin filling that gap, a statewide energy efficiency utility investigated heat pump equipment performance in two different industrial use cases in 2022: municipal wastewater treatment (with equipment installed) and dairy production (with equipment modeled).

Many wastewater facilities dispose of treated sewage sludge by hauling it to a landfill permitted to receive contaminated waste. Significant hauling and tipping costs can be eliminated via heated drying and pasteurizing of sludge to safe levels for fertilizing farmland. However, this industrial practice typically requires fossil fuel combustion. A Northeast municipal wastewater treatment plant installed the nation's first Shincci heat pump sludge dryer unit in 2021. The efficiency utility sub-metered the process to study performance and potential optimization. The results prompted a second municipality to pursue a dryer unit project for their own wastewater facility, with partner incentives from a local power utility.

For the dairy use case, the efficiency utility analyzed a yogurt-producing plant, where a single high temperature heat pump (HTHP) could potentially replace both the propane steam boilers and a glycol chiller. The efficiency utility hosted a site visit and applied its knowledge of local energy economics to inform the modeling, using the dairy's data in a customized Python-based model. Researchers demonstrated a positive net present value of a modeled HTHP installation and operation, as well as promising thermodynamic performance.

Introduction

Industrial operations are responsible for more than a quarter of U.S. total energy use and energy-related carbon dioxide (CO_2) emissions. So, any effective nationwide decarbonization strategy will have to tackle the industrial sector comprehensively, given the wide and deep scopes of American industry. Most energy analysts consider the decarbonization of industry to be problematic. The primary reason for this rests with the challenges from higher temperatures needed for process heating; most conventional heat pumps cannot efficiently deliver those temperatures. Process heat—the use of thermal energy for industrial production—accounts for more than half of on-site energy use at industrial sites (ACEEE 2022).

Fossil fuels currently supply over 95 percent of industrial process heat. These fuels are therefore an attractive target for decarbonization through electrification (ACEEE 2022). Figure 1 shows that much of American industry's process heat requires temperatures higher than electric heat pumps can deliver. Not all industrial processes require high heat, however; a significant percentage of U.S. process heat has maximum temperatures below 150°C, or about 300°F (Hoffmeister 2023).

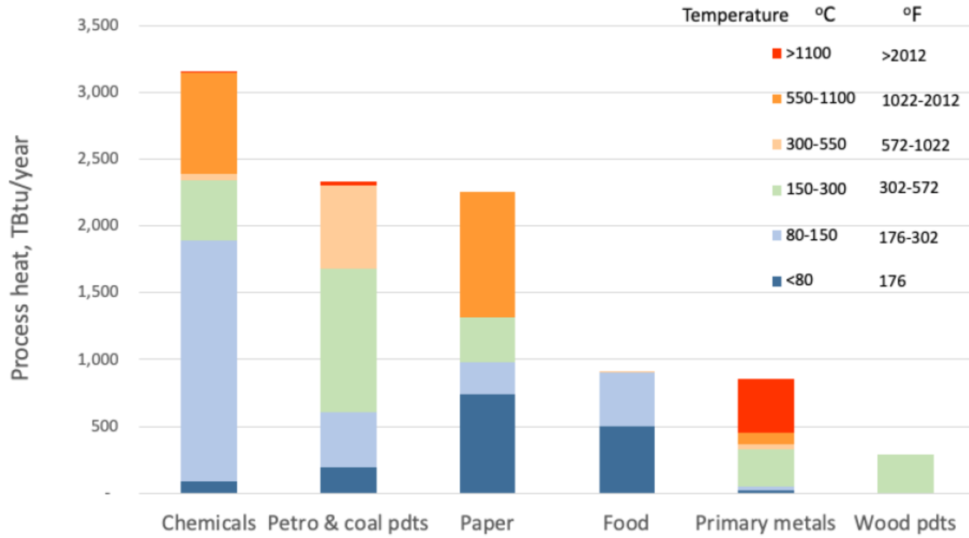

Figure 1. U.S. industrial process heat, categorized by industry type and maximum required temperature. *Source:* Hoffmeister 2023.

Heat pumps are an appropriate method for efficiently electrifying process heat wherever possible. Most mechanical commercial heat pump models use a vapor compression cycle that exploits the phase change of a working fluid to move heat against its natural gradient, as illustrated in Figure 2. The heat pump in this cycle receives heat from a source, increases the heat's temperature, and delivers useful heat at the elevated temperature (Cox, Belding, and Campos 2022).

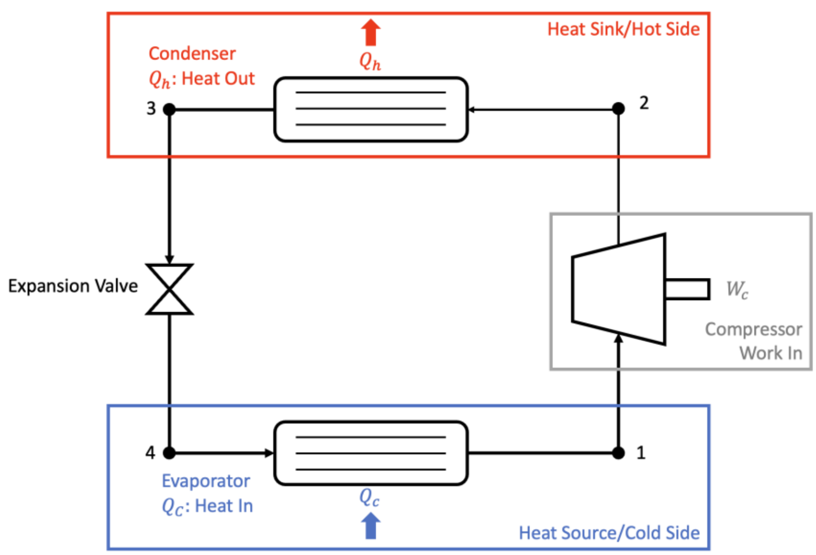

Figure 2. Schematic of a mechanical heat pump. *Source:* Cox, Belding, and Campos 2022.

Conventional heat pumps used in heating, ventilation, and air conditioning (HVAC) applications can efficiently deliver maximum temperatures around 140°F, but newer high-temperature heat pumps (HTHPs) can reliably yield maximum temperatures up to about 300°F.

Since they transfer and amplify existing heat sources into more useful heat streams, heat pumps can be even more efficient in these applications if a waste heat source is available (EHPA 2020; ACEEE 2022; Rightor, Scheihing, and Hoffmeister 2022).

Processes with maximum temperatures below 300°F are ubiquitous in many industries, notably food and beverage, including dairy. In fact, any context that requires a drying process, such as municipal wastewater treatment, also requires maximum temperatures not exceeding 300°F. Such industries with process heat needs below 300°F are excellent targets for decarbonization through efficient electrification of processes that combust fossil fuels. However, even though global research and development have led to more efficient industrial heat pump products in the last decade, they are relatively unknown in the United States, even in prime target industrial settings (Cox, Belding, and Lowder 2022; Rightor, Scheihing, and Hoffmeister 2022).

As a result, researchers have called for increased visibility and publication of case studies on the application of heat pump technologies to industrial processes. Barriers to widespread adoption of heat pumps in industry primarily involve financing, how to integrate them into complex processes, low product availability, lack of equipment lifetime support (for example, service, maintenance, and replacement part availability), and workforce limitations (Rightor, Scheihing, and Hoffmeister 2022). U.S. policymakers can help make any technology less expensive, but they cannot assuage a likely early adopter's worries about these other obstacles. European and other non-American case studies can demonstrate the thermodynamic capabilities of industrial heat process heat pumps (EPHA 2020), but it can be difficult to apply them to American energy contexts.

In 2022, the Industrial Process Technical Solutions Group of the statewide energy efficiency utility Efficiency Vermont investigated how heat pump technologies could affect commercial and industrial energy customers' electrification strategies. Vermont's electric generation supply is among the lowest in the nation in carbon dioxide emissions. Also, in most of the state, low-cost natural gas is not available. These factors have led to a reliance on expensive propane and oil. Thus, the combination of an electricity grid with low carbon emissions and the high cost of fossil fuels makes adoption of heat pumps particularly attractive.

The Efficiency Vermont team explored two different use cases: municipal wastewater treatment and the manufacture of dairy products.

To help meet the domestic need for real-world examples and best practices, VEIC, which operates Efficiency Vermont, is sharing the results and research experiences via these case studies. The purpose of this work is to promote advantageous industrial heat pump adoption, share best practices across the energy sector, and contribute to the national body of knowledge on the efficient electrification of industrial process heat.

Case Study 1: Bellows Falls Wastewater Treatment Facility

Summary

Municipal wastewater treatment processes yield an organic by-product known as *sludge.* Sludge can be solid, semi-solid, or liquid, and its qualities depend on a specific facility's local wastewater characteristics and treatment processes. Although treated water can be released into the local environment, sludge must be disposed of separately (EPA 2023a).

In the Northeast, sewage sludge is most often hauled to a landfill, incinerated, or treated for beneficial reuse according to State and federal regulatory guidelines. However, the infrastructure needed for such disposal is significantly stressed, primarily because of reduced landfill capacity (NEIWPCC 2022; Miller 2023).

Sludge can be dried and pasteurized to safe levels for beneficial reuse as a land-applied fertilizer, thus eliminating landfill disposal costs and environmental impacts. Sludge reuse also frees a wastewater facility from depending on landfills' changeable capacity, sludge acceptance policies, and pricing.

The U.S. Environmental Protection Agency (EPA) sets standards for the land application of sewage sludge "biosolids." The standards are based on limits for pathogens and heavy metals (EPA 2018). There are three classes of biosolids: Class A Exceptional Quality (EQ), Class A, and Class B. The public may use only Class A EQ and Class A biosolids. They may also be sold or given away for land application without specific permitting for end use. Class B biosolids can sometimes be applied to agricultural land with special permits (EPA 2023b). However, some states are reducing or eliminating Class B application permits because of emerging contaminants from the sludge. Those same concerns have led some landfills to reject Class B biosolids altogether, leaving wastewater treatment facilities in a sludge disposal crisis (NEIWPCC 2022; Miller 2023).

Typically, a wastewater treatment facility processes sludge in batches, accumulating it over a specific period, the frequency and duration of which are a function of the volume rate of sludge recovery and storage capacity. Mechanical dewatering is the primary method of moisture removal, most commonly using belt press, screw press, or centrifuge technologies. Heat drying processes sometimes further reduce sludge moisture content, which significantly reduces weight and transport costs. Heat can also be used to process and dry sludge to a Class A biosolid, which can be safely stored, sold, or given away for use as fertilizer. However, heat drying usually requires fossil fuel combustion, and the associated energy costs can be prohibitive (EPA 2006).

Until recently, the wastewater facility in Bellows Falls, Vermont, finished dewatering with a screw press that yielded Class B sludge with disposal at a Vermont landfill. The facility has a rotating biological contactor (RBC) and produces about 350 wet tons of sludge per year. The sludge is anaerobically digested prior to dewatering and disposal.

Bellows Falls removed an older belt press and installed a new screw press for their final sludge dewatering step in 2021. Also in 2021, they installed a heat pump electric sludge dryer as a new post-dewatering step in their overall process, which is shown in Figure 3. The Town based its decision to buy the sludge dryer technology on the economic paybacks of handling their own sludge disposal versus paying for landfill hauling and tipping. The municipality was also concerned about future acceptance of sludge disposal at the nearby landfill in Coventry, Vermont. The Town bought the dryer (Shincci 2023; manufactured in China) from Resource Management, Inc. (RMI), a residuals management company in the Northeast. The dryer is one of only two known units of its type in the United States (C. Hanson, Senior Project Manager, RMI, pers. comm., November 2022).

The Shincci sludge dryer has a perforated conveyor belt (Figure 4 and Figure 5). It uses a heat pump in a simultaneous heating and cooling process to remove moisture. Upon start-up, the dryer requires supplemental electric resistance heating to the circulating air stream to begin evaporating liquid from the sludge. A refrigeration cycle condenses the released vapor, and after the initial start-up, steady state is achieved and the heat from compression of the refrigerant cycle replaces the electric resistance heating, continuing the evaporation process. The heating temperature and retention time are high enough to achieve pasteurization of the end product.

Exploitation of simultaneous evaporation and condensation with simultaneous achievement of pasteurization makes this sludge drying process energy efficient, and electrification of the entire process is therefore both feasible and advantageous. The final product is a dry, stable, Class A biosolid product, according to the EPA regulations governing biosolid classification U.S. EPA 40 CFR Part 503 (EPA 2018). The heat pump and a few other components of the system are proprietary to Shincci. More details on the Shincci sludge dryer operation and model types are available at RMI (RMI 2021a, 2021b).

Figure 3. Shincci heat pump sludge dryer installed in Bellows Falls, VT. *Source:* Efficiency Vermont.

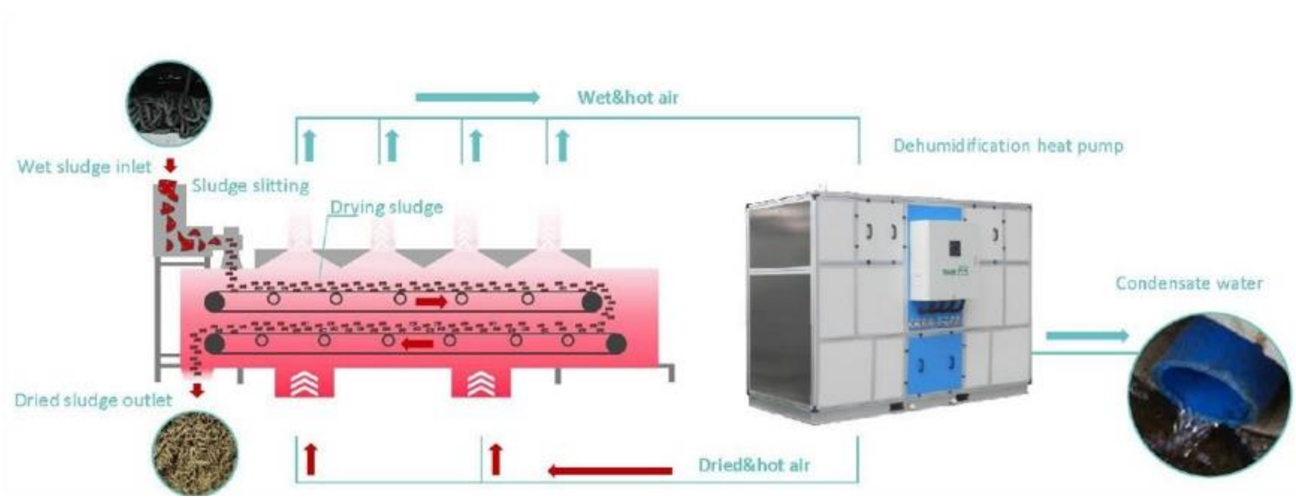

Figure 4. Process diagram of Shincci sludge dryer. *Source:* Resource Management, Inc.

Figure 5. On-site photos at the Bellows Falls wastewater treatment facility. Left: Sludge dryer with panel open,showing conveyer system. Right: Dried Class A final biosolid product. Source: Efficiency Vermont.

In early 2022, Efficiency Vermont met with Rob Wheeler, the chief operator of the Bellows Falls wastewater treatment facility. He was pleased with the facility's Shincci sludge dryer experience with respect to the biosolid final product. The dry Class A biosolids were easier to handle and approximately a quarter of the volume of the Class B product of the facility's previous dewatering process. He observed that the landfill disposal cost savings were significant. He said the operators had noticed sub-metered data that suggested they could optimize the unit's operation even further and had reached out to Efficiency Vermont for technical assistance.

Efficiency Vermont was eager to explore further energy optimization, but also hoped to compare performance data of this novel heat pump technology to conventional fossil-fuel-based sludge-drying methods. The purpose of the investigation was to learn more about the new electrified process heat application in the wastewater treatment sector. Bellows Falls agreed to allow mutually beneficial data gathering on their processes and equipment. Efficiency Vermont toured the facility, provided new submetering equipment for the sludge dryer, and performed analyses—in cooperation with Mr. Wheeler, his operations staff, and the Town.

Methods

To gather useful data, Efficiency Vermont met with Mr. Wheeler and other members of the Bellows Falls wastewater operations staff operating the Shincci dryer. They noted that the dryer's operation was less efficient than expected, compared to RMI experience at a prior installation in Hooksett, New Hampshire. That facility's dryer used an average of 180 kWh per processed ton of wet sludge "cake" (RMI 2021b). Bellows Falls' wet sludge had a similar water content to Hooksett's, so Mr. Wheeler was disappointed by his 14 months of submeter readings on sludge dryer operation, showing a monthly average of about 400 kWh per wet ton of sludge processed. He wanted to experiment to learn whether minimizing start-ups and processing more sludge over longer times might increase the efficiency of the process. He reasoned that reducing the number of times the dryer had to start cold would reduce the use of the supplemental electric resistance heating feature to come up to operating temperature. Mr. Wheeler needed data to inform the Town's budgeting decision on his proposal to increase storage infrastructure for dry biosolids, which would allow the site to run longer, less-frequent heated dryer batch runs. He asked Efficiency Vermont to help measure and evaluate the data.

Mr. Wheeler provided Bellows Falls records of data on sludge dryer performance, including their power submeter readings, the weight in tons, and percent solids versus water of both the wet sludge and of the dried biosolids. The data showed an average kWh per pound of water removed by the dryer, since "wet tons" can vary significantly in percentage of water versus solids. The Efficiency Vermont analysts compared this value to the median value reported by the EPA in facilities that use fossil fuel-based thermal technologies to dry sludge. Efficiency Vermont also compared this analysis to the total site's electricity consumption data, which led to the conclusion that either the submeter used at Bellows Falls was faulty, or the unit was using an unrealistic proportion of the facility's total energy. The analysis also showed that when the sludge dryer process was added in 2021, the facility's average monthly consumption increased by about 8,900 kWh per month, or a 27% increase in average power use versus the previous overall treatment process which ended at dewatering. This led to additional monthly power costs of about $1600 per month. Landfill tipping fees for dewatered sludge was almost 5 times that amount, so the additional power cost was considered well spent by the town.

To clarify the correct power consumption of the sludge dryer unit, Efficiency Vermont loaned the Town a Dent Instruments ElitePro XC Series sub-power meter, a calibrated power meter with utility grade accuracy (Dent Instruments 2023), to log true power consumption across two months in early 2022. There were 12 7-hour daytime sludge dryer runs during the metered period. The loaned power meter proved the original submeter was not accurately recording the power use, reading over 2.5 times the actual power use.

In December 2022, operators at Bellows Falls ran the dryer continuously for 55 hours. They requested help in interpreting the power consumption logged by their submeter, which was still operating as it had prior to the temporary installation of the Dent Instruments meter earlier that year. Efficiency Vermont analysts calculated a conversion factor based on historical submeter records to estimate the dryer's consumption during the winter multi-day dryer run. They compared the power required per pound of water removed from the sludge to the prior analysis, to determine whether the multi-day continuous run led to more efficient operation than the 12 single-day runs. Results were inconclusive because of the uncertainty from the faulty submeter and the need for a sludge dryer repair that was discovered after the multi-day run.

To prevent a similarly inconclusive result for future operational experiments, in early 2023, Efficiency Vermont bought an eGauge Core (EG4015) energy meter for the Town of Bellows Falls. The meter monitored permanent energy consumption on the sludge dryer unit (eGauge 2023). eGauge granted Bellows Falls operators permanent access to the its online portal, where they can now see and download their logged data and live meter readings. This access allows the facility operators to observe the effects of operational changes as they go, and to observe trend data for patterns and further efficiency opportunities.

Results

Table 1 shows the results of the energy consumption analyses of recorded consumption data at Bellows Falls, and meter data logged by the Dent Instruments ElitePro XC Series across April and May 2022. These results clearly show that Bellows Falls' Shincci dryer compares favorably to conventional thermal dryers in terms of kWh per pound of water removed, reducing energy consumption by more than 40 percent relative to the meter data from the 12 single-workday batch runs in April and May 2022.

Discussion

After receiving the results of the meter data analysis, Mr. Wheeler was still interested in tweaking his process for maximum efficiency, even though he and the town administrator had learned that the purchase of the new dryer was as economically justified as they'd hoped. The secondary biosolids quality and handling benefits of the sludge dryer, combined with the elimination of landfill hauling and tipping costs, made the Shincci heat-pump-based system well worth the capital investment.

Table 1. Shincci heat pump sludge dryer energy analysis results

Measure	Results
Heat drying sludge median consumption, conventional equipment*	0.45 kWh / pound of water removed
April-May 2022 Shincci unit consumption	0.24 kWh / pound of water removed
Reduction in energy use vs. conventional sludge drying	47%

**Source:* EPA 2006.

However, analysis to date of energy use during multi-day continuous runs has been inconclusive. Now that a reliable, permanent energy meter has been installed, future operational experiments should be relatively easy to analyze for efficiency effects. Mr. Wheeler and Bellows Falls officials hope to continue to optimize and field-test this cutting-edge wastewater sludge handling solution. They are also willing to share their findings and resulting best practices with other municipalities.

In mid-2022, another town in Vermont was evaluating sludge disposal options, and asked for guidance from Rob Wheeler and Bellows Falls Town officials. Based on the sludge-handling experience to date and the efficiency analysis, Bellows Falls enthusiastically recommended the purchase of a Shincci sludge dryer unit. The other town's superintendent of wastewater brought sample buckets of their wet sludge to Bellows Falls for a successful test run, and Efficiency Vermont partnered with the local power utility, Green Mountain Power, in offering substantial incentive payments to make the conversion to the more efficient system. Efficiency Vermont based a purchase incentive on energy efficiency and reduction of fossil fuel use via electrification.

Problems with the supply chain meant RMI could install only one Shincci unit in 2023. A municipality in a different state purchased the single available Shincci sludge dryer before Town's Select Board came to a final purchasing decision.

The testimony of wastewater operators in Bellows Falls and the energy consumption analysis have together indicated that heat-pump wastewater sludge dryers are a more cost-effective solution for managing wastewater biosolids, compared to conventional thermal methods of sludge drying. An additional benefit is that the heat-pump sludge-drying process provides a local, nutrient-rich fertilizer that can be directly applied to nearby land. This obviates the need for hauling and landfill disposal.

Although “first adopter” barriers exist and true third-party verification is key to lowering them, the primary obstacle to implementation of this technology is the lack of sludge dryer inventory.

Case Study 2: Commonwealth Dairy

Summary

Researchers at the National Renewable Energy Laboratory (NREL) have created a model of high-temperature heat pumps for use in industrial process applications. “High temperature” in this class of heat pumps is defined as *the capability to deliver heat at temperatures greater than 90°C*, or about 200°F. NREL’s open-source model uses the Python programming language and performs both economic analysis and physics-based performance estimations to evaluate the potential performance and costs of HTHPs in specific settings. NREL’s primary objective for developing an HTHP model is to offer a reliable estimate of the economic potential of heat pumps in industrial applications. The secondary objective is to encourage and promote higher rates of adoption in the United States (Cox, Belding, and Campos 2022).

Efficiency Vermont learned that NREL was looking for real-world contexts to use as case studies for demonstration of their HTHP model. The Efficiency Vermont team also knew that the American Council for an Energy-Efficient Economy (ACEEE) and others had concluded that food and beverage production could be excellent “first mover” industries for HTHP technology, because their maximum temperatures for heating processes are above 160°F. That level is the maximum for conventional, non-high-temperature heat pumps, but below the reliable maximums of approximately 300°F for HTHPs. These industries’ complex operations have many different types of processes. This variety creates the possibility for simultaneous heating and cooling process needs. Simultaneous cooling loads can increase heat pump efficiency in fulfilling process heat requirements (Jakobs and Stadlander 2020; Rightor, Scheihing, and Hoffmeister 2022).

Based on decades of engagement with local industries, Efficiency Vermont recommended Commonwealth Dairy, a customer in Brattleboro, Vermont, as a good fit for NREL’s research. Efficiency Vermont staff knew that this customer was exploring replacement chiller equipment, so analysis and a case study from NREL could be of high value to company decision makers. Further, Commonwealth Dairy is owned by Lactalis, Inc., an international firm with strong greenhouse gas reduction goals. Efficiency Vermont recommended the customer too because dairy production involves relatively coincident heating and cooling processes, making the dairy a well-matched application for heat pumps.

Commonwealth Dairy agreed to participate. As part of the modeling, Efficiency Vermont provided customer liaison and on-site visit logistics support to NREL. Efficiency Vermont also analyzed site-specific energy consumption and utility cost data for model inputs. A data-gathering site tour hosted by the dairy for two members of NREL’s research team occurred on September 20, 2022.

Commonwealth Dairy produces yogurt, processing an average of 95,000 pounds of dairy product per day. Its system requires a glycol chiller and two propane steam boilers for equipment clean-in-place (CIP) and space heating. At the time of the case study analysis, the dairy was considering replacing its chiller facilities and could potentially replace both the propane boilers and glycol chiller with a single HTHP. These systems provide a hot loop of 98°C (208°F) and a cold loop of -2°C (28°F). The dairy estimated that replacing the boilers and glycol chillers separately would cost approximately $750,000.

Energy efficiency is especially important in Commonwealth Dairy's region of Vermont since natural gas is not available for thermal processes. The only conventional and locally available fuels are oil and propane. Compressed natural gas (CNG) and biomass (wood chips or pellets) are available in the area, but Commonwealth Dairy uses propane because it is more cost effective than CNG. Biomass requires high upfront investment and a large space for storage. However, propane's price is both volatile and high compared to natural gas, which makes efficient electrification a favorable option.

Because piped natural gas is typically not available in Vermont's rural areas, propane meets many fuel needs. Electricity averages $0.12 per kWh, but the rate structure has a long on-peak demand period, resulting in widely varying costs. Commonwealth Dairy's power utility, Green Mountain Power, charges the dairy for both on-peak and off-peak demand, as shown in Table 2.

Table 2. Commonwealth Dairy energy rates

Energy source and type	Cost
Electricity cost demand charge, on-peak (6 a.m. – 11 p.m.)	$16.401 per kW
Electricity cost demand charge, off-peak	$4.723 per kW
Electricity cost energy charge, on-peak (6 a.m. – 11 p.m.)	$0.11573 per kWh
Electricity charge, off-peak	$0.08795 per kWh
Propane charge* (1 gallon = 27 kWh of electricity)	$1.81 per gallon

**Source:* Commonwealth Dairy, facilities staff, pers. comm. August 2022.

The Commonwealth Dairy modeling case study compared economic competitiveness to conventional gas heating systems. The NREL case study report is pending publication (Cox, Belding, and Campos 2022). With its permission, NREL supplied Efficiency Vermont with details from the draft report, to inform this paper's methods, results, and discussion sections.

Methods

NREL's open source HTHP model. NREL's Python-based model is based on heat pump types that use a mechanical vapor compression cycle with a working fluid refrigerant to receive heat from a source, increase the heat's temperature, and deliver useful process heat at the elevated temperature. The model has four modular physics-based components: a coefficient of performance (COP) calculator for heat pumps, given boundary operating conditions; a heat pump energy balance module; a gas boiler energy balance module; and an electro-resistive energy balance module. These four modules can be combined into a system of heat technologies based on the specific context being modeled. The COP calculator module defines COP as the ratio of heat supplied by the pump (Q_h) to the input power required by the compressor (W).

$$COP = \frac{Q_h}{W}$$

The higher the COP, the more heat can be supplied per unit of electricity, and thus, the more effective the heat pump. COP is an important calculation because a heat pump with a suitably high COP can provide cost savings compared to non-heat-pump technologies.

The model also has an economics module that can compare any two system configurations for net present value (NPV), internal rate of return (IRR), and payback period (PBP).

The comprehensive model is open source and available on GitHub. NREL plans to publish a report providing the equations for each module and a guide on how to construct a system using Python coding for economic comparison—to help inform decarbonization and electrification strategies.

Commonwealth Dairy analysis. Commonwealth Dairy provided thermal demand information from its daily dairy product production. The daily demand spanned from January to July. NREL mirrored the same profile for the remainder of the year to approximate a full-year profile, as shown in Figure 6.

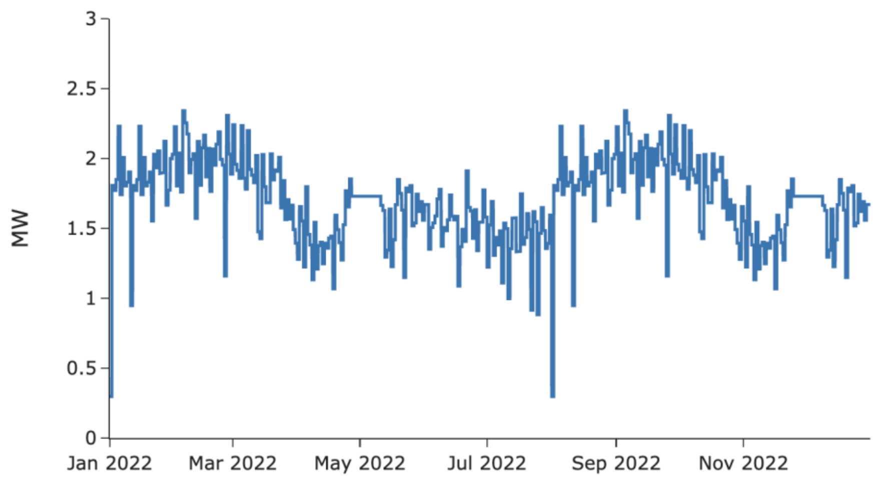

Figure 6. Commonwealth Dairy daily thermal energy demand. *Source:* Cox, Belding, and Campos 2022.

As was shown in Table 2, there are both off-peak and on-peak demand charges for this facility's electricity. The researchers chose the more expensive, on-peak charges because the model cannot handle both. Table 3 shows the model's inputs for the potential HTHP system versus the system that uses propane and the chiller.

This analysis assumed that the chiller energy costs were not added to the gas system costs; it also assumed that the off-peak demand charge would be significantly lower than the on-peak demand charge. Disregarding the chiller costs made the heat pump less competitive, relative to the traditional system. Ignoring the off-peak demand charge made the heat pump more competitive. Therefore, the team reasoned that disregarding both had a leveling effect.

Table 3. Commonwealth Dairy model input values

Model input	HTHP	Propane boilers + chiller
Purchase cost	$960,000	$750,000
Electricity demand charge, on-peak (6 a.m. – 11 p.m.)	$16.401 / kW	NA
Electricity energy charge, on-peak (6 a.m. – 11 p.m.)	$0.11573 / kWh	NA
Electricity energy charge off-peak	$0.08795 / kWh	NA
Propane cost	NA	$19.83 / MMBTU

Source: Cox, Belding, and Campos 2022.

This approach was necessary because the model does not have a chiller component and cannot handle two demand charges. NREL will address this challenge in its future work and will update the results to Commonwealth Dairy before they decide on their purchase. Further, facilities staff of the dairy explained to the team that the need for hot water was much greater than that for cold water, so heating would be the driver of a simultaneous heating and cooling HTHP system. To justify this assumption, the team assumed a 30 percent higher capital cost for the HTHP to accommodate the possible need for chilled glycol, chilled water, or ice energy storage that could be used as a buffer. The team used a discount rate of 10 percent for financial calculations with an assumed system lifetime of 20 years.

Results

The modeling case study for Commonwealth Dairy shows a positive NPV for HTHP deployment, which confirms that it could be an economically viable option. Previous work by Cox et al. had found that HTHPs were often not economical in similarly complex applications with COPs below 2, when relatively inexpensive natural gas is available. However, this case has increased capital cost due to the combined water heater and chiller and very high levelized cost of heat (LCOH) of the hot water heated by propane ($26.60 / MMBTU). This means that even a poorly performing HTHP can provide value in this context if it is used for simultaneous heating and cooling. Table 4 shows all of the model output results.

Table 4. Commonwealth Dairy NREL HTHP model key indicator results

Indicator	Result
Average COP	1.7
Average power draw	468 kW
Capital cost of HTHP	$960,000
HTHP lifetime LCOH	$24.95 / MMBTU
Propane lifetime LCOH	$26.60 / MMBTU
Net present value	$371,225
Internal rate of return	0.003%

Source: Cox, Belding, and Campos 2022.

Discussion

Although the initial economic analysis at Commonwealth Dairy shows that an HTHP can perform better than competitor technologies, further work is needed to determine whether an HTHP should be deployed at the facility.

The goal of the NREL HTHP model research is to accurately estimate the economic potential of heat pumps in industrial applications, with an objective of encouraging and promoting the technology in the United States. By making their model publicly available and providing case studies, NREL hopes that their work will support U.S. adoption by providing tools to help interested industries better understand their choices.

In this version of the model, NREL contacted heat pump manufacturers that shared insight into refrigerant selection and compressor performance. These factors affected NREL's final HTHP model. However, building an HTHP in a specific application will require additional manufacturer input, especially since the majority of HTHPs are currently highly custom designs rather than off-the-shelf products. Either as further HTHP models are released or in partnership with their design, NREL's work would benefit from additional data from real-world facilities.

Despite the conservative assumptions of HTHP performance in the current version, this case study demonstrated that an HTHP could be economically competitive. However, this economic competitiveness was relatively close with a low IRR (as shown in Table 4). It would be understandable if the customer ultimately did not want to be a first mover on a novel technology since the technology is considered unproven and demonstrates only a slight economic edge over conventional options. Reducing the capital cost or increasing economic competitiveness (such as placing a value on carbon emissions) could help address this issue.

The NREL HTHP model is publicly available and can estimate the performance and economic competitiveness of HTHPs in other industrial settings. Future work could seek to couple this model with experimental demonstration and pilot project facilities. Until then, this case study shows promise for demonstrating the viability of HTHPs as an industrial heat supplier in the United States.

Conclusions from Both Case Studies

A small research team at Efficiency Vermont had an objective in 2022 to learn more about process heat applications of heat pump technologies as a way of helping the state's commercial and industrial energy customers decarbonize their operations and facilities. Through these two different investigative case studies, the team derived best practices and clarified the barriers to heat pump adoption for process heat applications. The team also built collaborative relationships with new partners.

However, in the long term, Efficiency Vermont is seeking a more informed advising role to customers. Many of them have told staff that Vermont's low carbon emission profile on its electric grid, the rising and volatile costs of unregulated fossil fuels, and corporate decarbonization target programs are pushing them to look for creative ways to electrify. Efficiency Vermont wants to support that interest quickly. In support of that objective, the Efficiency Vermont team has drawn several conclusions from these case studies.

First, although short-term economics and capital cost are still a significant, collective concern for most customers, heat pump technologies can be appealing to customers even when the economics are not compelling—if they can see other value. At the Bellows Falls wastewater treatment facility, the long-term unpredictability of landfill disposal costs, environmental benefits, and operational advantages of the Shincci sludge dryer were of equal or greater weight to energy costs in the Town's purchasing decision. The efficient performance of the unit was helpful, especially for making a case to other municipalities, but it was not the deciding factor. At Commonwealth Dairy, the ambitious decarbonization goals of parent company Lactalis, Inc., were a major reason for that facility's interest in helping with a demonstration case study for NREL's HTHP model. Although the results brought value to decision makers at the company, budget concerns alone did not drive the enthusiastic cooperation of staff.

Second, any corporate decision to decarbonize via electrification must consider efficiency and design. A common complaint in process heat electrification discussions is that there are no "off-the-shelf" heat pump products available that work well in most industrial process heat applications. It would make a system design much easier if there were more generally accepted products for these types of applications. Manufacturers have substantial expertise and research to bring to that concern. However, these two case studies highlight the ways in which every process heat situation is unique. Design needs are equally important for—or even more important than—the specifications of the heat pump unit itself. That is, simultaneous heating and cooling processes or other capture of waste heat sources can make or break the economics of a project.

Last, although the band of U.S. industrial process heat users that can be served well by currently available technology is narrow, there are still many businesses that fall within it. Efficiency Vermont works with many customers in the food and beverage industry, as well as in the paper and wood industries. And as with the wastewater case study, there might be other surprising kinds of energy users with process heat applications who can readily benefit from heat pump technologies. The efficient electrification of process heat at the higher range of maximum temperatures is a topic that needs ongoing research. But at the lower ranges, the field can move now.

It is hard for commercial businesses to make decisions that make them feel as if they are the first to try a new technology, especially if they are not fully supported in making the jump into heat pump technology as an effective method to decarbonize their process heat. As of this writing, there is no accessible, clear information on the types of North American heat pump equipment that can be used in these applications. With the constraint on the inventory of imported equipment, as in the case of the Shincci sludge dryers, manufacturers might consider whether the heat pump technologies they currently sell only to non-industrial markets could be used or modified for process heat. Boutique custom projects will not reach enough of the industrial sector for high-value, widespread decarbonization. Policymakers, energy efficiency programs, and engineers should encourage heat pump adoption in this important category of industrial decarbonization—at least at the outset, with the tools they have at their disposal.

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