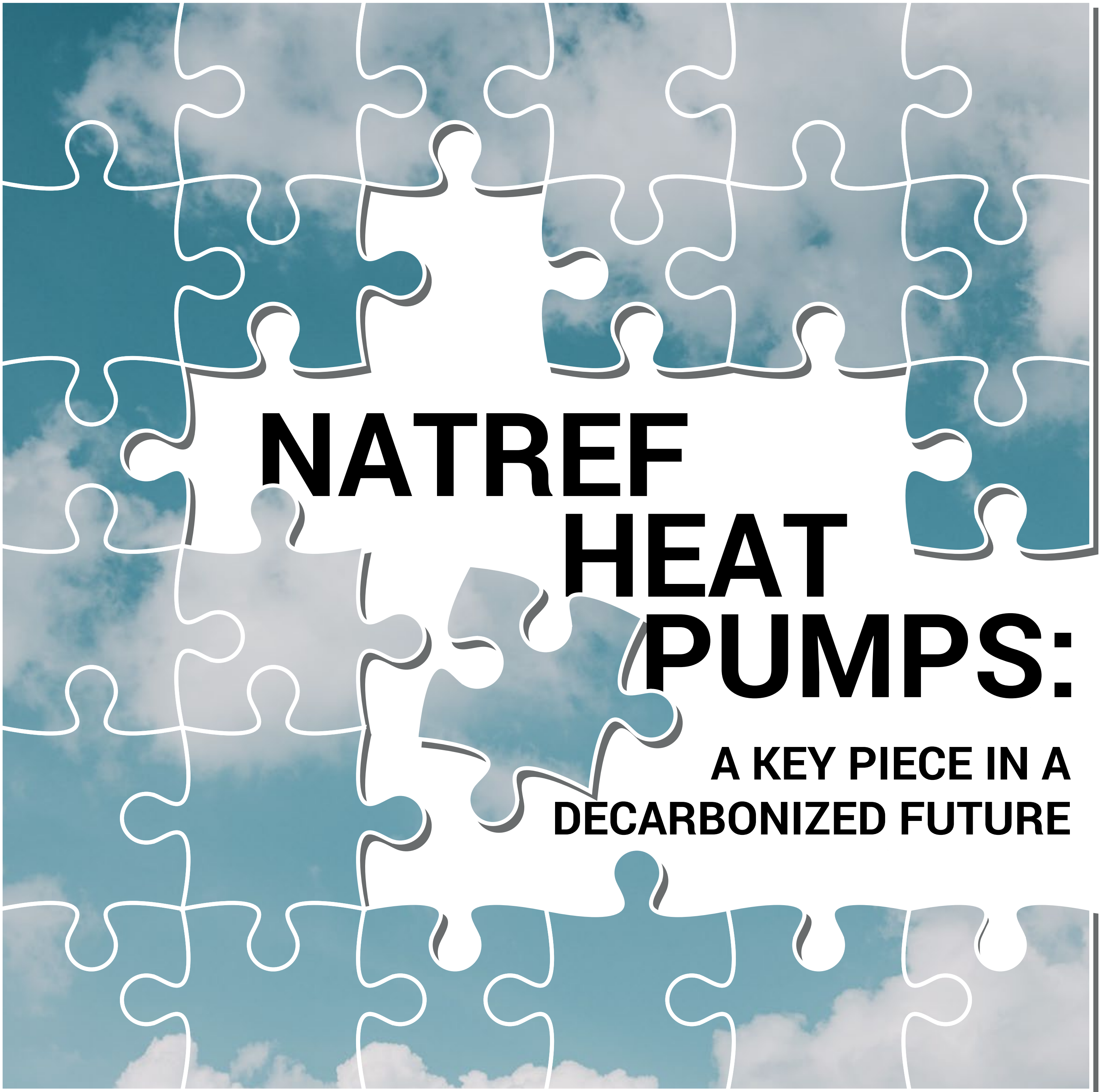


NATREF HEAT PUMPS:

A KEY PIECE IN A DECARBONIZED FUTURE

As buildings seek alternatives to fossil fuels for heating, electric heat pumps using CO_2 and other natural refrigerants are finding a growing market in North America

– By Michael Garry

For the past decade, Troy Davis, energy group manager for Mayekawa USA MYCOM, has been promoting the Japanese company's CO_2- and ammonia-based heat pumps for space heating and domestic water heating in North America.

But unlike in Japan and Europe, where heat pumps using natural refrigerants have been widely used in commercial and residential applications, the North American market has been difficult to penetrate. "Ten years ago, I thought we'd have thousands [in North America] by now," said Davis. Instead the number is about 25 CO_2-based UNIMO units.

But that's beginning to change.

Over the last four to six months, Davis has been getting "a lot of phone calls and emails" about a wide variety of heat pump applications, particularly from multi-family apartment buildings on the West and East Coasts of the U.S. seeking domestic hot water heaters. One example is Stuy Town, an apartment complex in Manhattan. Multi-family buildings are considering both water-source and air-source CO_2 units.

"CO_2 heat pumps are great for domestic hot water heating where you take cold water and heat it to a higher temperature," he said.

In general, Davis said he is seeing "huge potential" in the U.S. for heat pump technology using CO_2, and to a lesser degree, ammonia. "The market is untapped here," he said. "But things are starting to line up," though he acknowledged that Mayekawa needs to "fine-tune" its large Japanese units to make them a better fit for the U.S. market.

John Miles, general manager – eco systems, Sanden International (USA), said sales of home heat pumps (still largely for units using R410A) are "booming" in Northeastern U.S. states like Maine and Vermont, which are aggressively marketing the products with rebates. But heat pumps are still a small slice of the overall market for hot water heaters in the U.S.; for example, only 1,800 were sold in Connecticut in 2017.

Miles, who is marketing Sanden's CO_2 heat pumps for domestic water heating and space heating, has been crisscrossing the U.S. to train contractors and distributors, and raise awareness about the advantages of the technology.

For Sanden, the greatest growth for its CO_2 hot water heat pumps is in the commercial sector, which includes multi-family apartment buildings and restaurants, though that currently represents 40% of installed units compared to 60% for residential homes.

"Multi-family homes use more hot water and typically can see a quicker ROI than residential homes," noted Miles, adding that apartment buildings can amortize the capital cost of the equipment. Examples of multi-family homes using the Sanden equipment include Kingway Apartments in Seattle, Wash., and Edwina Benner Plaza apartments in Sunnyvale, Calif., both low-income housing complexes. (See, "Hot Water, Courtesy of CO_2" *Accelerate America*, January 2018.)

THE DECARBONIZATION MOVEMENT

Probably the biggest driver of the new interest in heat pumps is the growing movement toward "decarbonization" and "electrification" of building heating systems – switching from natural gas, oil or propane boilers to electric heat pumps – and the development of renewal energy sources like solar and wind energy to produce electricity for utilities.

SIlver Oak's winery in Healdsburg, Calif., which heats water with solar energy and CO_2 heat pumps

"Utilities are interested now in electrification [of heating in buildings]," Davis said. "They're promoting heat pump electrification and taking gas customers off natural gas or propane."

States, he added, will be hard-pressed to achieve their carbon emission goals "unless they do a lot more with heat pumps and other technology."

In April, Energy and Environmental Economics, a research firm based in San Francisco, Calif., issued a report, "Residential Building Electrification in California," which analyzed the economic, environmental and electric grid impact of converting from natural gas to electricity in California homes.

The report found that building electrification – substituting electric technologies like heat pumps for gas-burning ones like furnaces – "is a relatively low-cost, low-risk way to reduce California's building-related GHG [greenhouse gas] emissions."

Another California-based group, the Building Decarbonization Coalition, in February issued a report called "A Roadmap to Decarbonize California's Buildings" that lays out a plan for the state to cut building emissions 20% in the next six years and 40% by 2030. In the report, the group calls for an increase in the share of high-efficiency heat pumps for space heating from 5% of sales in 2018 to 50% in 2025 and 100% in 2030.

To make the switch to heat pumps possible, the California Public Utilities Commission is implementing SB (senate bill) 1477, which deploys $200 million in incentives for manufacturers and builders.

California is better prepared to make the transition to electrification because of its high usage of renewable energy. In 2018, California generated 34% of its electricity from renewable sources (solar, wind, geothermal, biomass and hydro), according to the California Energy Commission.

However, in the U.S. as a whole, only 17% of electricity came from renewables (and 19.3% from nuclear energy) in 2017, according to the U.S. Energy Information Administration. But even while the grid is largely linked to fossil fuels, an appliance with a COP (coefficient of performance) over 3.0 is "incrementally better [in terms of emissions] than burning natural gas in the home," said Miles.

The effort to decarbonize homes and transition to electric heat pumps is being opposed by the American Gas Association (AGA). Richard Murphy, managing director of energy marketing for AGA, argues that heat pumps are not competitive in colder parts of the U.S., according to a report in *E&E News.* AGA also contends that electrification of homes would raise average home energy costs up to 46%.

Miles noted that "the gas industry has to do everything it can to stop decarbonization as it threatens their very future." He added that new technology such as inverter compressors and improved controls "are providing much better heat pump performance in lower temperatures and we are slowly seeing this technology being applied."

The Sanden CO_2 heat pump's COP is 5.2 at an ambient temperature of 67°F, making it more efficient than other heat pumps and heating appliances. But its COP drops to 4.5 at 47°F, 3.0 at 23°F, 2.25 at 5°F and 1.6 at -20°F, which is its lowest operating temperature. Averaged over the entire winter, the COP is more favorable, noted Miles. By contrast, "the very best gas water heaters have a COP of 0.96 and can never get higher than 1.0," he said. On the other hand, the low cost of gas makes gas water heaters overall "a wash" cost-wise compared to the Sanden heat pumps.

About 20% of Sanden's North American installations, which number "a couple of thousand," Miles said, are used for both radiant space heating and domestic hot water in residential homes. One homeowner in the San Francisco area who installed Sanden's combination space heating-hot water heater system, and compared it to a previously used gas heating system, found a 74% drop in energy consumption (kBTU/day) and a 78% decline in GHG emissions (kgCO_2/day).

Haley Duncan, SIlver Oak Cellars

COOLING, TOO

In addition to providing heat, CO_2 heat pumps are used for cooling in some applications. "Everybody looks at hot water and cooling as separate, but there's a lot of potential in water source units to integrate the two," said Davis. "It really helps with the COP." At least 80% of Mayekawa's water-source units produce cooling that is leveraged rather than discarded, he said.

The use of cooling also helps produce an ROI for the water-source units, which Davis acknowledged can be a "little pricey." Compared to an electric-resistance water heater, the much more efficient CO_2 heat pumps offer a payback in 1.5 years. But the payback is much longer compared to a gas water heater because of the low cost of gas, he noted.

Sanden's heat pump water heaters, Miles acknowledged, are the most expensive water- heating products on the market, at about $3,000 per unit, compared to about $1,300 for traditional (HFC refrigerant) heat pump water heaters and $600 for gas and electric-resistance water heaters. Although Sanden's heat pumps are 30%-40% more efficient than conventional heat pump water heaters, "we need a dedicated home owner for ours," he said. "Water heating is a first-cost market."

But the cost of heat pumps in the U.S. is expected to drop as the market for them grows and manufacturers achieve economies of scale, according to the Rocky Mountain Institute.

Mayekawa also makes low-charge ammonia-based heat pumps for medium or large facilities like office buildings and industrial plants. To date, most have been deployed in Europe, the Middle East and Japan but Mayekawa has installed a few in North America food processing facilities. Ammonia would not have been considered a year or two ago in North America but that has changed with the advent of low-charge systems, more robust components, and semi-hermetic components that eliminate leak points, said Davis.

Davis sees "some potential" in North America for hydrocarbon-based heat pumps, which have a significant presence in Europe but not on this side of the pond. Isobutane, he noted, "is great for hot water heaters." But their prospects are constrained by very high costs in the U.S. where they have to be "explosion-proof," he noted.

MEETING THE LIVING BUILDING CHALLENGE

Silver Oak Cellars, a family-owned Northern California wine producer, is focused on making superb Cabernet Sauvignon, and doing so in the most environmentally friendly way possible.

Silver Oak's most recently constructed, facility is a 110,000-sq-ft production facility and tasting room, located in Healdsburg (Alexander Valley), Calif., that began operationsin 2017. It is the first new production winery to be designated LEED platinum, and is now being considered for an even more exacting certification by the Living Building Challenge, which will be determined in early 2020. (Silver Oak's other facility, in Oakville, Calif., was the first retrofit winery to achieve LEED platinum.)

To meet the Living Building Challenge (becoming the first winery to do so), Silver Oak chose two Mayekawa water-source CO_2 heat pumps (each providing up to 146.2 MBH on the hot side, with an average heating COP of 2.1), as well as a solar thermal heating system, in lieu of a traditional boiler system. The Living Building Challenge precludes combustion heating, but the winery was granted an exception to use a propane-fired boiler as a supplemental heating source during the harvest system (roughly August to November) when there is peak hot water demand.

"We're very invested in creating a system that has very little impact on global warming," said Haley Duncan, Silver Oak's project manager. "That's our motivation."

"Silver Oak made it clear early in the design process that they wanted to be the greenest winery in the world," said Andy Souza, licensed mechanical engineer and project manager for TEP Engineering, Santa Rosa, Calif. He worked with TEP Engineering president Rob Main on the design of the production facilities' water heating systems heating system at Silver Oak's Healdsburg facility.

The water heating system, supported by 2,595 solar voltaic panels and 48 solar thermal collectors across three building rooftops and the two CO_2 heat pumps, is designed to produce outlet hot water temperatures around 140°F that is used for barrel washing, fermentation tank cleaning, floor and equipment washdown. "Everything in a winery needs to be incredibly clean and sanitized," noted Duncan.

The facility also employs a membrane bioreactor to collect, clean and recycle the winery's process wastewater and turn it into essentially potable recycled water that can be used in floor rinsing and the initial washdown of barrels and tanks. This process vastly reduces Silver Oak's water usage.

The heat pumps and solar thermal systems handle two separate water flows for winery uses – one for recycled process water, which does most of the initial cleaning, and one for potable (not recycled) process water that is used for final rinse and washdown.

Domestic hot water, for the tasting room, employee showers and administration restrooms, is generated only by the solar thermal water heating system, with back up from a solar-powered electric water heater. There is also a separate glycol water flow used for heating and cooling of the fermentation tanks and barrel rooms, The heat pumps provide both the heating and cooling, with excess cooling rejected outdoors.

Initially, the incoming well water (about 50°F) is preheated by the heat exchanger coils inside of a large solar water thermal tank. "It would be ideal if we could get 140°F water out of the

CO_2 heat pumps at the SIlver Oak's Healdsburg, Calif., winery

solar tank all year long," said Souza. (Recently, the solar tank water reached 151°F.)

After the solar thermal heating process, the recycled water and the potable process water can pick up additional heat as needed via a separate heat exchanger fed by hot water from the CO_2 heat pumps, which raises the water temperature to 194°F. The extra heat is required when the solar thermal tank is not producing outlet temperatures of 140°F.

These water heating systems are managed by an elaborate building management system that logs data on water usage and sends out alerts to maintenance staff if something is amiss.

The equipment and installation cost of the systems was more than a conventional boiler setup, Duncan noted. But Silver Oaks cut its energy costs dramatically last year at the Healdsburg facility by generating 86% of its electricity from the solar panels; overall it achieved a 73.7% energy cost savings compared to similar buildings, said Duncan. With additional panels installed at a nearby warehouse, Silver Oak will be producing more than 105% of its energy from solar energy by the end of 2019, which is another requirement of the Living Building Challenge.

The elaborate hot-water system design "is the first combined solar thermal and CO_2 heat pump system] has ever been done that I'm aware of," said Souza. "It's one of the most complex projects I've worked on."

Duncan acknowledged that it took a while to get used to the complexity of the water heating system. "It was a big learning curve," she said. "But, overall, it has worked well for us."

SAVING ENERGY IN ALASKA

Another highly innovative project involving Mayekawa water-source transcritical CO_2 heat pumps took place in Seward, Alaska, where in January 2016 the 120,000-sq-ft Alaska SeaLife Center, an aquarium and research facility, installed four 20-TR units.

The grant-supported project, orchestrated by Anchorage, Alaska-based YourCleanEnergy, leveraged ocean water from nearby Resurrection Bay to heat glycol that supports the heat pumps. (See, Tapping CO_2 and Seawater in the Last Frontier," *Accelerate America*, May 2016.) It is one of the first examples in the U.S. of CO_2 heat pumps replacing conventional oil burners in a commercial facility.

A SANDEN TINKERER

On his website (http://greencomfort.nationbuilder.com), Dave Sweet calls himself an "eco-friendly homeowner and builder" whose goal is to "use as little energy as possible while maximizing comfort for my wife, my daughters and I."

Sweet, who has been building his own homes since the 1980s, described the steps taken in building his current (and ninth) home in Old Saybrook, Conn., in a series of videos on his website. One of the innovations was the installation of two Sanden CO_2 heat pumps outside the house to generate hot water and space heating. He's also using an induction cooktop and an electric fireplace, and generating more than half of his electricity from 42 solar panels (13 kW). "The idea was to totally decarbonize," he said.

Sweet admires the efficiency of the Sanden units, derived from the large differential (from 60°F to 100°F) between the temperature of the return water from the house and the temperature to which the temperature is heated in the units. Sanden's hot water temperature setting ranges from 130°F to 175°F.

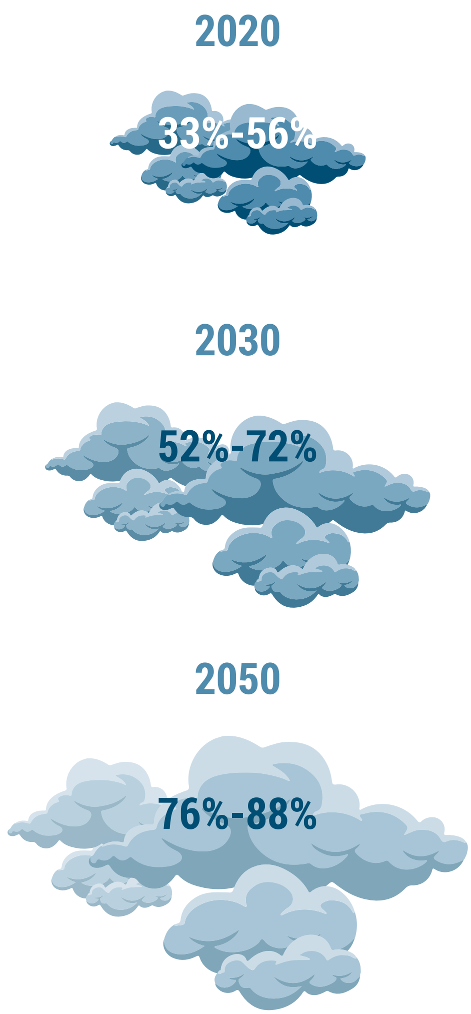
The standard Sanden system that supplies space heating and hot water employs only water, a water tank and a separate heat exchanger. Sweet created his own design that employs a glycol solution. "I'm a tinkerer," he said.

The heat pumps, each with a capacity of about 14,000 BTUs/hr, generate a hot glycol solution that is delivered to a 119-gal tank with a heat exchanger coil at the bottom, where potable water is heated and pumped out to the house. Separately, the heat pumps deliver heated glycol to the radiant heating systems in his home. He uses an electric element backup.

Though the Sanden units are more expensive than alternative heating systems, Sweet believes there is a good payback. "I can't imagine a conventional piece of equipment being able to do space heating and domestic hot water; this is the only product in that classification." He also recommends it as a domestic water heater only.

Sanden CO_2 heat pumps outside of Dave Sweet's home in Connecticut.

Percentage Drop in Greenhouse Gas Emissions As a Result of Switching from Natural Gas to All-Electric in California Single-Family Homes



Source: Energy and Environmental Economics, Inc.

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The project was driven by the SeaLife Center's need to replace its oil burners due to the skyrocketing cost of oil in Alaska, which has sub-arctic temperatures in the winter. By installing the heat-pump system – which handles a variety of heating loads, from outside pavements and domestic hot water to baseboards in offices and labs to coils in public areas – the facility was able to save $15,000 per month at existing oil and electricity rates, a savings that still holds. Absent grants, the $1.5 million project (including $200,000 for the four CO_2 heat pumps) would have an ROI of less than nine years, according to the Sealife Center.

The SeaLife Center initially purchased two 90-TR Trane heat pumps, but that still left 40% of its heating generated by an electric boiler. To handle higher-temperature loads, the Mayekawa CO_2 heat pumps were installed, cutting back the electric boiler's usage to 2%. The CO_2 units produce hot water at 194°F, with an initial COP of 2.25. Hot water is distributed in the facility through an elaborate network of water pipes architected by Andy Baker, owner of YourCleanEnergy, in a design that he dubbed "loopsametrics."

The power of the CO_2 heat pumps, Baker said, comes from their ability to raise the temperature of return water to 194°F with about the same energy input even as the return temperature drops (down to a minimum of 90°F at the SeaLife Center). "The Mayekawa units put out 194°F water no matter what you throw at it."

Initially the return temperature of the system, after supporting multiple loads, was 130°F, but additional loads would lower it further and raise the COP – with a minimal energy penalty, noted Baker. In 2017, the return temperature was lowered to between

Andy Baker, YourCleanEnergy

100°F and 110°F with the addition of a basement condensation load, raising the COP to 2.3; that makes the CO_2 system's energy consumption less than half the cost of an electric boiler and half the cost of an oil boiler, he said.

The system also provides cooling via ocean-warmed glycol (starting at 40°F) to fan coils in a mechanical room and an electrical room, boosting the temperature of the glycol and reducing the work required by the heat pumps. Baker is now overseeing the installation of fan coils in two more parts of the facility – a server room and a freezer room. The additional waste heat absorbed by the glycol in those rooms will allow the SeaLife Center to turn off the seawater flow in the summer for the CO_2 heat pumps, he noted.

This use of heat reclaim is important, he said, because it demonstrates how facilities that can't tap into ocean water heat can still employ CO_2 heat pumps.

Baker's next grant-supported project is to deploy six water-source Mayekawa CO_2 heat pumps to provide heating to four municipal buildings in Seward, Alaska – City Hall, City Hall Annex, the Community Library and Fire Hall. He expects the district-heating project to be completed by the end of 2019.

The heat pumps will be located in the library basement, with oil and electric boilers as a backup. Hot water will be circulated to the other three buildings through an Alfa Laval heat exchanger to prevent contamination of the heat pumps. Baker projects using the heat pumps for 80%-90% of the heating load in the buildings, and achieving a COP of 2.4, with the temperature of return water reaching 100°F "more consistently with big radiant heat loads in the library."

Source heat for the project will come from ocean tides in nearby Resurrection Bay, tapped through a 200-ft-deep closed glycol loop and delivered to the library 500 ft away. A nearby hydroelectric energy plant under consideration in Seward could be a future source of waste heat for the district-heating project.

It is estimated that the district heat pump system will save Seward $25,000 in annual heating costs compared to a fossil-fuel system – another step toward a decarbonized society. ■ MG

SMTI'S HEAT PUMP ALTERNATIVE

Stone Mountain Technologies, Inc. (SMTI), based in Johnson City, Tenn., is developing what it calls a "next-generation heating innovation" – a compressor-free, thermally driven heat pump that uses low-charge ammonia- water absorption, triggered by natural gas, to generate space heating and domestic hot water.

Having undergone a series of field tests in homes and restaurants, SMTI's residential space heating and water-heating systems are slated to hit the market in early 2021, said Scott Reed, SMTI's vice president of strategy and marketing. The restaurant unit, which also supplies cooling to the kitchen area, will have a later release, he said.

SMTI's systems will be marketed by an HVAC manufacturer that has not been named.

The units comes in different sizes and configurations, including a 10,000 BTU/hr heat pump attached to a water tank; an 80,000 BTU/hr combination space/domestic hot water unit; and a 140,000 BTU/hr system that can handle space heating and domestic hot water for light commercial applications. The COP is about 1.6 (2.0 in the restaurant application), said Michael Garrabrant, founder and CEO of SMTI.

Garrabrant sees the SMTI unit mainly competing against gas-fired water heaters and boilers, using half the gas with twice the efficiency. He contends that his system works better than an electric heat pump in cold climates where the heat pump's COP suffers. "We feel we have a better path forward to reducing carbon emissions for space heating in cold climates," he said.

The growth of renewable natural gas will help make SMTI's system a greener alternative, noted Reed. "Methane can be made in ways that are renewable and carbon neutral," he said.

SMTI ammonia-absorption heat pump