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Enabling the heat pump revolution

How Copeland is helping to accelerate adoption of medium to large heat pumps in commercial and industrial sectors

COPELAND

Copeland's commitment to the development of sustainable HVACR technologies spans a breadth of low- and ultra-low-global warming potential (GWP) refrigerant solutions in the residential, commercial and industrial sectors. This expansive product portfolio includes component-level items such as controllers, compressors, sensors and valves, as well as complete packaged solutions such as condensing units and heat pumps.

To meet the global demand for electrification of space and water heating, Copeland has dedicated significant research and development (R&D) investments toward innovations in medium- to large-scale heat pumps (i.e., 1 megawatt [MW] and greater) utilizing natural refrigerants. Although the application of heat pumps in large commercial and industrial process is not new, the next generation of heat pump technology is poised to play a critical role in reducing greenhouse gas (GHG) emissions, helping to achieve global decarbonization targets and meeting corporate sustainability goals.

This article will present several examples of how Copeland is applying its low- to ultra-low-GWP, natural refrigerant heat pump technologies in commercial and industrial markets. It will share the success stories, discuss key challenges to greater adoption, and examine potential strategies for overcoming these hurdles.

CO_2 heat pumps for large commercial buildings

As a natural A1 refrigerant, CO_2 (R-744) is non-toxic, low-GWP and free of polyfluoroalkyl substances (PFAS). Already widely adopted in commercial refrigeration systems, it has been identified as an ideal refrigerant for use in commercial heat pumps as an HVAC heating and cooling alternative. Copeland has been testing a CO_2 heat pump system in a lab environment since 2020.

The system models the heating and cooling demands of an actual multi-MW building. The 1.3 MW heat pump has produced 99.6 percent fewer GHG emissions than comparable boiler/chiller technologies, resulting in an annual savings of 2,476 tons of carbon dioxide emissions (CO_2 e/yr.). The model is designed to evaluate and document system performance at various environmental conditions and heating and cooling loads — as well as validate the concepts of thermal storage and demand response via electrical grid interactivity.

Designed for large commercial space heating and cooling, domestic hot water production, and industrial process heating and cooling applications, Copeland's Vilter high-pressure, low-displacement (HPLD) CO_2 single-screw compressor can simultaneously generate up to 1.70 MW of heating and 1.30 MW (~370 TR) of cooling. The compressor has a maximum design pressure of 138 bar (2,000 psia) and displacements of 128 to 243 cubic feet per minute (cfm) at 3,600 revolutions per minute (rpm) — capable of running at 4,500 rpm. From an efficiency standpoint, the solution can produce a combined coefficient of performance (COP) of 6.4 at HVAC conditions.

The system consists of a single compression skid that houses the Vilter HPLD CO_2 compressor, motor and oil management components. A separate heat transfer unit contains key CO_2 system components, including the gas cooler, evaporator, flash tank, control devices and sensors *(see Figure 1)*.

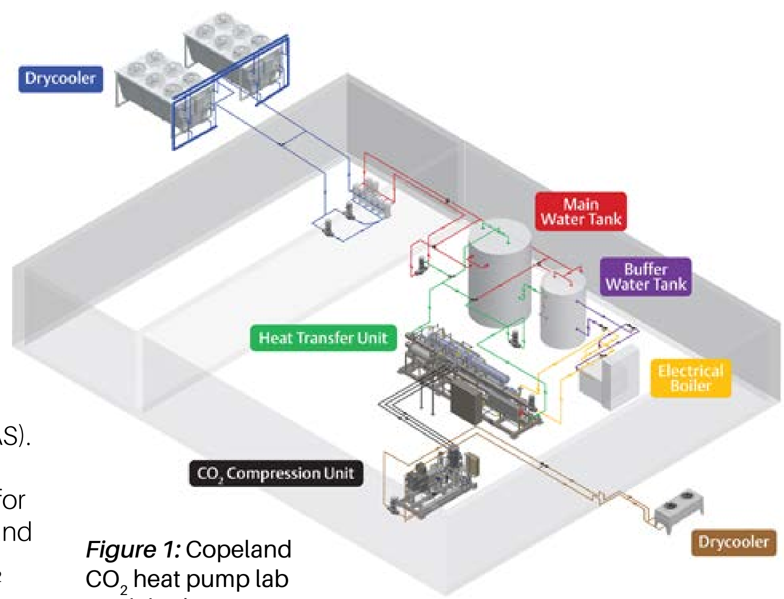

Figure 1: Copeland CO_2 heat pump lab model schematic

To simulate actual building heating and cooling loads, the lab is equipped with a 1.3 MW electric boiler used to create a typical building's cooling load. The heating load is simulated with the use of dry coolers that reject the system heat to the ambient environment. Since the location experiences below-freezing temperatures in the winter months, the dry coolers are connected to the hot water side of the system via a separate glycol loop for low-ambient freezer protection. Additionally, the compression skid's oil cooling load is managed with an external dry cooler, where the rejected energy is closely measured and accounted for in the overall heat pump performance. In an actual heat pump installation, this oil cooling load would be used to heat the process water stream.

The system is equipped with two thermal storage tanks that enable testing of demand response and thermal storage capabilities. The tanks hold a total of 60,000 liters of water that are used to store both hot and cold water simultaneously using a thermocline principal. The model demonstrated that a heat pump with sufficient thermal storage capacity could participate in demand response with a managed peak load at half of an equivalent electric boiler system — and for periods of time approaching a peak demand of a conventional gas-fired building *(see Figure 2)*.

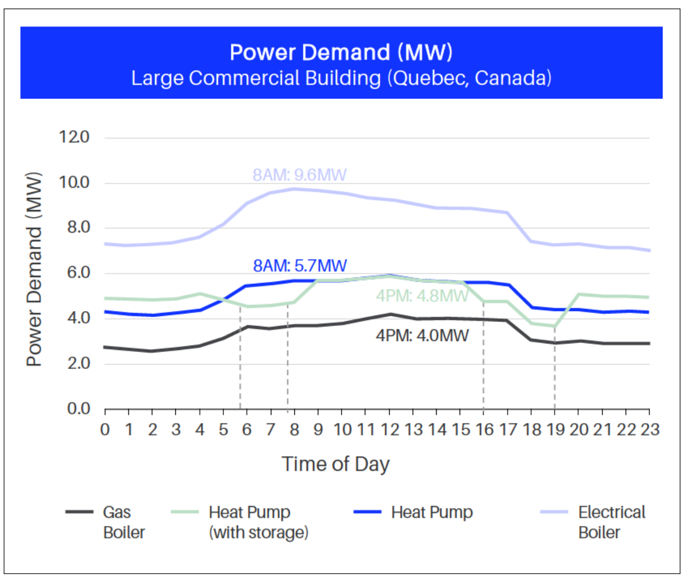

Figure 2: Comparative power demand of evaluated heating technologies

In terms of energy consumption, costs and GHG emissions, the model demonstrated that the CO_2 heat pump delivered significant improvements compared to traditional natural gas boiler/chiller and electric boiler/chiller systems *(see Figure 3)*.

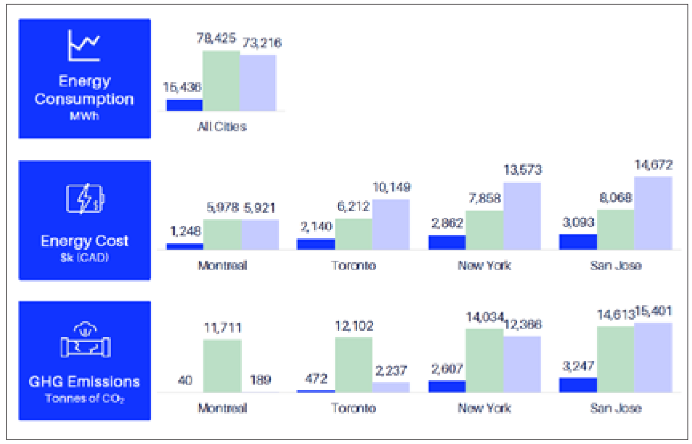

Figure 3: Comparative evaluation of energy demand, energy costs and GHG emissions (base case building seasonal average energy profile)

Challenges with CO_2 heat pumps

Compared to other synthetic refrigerants, CO_2 is non-flammable, non-toxic, PFA-free and inexpensive. It operates as a transcritical refrigerant in most applications, where ambient temperatures are near or exceed its critical point of ~31 °C. In heat pump applications, transcritical operation can be especially beneficial.

In simple terms, *transcritical refrigeration* is a process in which condensing does not take place in a condenser; instead, sensible cooling of the compressor discharge gas occurs in a gas cooler. The difference is not in the equipment; an air-cooled condenser and an air-cooled gas cooler are essentially the same. The difference is simply that CO_2 will not condense at temperatures above its critical point; for this reason, the equipment is referred to as a *gas cooler*.

The transcritical process can be very beneficial for heat pump applications, as it generates a larger quantity of high-grade heat compared to a traditional subcritical system, where the majority of the heat is available at the system's condensing temperature. Typical discharge temperatures for CO_2 heat pumps can be as high as 120 to 140 °C, which can be used for high lift on the process heating circuit. In the case of water heating, where city water temperatures start near 15 °C, it is possible to heat this water to 85 °C in a single pass with relatively good COP.

The challenge with CO_2 occurs when the hot water process loop has relatively high return temperatures (i.e., the water inlet to the gas cooler). For optimum performance, it's beneficial to cool the transcritical CO_2 gas close to the critical point when it is leaving the gas cooler; this makes the transcritical CO_2 process more efficient. However, if the return water temperature is relatively high (i.e., 60 °C), then the potential to cool CO_2 gas is limited to a temperature greater than 60 °C, which is well above the CO_2 critical point. The presence of high return water temperatures limits the quantity of heat that can be transferred to the water, which directly impacts the COP of a heat pump.

Heat reclaim

In winter, when space heating and/or high-quality or high-quantity heat is required, the head pressure can be pushed into the supercritical zone to about 1,100 psig.

Since pressures operate independently to temperatures as a supercritical fluid, the temperature at outlet of gas cooler drops due to cold ambient improving system efficiencies.

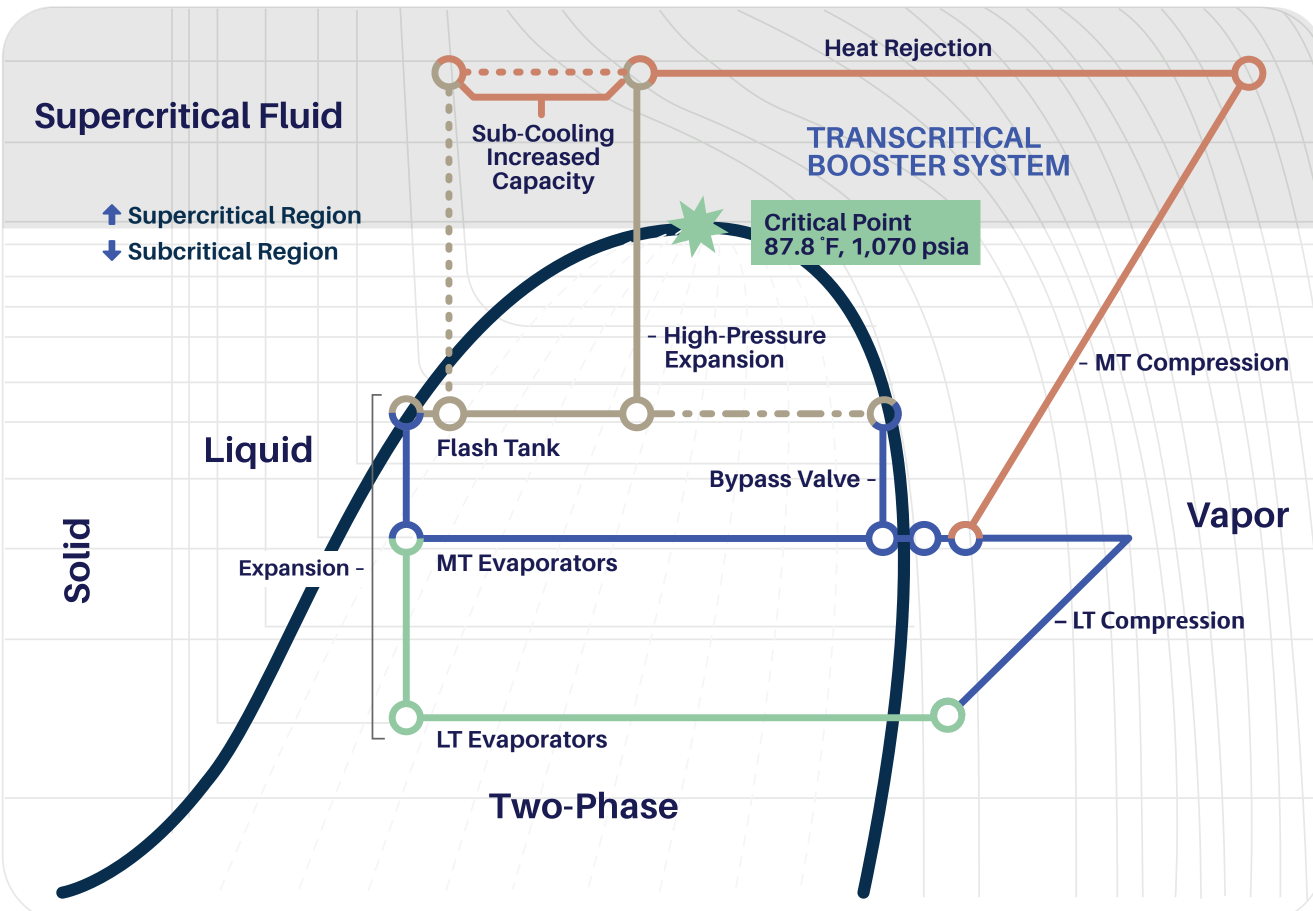

Figure 4: Improving heat reclamation in winter months

The solution to this dilemma is to fully integrate as many thermal loops as possible into a CO_2 heat pump system, where in many cases a facility may have different temperature processes. By integrating low-, medium- and high-temperature water heating loops into the heat sink circuit, it is possible to achieve optimum benefit and COP from the heat pump process. Although this approach does add to system design complexities, it has been validated and used in European CO_2 heat pump projects for many years. And when evaluated from a total cost of ownership (TCO) perspective, it typically results in the most favorable outcome for the end user.

Ammonia heat pump—meat processing plant

In this real-world example, an ammonia (NH3) heat pump was installed at a pork processing plant — an example application that could be replicated in the vast majority of medium-to-large facilities in the meat processing and food and beverage industries in North America. Previously, the plant had used an ammonia refrigeration system and a gas-fired steam boiler that provided the plant's thermal process loads. Since its installation nearly 10 years ago, this Vilter heat pump installation has provided efficient and reliable service while significantly reducing the facility's operating costs and carbon emissions.

The plant operator's objective was to identify a solution that would address its need for expanded capacity, while also providing benefits in reliability, efficiency, sustainability and an improved potential for return on investment (ROI).

From a design perspective, one of the key challenges was meeting the plant's fluctuating demand for hot water, which varied with seasonal weather conditions and production shifts. To account for these conditions, the heat pump was sized to meet the system base load, in which the final temperature lifts and intermittent load requirements would be managed by the existing boiler system.

System-level analysis and optimization techniques were employed to determine an effective strategy for balancing the water pre-heat temperature produced by the heat pump with the inlet water temperature — which was required to maintain acceptable thermal efficiency in the existing boiler system. The optimal solution utilized the heat pump to preheat water from 55 to 100 °F and increase the water temperature to 140 °F using an on-demand boiler system.

The ammonia heat pump installation supplies simultaneous process cooling and hot water heating for the pork processing operation. Process cooling loads are used to chill fresh pork, while hot water loads are used for clean-in-place (CIP) and wash-up processes. The additional cooling capacity was also critical for the planned facility expansion *(see Figures 5 and 6)*.

Figure 5: Vilter ammonia heat pump installation at a pork processing facility

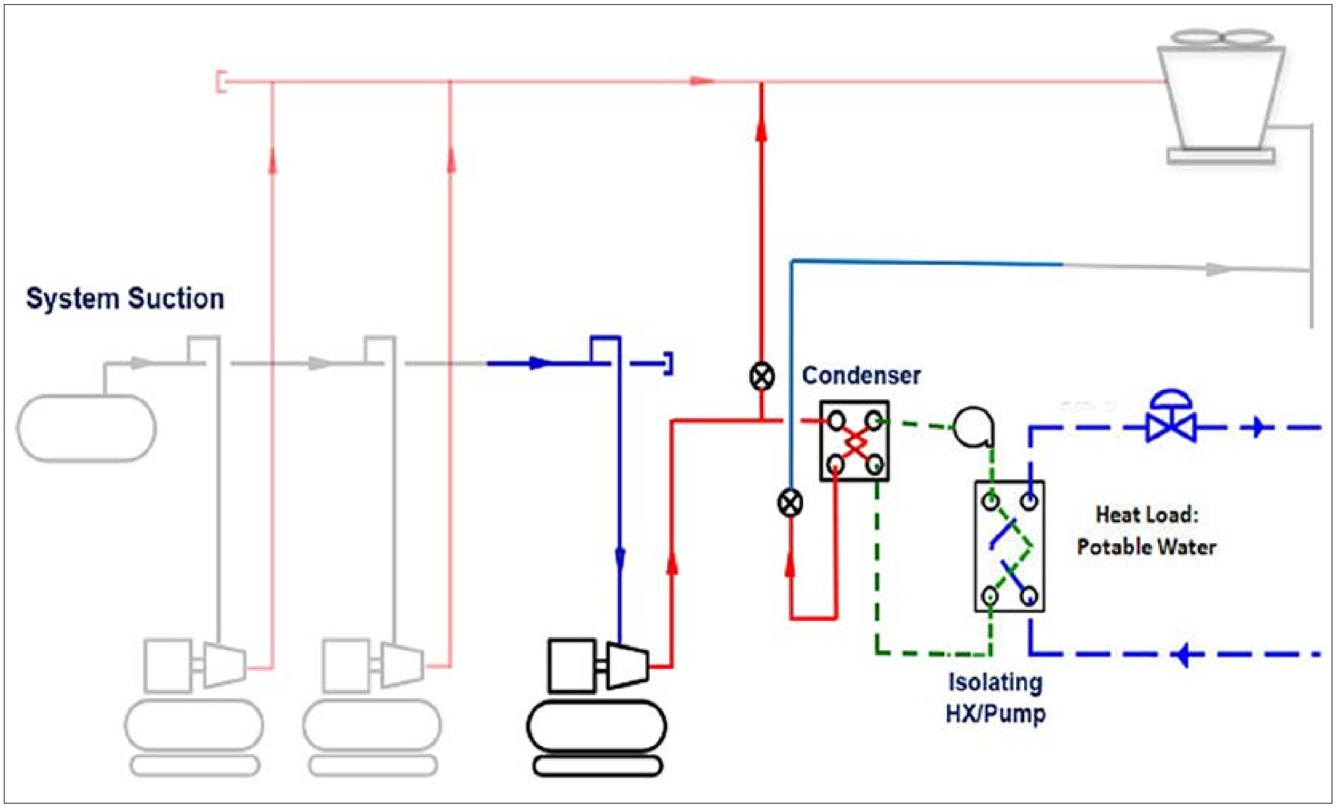

Figure 6: Ammonia heat pump integration in a pork processing facility schematic

The ammonia heat pump system operates on a continuous basis, more than 360 days per year, delivering water heated to 100 °F and chilled glycol at ~20 °F. By providing beneficial cooling in addition to heat production, the system yields a combined COP of 6.19.

The heat pump runs in parallel with a refrigeration plant and was sized to meet the base loads for both the refrigeration and hot water systems. This approach has resulted in high system utilization, which helped to shorten payback. Original projections were based on a simple payback of less than 3.5 years, but plant operators reported that this occurred in less than 2.5 years due to elevated production rates, increased natural gas costs and lower than projected maintenance expenditures *(see Figure 7)*.

Sustainability performance — annual savings	
Greenhouse Gas Reduction: • 3,000 metric tons of CO_2 **Energy & Water Savings:** • 3,374 MWh of energy • 3.1M gallons of water	**Natural Refrigerant:** • Ammonia refrigerant (<50 lbs charge) with 0 ODP and 0 GWP

Figure 7: Sustainability profile of the installed ammonia heat pump system

Ammonia heat pump — system specifications

Existing refrigeration system — built-upon refrigeration system

- Refrigerant: ammonia (NH_3 or R-717)
- Saturated suction: -10 °C
- Condensing temperature: 95 °C

Heat pump — single heat pump

- Refrigerant: ammonia, ~25 kg
- Entering water temperature (EWT): 12 °C
- Leaving water temperature (LWT): 40 °C
- Heat pump combined COP: 6.19
- Heat output: 440 kW

Ammonia heat pump — dairy industry

The Canadian dairy industry produces approximately 95 million hectoliters (hl) of milk annually *(Source: Statistics Canada)*. For each liter of milk produced, 0.22 kWh of thermal energy is required. Today, more than half of the thermal energy used by dairies is generated using natural gas or other fossil fuels.

In this real-world example, a 1.5 MW natural refrigerant (i.e., ammonia) heat pump was applied to an existing dairy processing plant — a scenario that could be repeated in similar dairy applications throughout the North American landscape.

The facility meets its process chilling demands via an ammonia refrigeration plant while relying on natural gas-fired boilers to meet its hot water requirements. In this instance, the solution leverages the heat of rejection from the refrigeration plant as a heat source for the heat pump. Discharge ammonia from the refrigeration plant's compressor is sent directly to the heat pump evaporator, where it is desuperheated, condensed and subcooled. The condensed refrigerant is returned to the refrigeration plant's high-pressure receiver. This process can operate in parallel with the existing evaporative condenser or handle all the condenser heat rejection via the heat pump's evaporator, depending on heating and cooling requirements.

This type of heat pump arrangement is referred to as a *scavenging heat pump* system (i.e., leveraging an existing heat source, such as the refrigeration plant condenser). In this case, a heat exchanger (aka *cascade evaporator*) is used to maintain separation between the ammonia circuits in both the refrigeration plant and the heat pump *(see Figure 8)*. This simple design makes for a reliable application without concerns of directly intermixing refrigerant flows — which can potentially cause technical challenges due to the mixing of system oils and other system contaminants.

In these types of applications, adding a heat pump to an existing refrigeration plant can offer a year-round, fixed condensing temperature if there is a demand for heating. Not only does this provide a steady-state condition for the refrigeration plant, but the heat pump can also help to lower its condensing temperature and improve its COP in certain scenarios.

In this case, the demand for heat dictates the use of a higher system condensing temperature. Thus, it is critical to fully understand the thermal balance of the refrigeration and heating processes to establish a design in which equipment costs, operating efficiency and carbon emissions can be optimized.

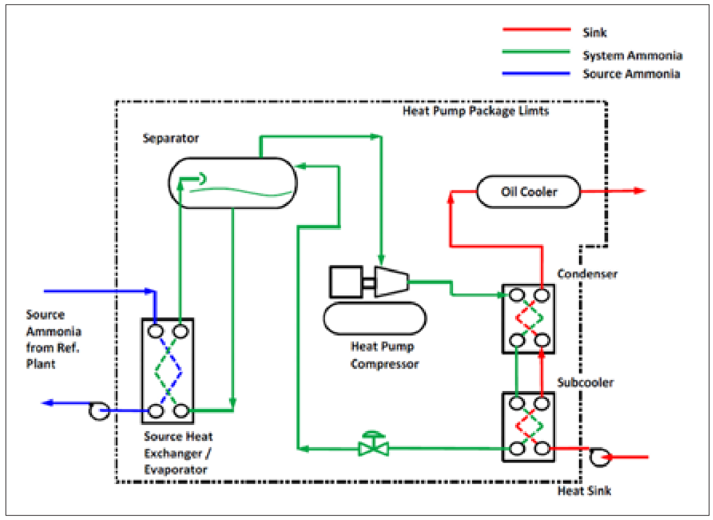

Figure 8: Ammonia heat pump using an existing ammonia refrigeration condensing loop as a source

System specifications

Existing refrigeration system — built-upon refrigeration system

- Refrigerant: ammonia (NH_3 or R-717)
- Compressor(s) name plate horsepower: 475 HP
- Saturated suction: -5 °C
- Condensing temperature: 80 °C
- Condenser heat of rejection: 1,071 kW

Heat pump — single heat pump package

- Refrigerant: ammonia, ~250 kg
- Compressor name plate horsepower: 600 HP
- EWT: 50 °C
- LWT: 85 °C
- Heat pump COP: 3.2
- Heat output: 1,457 kW

Food and beverage energy users

National footprint

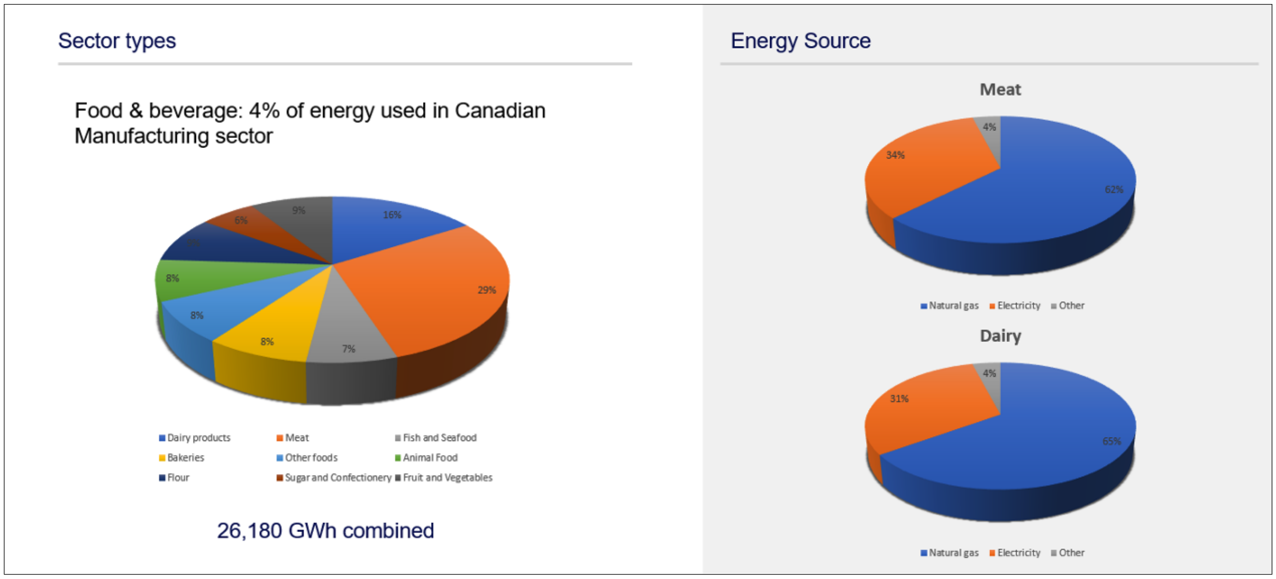

Figure 9: Energy distribution and sources per key industrial segments

The industrial heat pump examples presented herein highlight the vast potential to apply these technologies in adjacent markets, such as food and beverage plants, breweries and bottling facilities. These opportunities are significant in terms of offering end users benefits of equal scale, while contributing to global efforts to decarbonize vital industrial processes *(see Figure 9)*.

District energy heat pump applications

District energy systems present significant opportunities for sustainability improvements, especially considering the scale in which their impacts are realized, compared to more traditional point-of-use infrastructures. With a single infrastructural upgrade, a district energy system can potentially decarbonize large networks of consumers at one time.

The use of district energy networks is neither new in Canada nor North America. Nearly all large medical and educational campuses have some form of thermal energy network typically served from a central infrastructural point *(see Figure 10)*. Another common theme is that the majority of these systems are currently being evaluated for decarbonization retrofits.

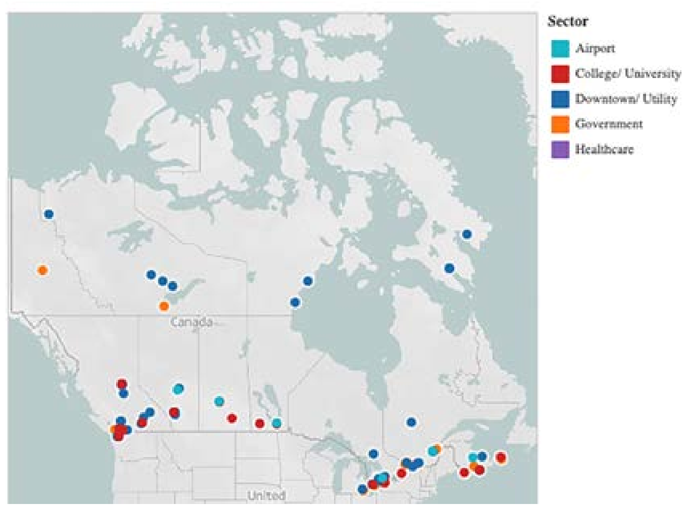

Figure 10: Existing district energy systems in Canada (HVAC heating and cooling)

The opportunities for decarbonization of these systems fall into two primary categories: new systems and existing system retrofit projects.

New systems can be categorized as new commercial developments, existing developments that are being retrofitted to a central thermal network, and existing thermal networks that are being expanded with new infrastructure to serve new customers.

Existing systems often utilize conventional technologies such as steam, gas- or fuel-fired boilers for heating, as well as refrigerant chillers for cooling loops. Heat pump technologies can decarbonize these systems to provide simultaneous heating and cooling without the use of fossil fuels.

One common retrofit challenge is the cooling loop temperatures of the infrastructure's design. Older district energy systems (i.e., early to mid-1900s) in which steam was commonly used to present the following heat pump retrofit challenges:

- Large-scale heat pumps are not readily available on the market for steam production.
- Steam-producing heat pumps operate at much lower COP than hot water applications.

Although the use of steam in heating networks is generally being phased out in favor of hot water systems, the requirement for steam cannot always be eliminated. Commonly, district energy or network systems are being upgraded to work with hot water. When steam generation is required, it is being applied via a point-of-use system with smaller equipment that is sized only for the equipment in a specific building or network. This configuration enables the heart of the system to be converted to hot water, while an older building or system on the network to be converted over time. This process has proven to be more financially viable in the short term, decarbonizing the majority of the system while providing a future upgrade path for the older components of the system.

District energy heat pump: system at a glance

One example of a district energy heat pump application is an ongoing project in Southern Ontario. There, a community-owned district energy system is currently being used to supply hot and chilled services to more than 10,000 residential and commercial customers. This system is providing a peak of 50 MW, with significant plans for expansion over the next decade.

In preparation for the installation, the customer chose to implement a ~20 MW wastewater-sourced heat pump system providing 95 °C LWT. Critical to the selection process was system COP, equipment footprint and TCO for the system over its operational life.

The customer selected an ammonia heat pump for several reasons, foremost of which was its ability to provide highly reliable and continuous heating throughout the Canadian winter months. Copeland's Vilter single-screw ammonia heat pump solution met this requirement, offering industrial-grade equipment used in rigorous industrial applications ranging from food and beverage and manufacturing to cold storage and industrial gas compression processes.

It also produced the desired water temperatures while providing an optimal combination of COP and equipment footprint. With its ability to deliver high capacities in comparatively small equipment footprints, the Vilter single-screw ammonia heat pump was critical to meeting the packaging constraints for this project.

Finally, Copeland's Vilter single-screw compressor, which is at the heart of the heat pump solution, offered excellent TCO with comparatively low maintenance and operating costs — all while providing best-in-class annual equipment run time.

Wastewater recovery is a process where low-grade heat can be recovered from a wastewater stream and upgraded to a usable temperature via a heat pump. In this case study, the customer was able to source ~15 MW of low-grade heat from a sewage main running below ground — beneath the parking lot of their thermal plant — which is available year-round at a temperature of ~10 °C.

Using specialized heat exchangers, the system was designed to capture this energy and provide it as a source water stream for a new ammonia heat pump capable of producing 95 °C LWT for the primary district heating loop. In addition, the solution utilizes a two-stage heat pump design in which both stages are connected via a water thermal loop.

During the summer months, the second stage is completely deactivated, and only the first stage is used as a chiller. During chiller-only mode, the hydronic connections are reversed such that condenser heat is rejected into the wastewater stream, and chilled water is connected to the district's chilled water loop. In systems of this scale, reversing the hydronic connections is far simpler than reversing the refrigerant circuit on the chiller/heat pump equipment.

Integration considerations

This district energy system has been in place for more than 20 years and relies on different systems to meet peak heating and cooling requirements. One key requirement for the new heat pump installation was that it must integrate with the existing system to passively increase the overall system's thermal capacity. Successfully doing so required several key considerations.

1) 95 °C supply water was required to ensure that the base system's heating load could be met during peak winter heating months. This temperature also allowed for the process stream to be injected directly into the main heating supply loop.
2) Variable capacity control was also identified as an important design requirement, enabling the heat pump to run at full capacity throughout the heating season, while shifting to partial load during warmer seasons. Thus, the heat pump solution consisted of four packages that could be controlled independently to enable operation at 25, 50, 75 and 100 percent capacities with no change in system efficiency. Beyond this, each package can modulate capacity down to approximately 20 percent of minimum load, which would far exceed any minimum load scenario envisioned for this application.
3) Finally, the heat pump packages needed to be designed for easy shipping, installation and commissioning to meet tight project timelines. As a turnkey factory solution, Copeland's Vilter VQ95 heat pump packages are completely self-contained in terms of their refrigeration circuits. Equipment is delivered on-site ready for field process water connections and electrical power feeds.

System specifications

Heat pump first stage — Quantity of four heat pump packages

- Refrigerant: ammonia (NH_3 or R-717) at ~250 kg each
- Compressor name plate horsepower: 800 HP each

Source

- EWT: 9 °C
- LWT: 4 °C

Interstage loop (sink)

- EWT: 43 °C
- LWT: 37.5 °C
- First stage heat pump COP: 5.5

Heat pump second stage — Quantity of four heat pump package

- Refrigerant: ammonia ~250 kg each
- Compressor name plate horsepower: 1,500 HP each

Sink

- EWT: 60 °C
- LWT: 95 °C
- Second stage heat pump heating COP: 4.5
- Heat output: ~20 MW

Bio

Jonathan Berney, P.Eng., is the Director of Business Development at Copeland Canada. With 20 years of industrial refrigeration experience, he has been involved in numerous sustainability-focused project initiatives in both the commercial and industrial sectors. Jonathan is focused on driving sustainability projects by assisting consultants, designers, contractors and end users with the planning and implementation of technology and practices for a more sustainable world.

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