CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Conversion of Low-Value Waste Heat into High-Value Energy Savings

Energy Efficiency Project at Joseph Gallo Farms

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Natural Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with research, development, and demonstration entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater natural gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency.
- Industrial, Agriculture and Water Efficiency.
- Renewable Energy and Advanced Generation.
- Natural Gas Infrastructure Safety and Integrity.
- Energy-Related Environmental Research.
- Natural Gas-Related Transportation.

Conversion of Low-Value Waste Heat Into High-Value Energy Savings is the final report for the Joseph Gallo Farms natural gas energy efficiency project (Contract Number PIR-15-007). The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

The Joseph Gallo Farms project installed an innovative heat recovery technology to capture waste energy from two existing 800-kilowatt biogas engines. Joseph Gallo Farms uses the captured energy in several ways to provide significant electrical and natural gas savings at its cheese plant. The core technology was an ammonia-based, industrial grade, 250-ton ThermoSorber™ absorption chiller that efficiently converts captured waste heat for chilling to offset the existing electrical chilling load. The ThermoSorber technology produces two waste-heat streams used to preheat the process dryer and boiler feed water for natural gas savings of roughly 20 percent when compared to the baseline. The project also provided 80 percent electrical savings on average compared to the baseline electrical chilling demand. The electrical and natural gas savings exceeded predicted annual 1,300 gigawatt-hours and 186,000 therms. These results demonstrate to the food processing industry an innovative, environmentally sustainable, and financially feasible use for energy that would otherwise be lost.

Keywords: Absorption, chiller, ammonia, ThermoSorber, natural gas, efficiency, waste heat, biogas, combined heat and power, CHP

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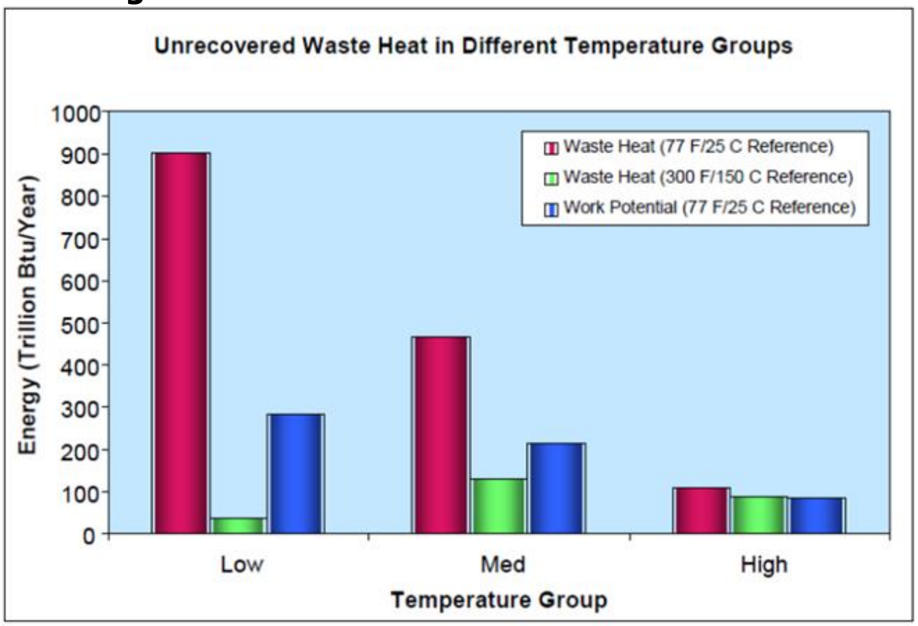
EXECUTIVE SUMMARY

Introduction

According to a recent research study conducted by the United States Department of Energy, the U.S. industrial sector produces an estimated 900 trillion British thermal units (Btus) of "low-temperature" waste energy each year. Waste energy produced at these low temperatures of less than 450°F is difficult to capture and implement in a useful way. The study did not identify the waste energy by state, but based on natural gas consumption by California's industrial sector (10.3 percent of U.S. industrial natural gas demand), an estimated 90.9 trillion Btus or 909 million therms of natural gas is lost in the low-value waste heat streams in California industries (Figure ES-1).

Figure ES-1: Waste Heat of US Industrial Sector



Source: U.S. Department of Energy

Furthermore, in a case study on absorption chiller technology by KEMA, Incorporated supported by the California Energy Commission (CEC), more than 26,000 commercial and industrial facilities need heating and cooling in the United States. The total estimated annual energy use at these facilities was 303 million therms of natural gas and 25,985 gigawatt-hours (GWh) of electricity. Because absorption chiller technology is currently most cost-effective in larger industrial facilities, the KEMA study concluded that there are 3,700 industrial facilities that employ more than 20 workers that would be the ideal target market.

Absorption chillers can use low-temperature waste heat to accommodate the chilling and heating needs of industrial processing. The conclusion of these case studies demonstrate a considerable market opportunity for absorption chiller technology that can demonstrate successful use of low-temperature waste heat to reduce the thermal and electrical energy demand in California's industrial sector.

Project Purpose

This project demonstrated an innovative, financially feasible, and environmentally friendly solution to capture low temperature waste heat and used the captured energy where it had the most industrial value in food processing.

The core technology for this project is the ammonia-based ThermoSorber™ absorption chiller manufactured by Energy Concepts Company. Absorption chillers use the input of a hot fluid to cool another fluid by manipulating phase changes (liquid to vapor and back). The standard lithium bromide absorption chiller technology has historically dominated the field. While this design is theoretically more efficient and cheaper than the ammonia-water technology used by ThermoSorber, lithium bromide systems have several limitations. First, lithium bromide crystallizes if conditions are not kept within narrow operating parameters. Consequently, these units cannot operate when it is too hot or too cold and therefore cannot be installed outdoors. Second, these systems must operate in a vacuum, so there are a variety of air leak concerns, especially as the equipment gets older. Finally, with chilling temperature minimums of 48°F, the lithium bromide systems cannot provide the level of cold chilling often needed in industrial settings. Consequently, it is difficult for lithium bromide systems to operate dependably in industrial environments. These limitations have severely hindered the market for absorption chillers, slowed the adoption rate, and curbed installations to space cooling, instead of the more valuable industrial process chilling that ammonia-based absorption chilling can support.

The ammonia-based ThermoSorber absorption chiller technology solves the problems presented by the lithium bromide technology and successfully demonstrates a stable, environmentally friendly, and economically beneficial use for absorption chiller technology in an industrial setting. The ammonia-based absorption chiller technology can deliver temperatures as low as -50°F, which greatly increases the possible food processing applications for this technology. The technology is also more industrially robust and dependable because it does not require a vacuum to operate. Finally, the ammonia-water mixture will not crystallize in ambient temperatures so the technology can be installed outdoors (as demonstrated by this project).

Project Process

Demonstration Site

The researchers chose the demonstration site for this technology, the Joseph Gallo Farms cheese plant in Atwater, California, for its existing waste-heat availability and large onsite chilling demand. The plant operates an anaerobic manure digester that produces biogas to run two 800-kilowatt (kW) gensets (the pairing of an internal combustion engine with an electric generator) to offset the electrical load of the plant. Waste heat from these gensets exits as exhaust gas and engine jacket water. While the plant already captured some of the waste heat before this project to create process heat, a significant amount of waste heat energy was still being lost to the atmosphere.

Project Team

The project team designed the Conversion of Low-Value Waste Heat Into High-Value Energy Savings project in conjunction with Joseph Gallo Farms and Maas Energy Works Inc. with engineering support from VVH Consulting and monitoring support from Enovity Inc. Several California contractors provided site construction and equipment installation.

Waste-Heat Collection

The first stage of the project was to collect the waste heat from the existing biogas gensets. The project team performed this stage in several steps. First, the two existing 800-kW biogas-powered gensets were cooled with "jacket water" cycling through channels in each engine collecting combustion heat. This jacket water is a 50/50 water-to-glycol mixture that normally operates with a flow rate of 250-350 gallons per minute (GPM) at temperatures ranging from 160°F to 185°F and functions as a heat exchanger to cool the engine and maintain proper operating conditions. After exiting the gensets, the jacket water is then normally cycled through radiators to vent heat to the atmosphere.

The project design proposed deviating from normal operations to maximize the value of this waste heat stream by (1) increasing the jacket water temperature to enter each genset at a starting temperature of 190°F, which required the flow rate of the jacket water to be increased to a peak flow rate of 400 GPM, and (2) upgrading the oil coolers of each engine to ensure that the engines didn't overheat with the new higher operating temperatures. The resulting wastewater stream exiting each genset was estimated to be 200°F-208°F.

The second step was to capture heat from the exhaust of each engine and add it to the water stream. The design called for installing an additional exhaust economizer on top of each genset to capture and transfer the heat from the exhaust to the jacket water. These steps were meant to increase the temperature of the waste heat stream to more than 209°F.

Waste-Heat Use

The project included a multistage energy use system to use the recovered energy to maximize the environmental and financial benefits obtained from the waste heat sources.

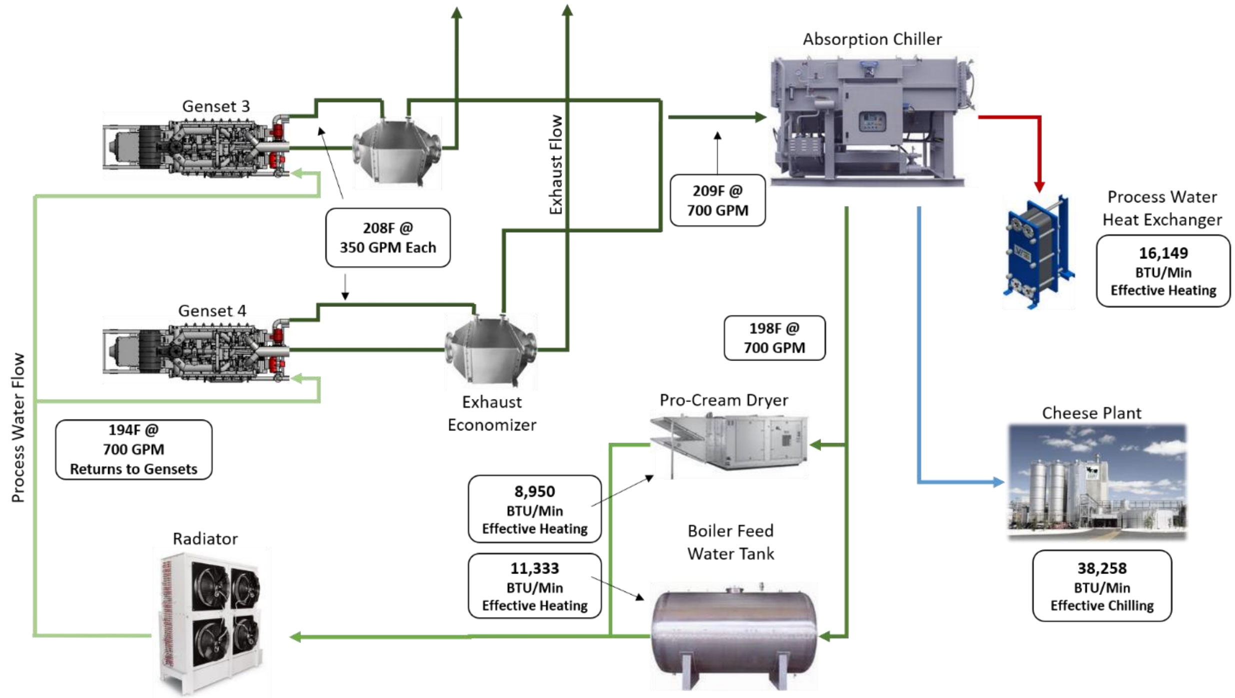
The heated process water stream was piped to an ammonia-water ThermoSorber absorption chiller to produce up to 250 tons of chilling, depending on time of day, for the cheese-making process. The plant received chilling at 32°F-38°F, the lowest temperature, and therefore highest value the facility can employ. The project team modified Joseph Gallo Farms' existing chilled glycol tank to be able to receive the new chilling provided by the ThermoSorber equipment.

After exiting the absorption chiller, the process water still contained significant energy at nearly 198°F. This waste-heat stream was piped to the newly installed heat exchangers to preheat the water in the boiler feed tank for the natural gas-powered steam boilers of the plant.

Finally, by repurposing an existing radiator, the project team cycled the process stream through the natural gas-fired process dryer to preheat air to dry procream (a protein-cream byproduct) resulting in additional natural gas savings. The resulting process water was then pumped back to the gensets to start the cycle over again with little to no heat lost to the atmosphere. The innovative design of the project to maintain the engine and waste heat in this desirable temperature range enabled more beneficial use.

In addition to chilling, the ThermoSorber created a separate low-value stream of 90°F-95°F waste heat. The project team designed the project to preheat well water being fed into the cheese plant for additional natural gas savings. A complete schematic drawing of the various waste-heat sources and uses is shown in Figure ES-2.

Figure ES-2: Waste-Heat Sources and Uses



Source: Maas Energy Works, Inc.

Project Results

Natural Gas Savings

The CEC asked the project team to report natural gas savings in therms per unit of product. The project team compared the monthly natural gas usage for the boiler and the procream dryer in the baseline year and production year and divided it by the total pounds of cheese the plant produced in each respective month. These savings resulted in an annual average of 1.45 therms of natural gas per 100 pounds of cheese produced, or 19,527 million Btus (MMBtus) per year.

Electrical Savings

After the ThermoSorber was installed and fully operating, Enovity measured the average power, chiller percentage on time, and average monthly electrical energy usage in kilowatt-hours (kWh) of the existing chillers and compared it to the 2016 established baseline. The research team used the difference between current monthly consumption of the chillers compared to the monthly baseline electrical consumption to calculate the percentage savings.

The results were substantial with the average monthly electrical usage decreasing from 145,840 kWh to 30,404 kWh. This decrease represents average monthly savings of 115,436 kWh or 1,385,227 kWh per year.

Benefits to California

Economic Sustainability

The project yielded energy savings of 19,527 MMBtu of natural gas and 1,385,227 kWh of electrical savings in the first year of operation. Using baseline historical costs of $4.49 per MMBtu of natural gas and $0.28 per kWh of electricity, the project team calculated the economic sustainability of the project for Joseph Gallo Farms. The resulting annual natural gas savings are $87,676 and electrical savings are $387,863, for total gross annual savings of $475,539. The operational expenses of the project are minimal at $25,568 per year. Total net annual savings of the project are $449,972. These savings yield a payback period of 3.5 years and an extremely favorable cost-benefit ratio that highly encourages the Gallo cheese plant to continue long-term project operations and upkeep. These results also demonstrate to the California industrial sector an economically beneficial means of reducing energy consumption.

Environmental Impacts

The annual natural gas and electric savings of the project are 19,527 MMBtu and 1,385,227 kWh per year as discussed above. Using conversion rates published by the U.S. Environmental Protection Agency of 117.08 lbs. carbon dioxide equivalent (CO_2e) per MMBtu and 1,559 lbs. per MWh, the total greenhouse gas reductions are 4,445,790 lbs. CO2e per year, a significant reduction in annual greenhouse gas emissions that is consistent with California's greenhouse gas reduction goals and beneficial to all Californians.

Possibilities

The project demonstrates that absorption chilling can work in a farm environment and provides the statistical information to estimate the benefits and payback prior to project installation. Furthermore, the project demonstrated an innovative way to collect waste heat in multiple stages and use the captured energy in the most economically beneficial form. The most natural expansion of this demonstration project would be to implement absorption chillers at all dairy farms because all such farms have manure (to create generator fuel) and milk (which needs to be chilled). This demonstration project was located at a large cheese processing plant with a very large chilling demand. The site was able to use all the available waste energy to create savings — enough savings that the project payback is commercially compelling. Most dairy farms do not demand nearly as much electricity or natural gas for on-site processes. However, Energy Concepts estimates that smaller systems could be manufactured to meet this demand at roughly $2,500 per ton of chilling, which is still comparable to the competing lithium bromide absorption chiller technology that ranges from $1,600 to $3,300 per ton of chilling. Even at the scale at which it was built, the possibilities are very broad for food processors and other industrial customers. It is unnecessary to limit the applications to biogas-fueled gensets; diesel- or natural gas-fueled engines could also be far more profitable and sustainable through harvesting the waste energy created by these systems.

Since the project was completed, the project team has marketed the ThermoSorber technology to several food processors. This industry has the most potential for cost effectiveness if it has unused, low grade waste heat and a need for both heating and cooling. Despite the marketing and the potential for grants through various state and utility programs, uptake of the technology has been slow. Recently, a California food processor indicated interest in installing a ThermoSorber. The plan is to capture the waste heat from internal combustion engine exhausts to operate two absorption chillers. The project is planned for completion in 2021.

CHAPTER 1: Background

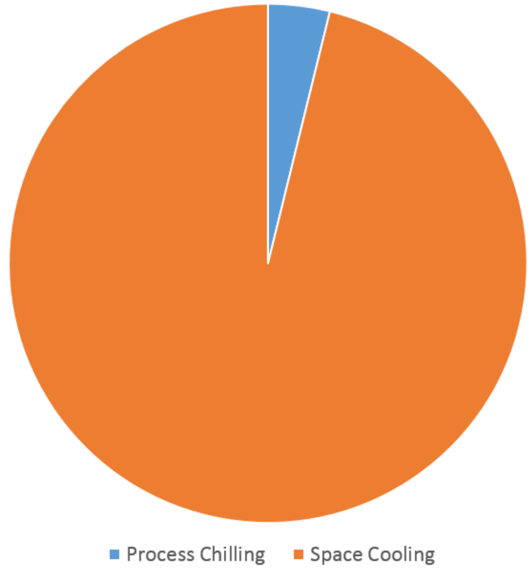
Introduction

The Joseph Gallo Farms cheese plant is an industry leader in demonstrating environmentally responsible and sustainable technology at a food-processing plant. The plant has received environmental awards, including the U.S. Dairy Sustainability Award and the Governor's Environmental and Economic Leadership Award. The cheese plant operates an anaerobic manure digester that powers two 800 kilowatt (kW) gensets to offset the electrical load of the plant. Waste heat from these gensets exits as exhaust and jacket water. While some of this waste heat was already being captured before this project to create process heat, a significant amount of energy was still being lost to the atmosphere. The "Conversion of Low-Value Waste Heat Into High-Value Energy Savings" project demonstrates an innovative, financially feasible, and environmentally friendly solution to capturing this waste heat for use where it has the most industrial value in a food-processing setting. The core technology for this project is the ammonia-based ThermoSorber™ absorption chiller technology.

Absorption Chiller Technology

Absorption chiller technology has been historically dominated by the standard lithium bromide absorption chiller technology. This technology uses lithium bromide as the absorbent fluid and water as refrigerant. This design is theoretically more efficient and cheaper than the ammonia-water model used by ThermoSorber, so major producers such as Trane have adopted the lithium bromide technology. However, lithium bromide crystallizes if the conditions are not kept within narrow operating parameters. Consequently, these units cannot operate when it is too hot or when it is too cold, and it cannot usually be installed outdoors. Transient operational conditions can lead to crystallization, meaning these systems can be installed only where loads are steady and predictable, with no quick start-ups or shutdowns. Furthermore, these systems must operate in a vacuum, so there are a variety of air leak concerns, especially as the equipment ages. Finally, the lithium bromide systems are not able to provide cold chilling that is often needed in a food processing setting, with chilling temperature minimums of 48°F. Consequently, lithium bromide systems have difficulty delivering dependable duty in industrial environments. Industrial food processors require very cold, reliable chilling and will not invest in systems that cannot perform under real-world operating conditions. These limitations have slowed the adoption rate and severely limited the market for absorption chillers to space cooling, as shown in Figure 1, with only a small share in the more valuable process chilling that ammonia-based absorption chilling can support.

Figure 1: Current Industrial Applications of Absorption Chillers



Source: Maas Energy Works, Inc.

The ammonia-based ThermoSorber absorption chiller technology solves all the problems presented by the lithium bromide technology and successfully demonstrates a stable, environmentally friendly, and economically beneficial use for absorption chiller technology in a food-processing setting. First, the ammonia-based absorption chiller technology can deliver temperatures as low as -50°F, which greatly increases the possible food processing applications for this technology. Second, this technology does not require a vacuum to operate, so it is more industrially robust and dependable. Finally, the ammonia-water mixture will not crystallize in ambient temperatures, so the technology can be installed outdoors (as was demonstrated by this project).

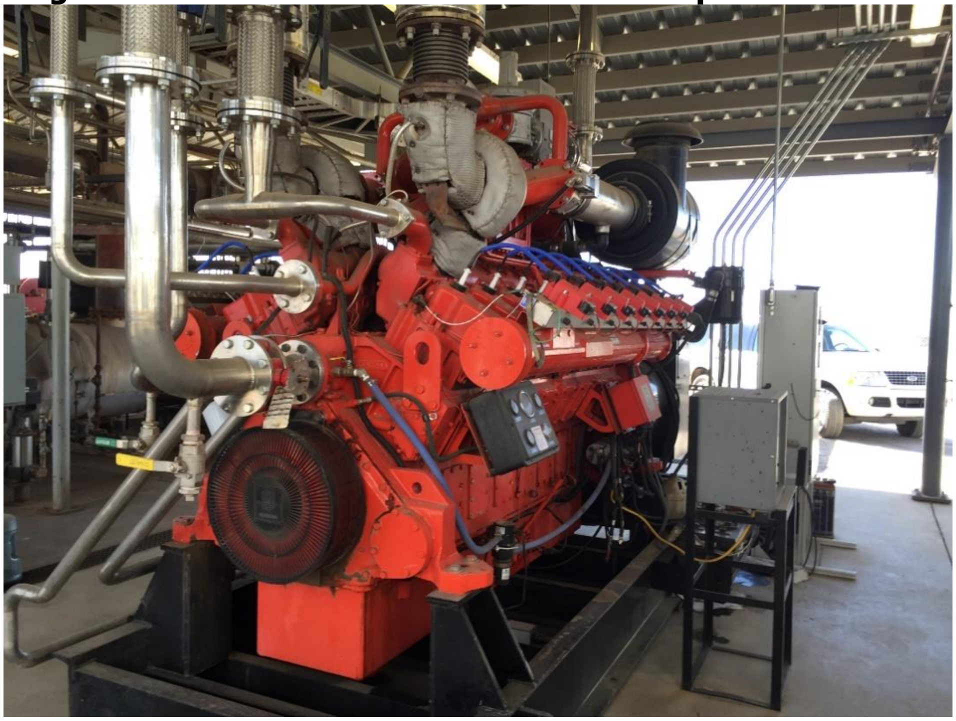
Existing Installed Equipment

There is a variety of previously installed equipment at Joseph Gallo Farms that was involved in this project, including two biogas engines, boiler, seven electrical chillers, and a procream dryer.

Biogas Engines

Joseph Gallo Farms operates an anaerobic manure digester that powers two 800 kW biogas engines that generate renewable electricity to offset the electrical load of the plant (Figure 2). These engines were the primary source of the waste energy used for this project by capturing waste heat from the exhaust and jacket water from each genset. Each biogas genset uses jacket water (50/50 glycol to water mixture) to cool the engine. This jacket water has a flow rate of 250-350 gallons per minute (GPM) with output temperatures from 160°F to 190°F. Moreover, the biogas gensets have an exhaust temperature output of greater than 750°F. Joseph Gallo Farms had already installed exhaust economizers to capture a portion of the value of the exhaust waste energy. However, the resulting exhaust was still being vented at 375°F, so it still had value that could be captured. The flow rate of the exhaust is 2,112 dry standard cubic feet per minute (DSCFM).

Figure 2: 800 KW Genset Installed at Joseph Gallo Farms

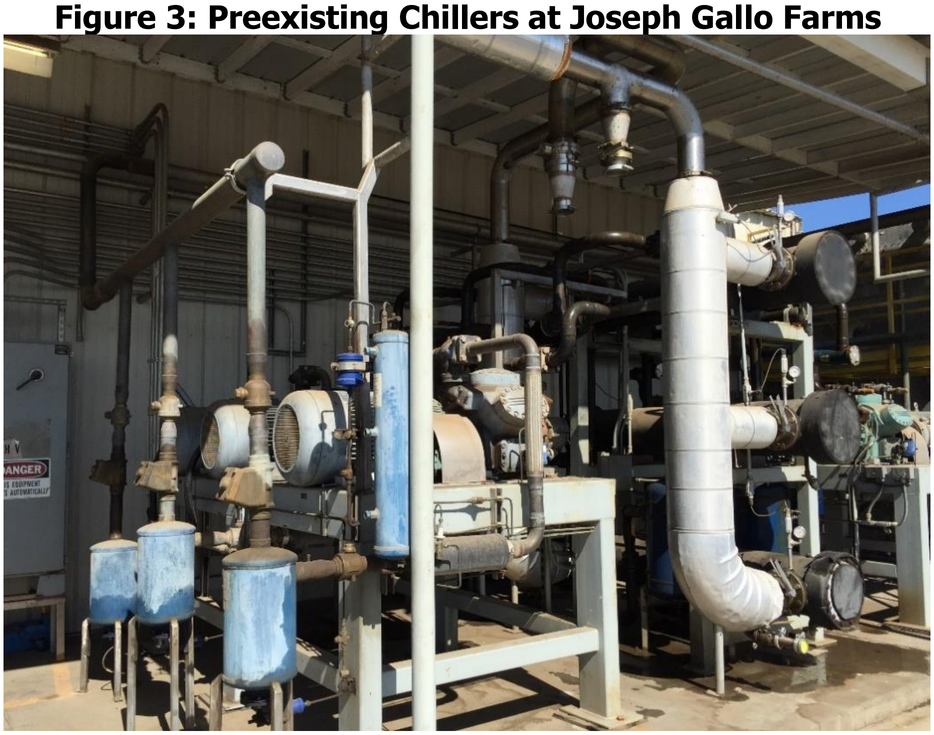


Source: Maas Energy Works, Inc.

Electrical Chillers

Joseph Gallo Farms has 192,000 gallons of silo storage for milk, whey, and cream that have to be chilled to temperatures of less than 40°F. The facility uses six electrical chillers to ensure these loads can be met regardless of the high average ambient temperatures with chilling loads of 58 tons per unit. Figure 3 shows the preexisting chillers at the Gallo plant.

Figure 3: Preexisting Chillers at Joseph Gallo Farms



Source: Maas Energy Works, Inc.

Procream Dryer

The procream dryer is used to produce powdered creamer at the cheese plant. This equipment uses natural gas to heat the air inside the dryer.

Boiler

Finally, the Gallo plant operates two industrial boilers (Iron Fireman Boiler and Dixon Boiler) that provide process heat to the facility. These boilers also consume natural gas.

Baseline Natural Gas

To determine the effectiveness of the project, the monthly natural gas consumption of the Iron Fireman Boiler, Dixon Boiler, and process dryer was measured using existing flow meters. Table 1 shows the results. Average monthly natural gas usage at the facility was 147,989 therms.

Table 1: Baseline Natural Gas Usage

Month	Iron Fireman Boiler (therms)	Dixon Boiler (therms)	Pro-Cream Dryer (therms)	Total
Jan 2016	23,636	26,506	26,088	126,372
Feb 2016	31,178	29,994	27,486	149,830
Mar 2016	33,951	29,914	29,259	156,989
Apr 2016	31,381	28,328	26,939	146,357
May 2016	33,502	32,982	28,330	161,298
Jun 2016	26,025	29,551	23,312	134,384
Jul 2016	28,105	34,221	25,936	150,588
Aug 2016	26,188	31,739	26,858	142,712
Sep 2016	25,653	31,315	24,713	138,649
Oct 2016	35,204	24,335	30,080	149,158
Nov 2016	35,651	22,568	28,215	144,653
Dec 2016	42,848	27,154	34,875	174,879
Total	373,322	348,567	332,091	1,775,869
Monthly Avg	31,110	29,047	27,674	147,989

Source: Enovity Inc.

Since the natural gas usage of the facility fluctuates with the amount of cheese production, the baseline numbers were normalized to the amount of cheese production (lbs.) for each corresponding baseline month. Table 2 shows the results.

Table 2: Baseline Natural Gas Usage per Unit of Cheese Produced (Therms/Lb.)

2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Preinstall Boiler Gas Therms/Unit Cheese (2016)	0.0126	0.0140	0.0140	0.0144	0.0131	0.0152	0.0154	0.0130	0.0146	0.0129	0.0133	0.0155
Preinstall Dryer Gas Therms/Unit Procream (2016)	0.091	0.095	0.083	0.089	0.091	0.082	0.081	0.073	0.075	0.086	0.090	0.104

Source: Enovity, Inc.

Baseline Electrical Usage

To determine baseline electrical usage for the chilling loads of the plant, third-party monitor Enovity Inc. was contracted to install electrical meters to isolate the seven existing chillers at the Gallo cheese plant. The meters were monitored for three months and measured for the percentage of time that the existing chillers were powered on and their average electrical load. Table 3 shows the results.

Table 3: Baseline Chilling Electrical Usage

Usage	2016 Baselin
Average Monthly kWh	145,840
Average Power (kW)	225
Chiller Percent ON Time	87%

Source: Enovity, Inc.

CHAPTER 2: Project Conception and Design

Goals

The project goals were to:

1. Install a comprehensive system to recover low-value waste heat from existing renewable energy equipment.
2. Use the recovered energy to offset high-value energy loads in an industrial food-processing setting.
3. Demonstrate to the industry an environmentally friendly and financially beneficial use for waste energy that would otherwise be discarded.

Objectives of Agreement

To accomplish these goals, the project team set the following objectives for the project:

4. Replace inefficient heat-shedding equipment with emergent energy recovery and reuse devices to capture waste hot water and exhaust energy streams of 86,250 BTU/min of usable energy.
5. Beneficially use all recovered heat in a manner that maximizes the value of each type of energy. Beneficial uses will include industrial chilling, boiler and cleaning water preheating, preheating pasteurization, and drying of food products.
6. Reduce total site natural gas consumption on site by 18,600 MMBtu per year or 23.5% of total plant natural gas usage.
7. Reduce total site electrical consumption on site by 1.3 million kWh or 38% of total plant electrical usage.
8. Reduce total site greenhouse gas emissions by 2,000 metric tons of CO_2e per year.
9. Create and disseminate quantifiable evidence of high-value energy savings from industrial waste heat recovery at a high-profile commercial cheese production facility.

Project Design

The project team designed the project in two-stages: waste-heat collection and waste-heat implementation. The predesign for both is discussed below.

Waste-Heat Collection

The first stage of the project was to collect the waste heat from the exhaust and jacket water of the existing biogas gensets. The project team performed this task in several stages:

The two existing 800 kW biogas-powered gensets were cooled using "jacket water" that cycles through each engine collecting heat. This jacket water was a 50/50 water-to-glycol mixture that normally operates with a flow rate of 250-350 gallons per minute (GPM) at temperatures ranging from 160°F to 185°F. After exiting the gensets, the jacket water was then normally cycled through radiators to vent heat to the atmosphere.

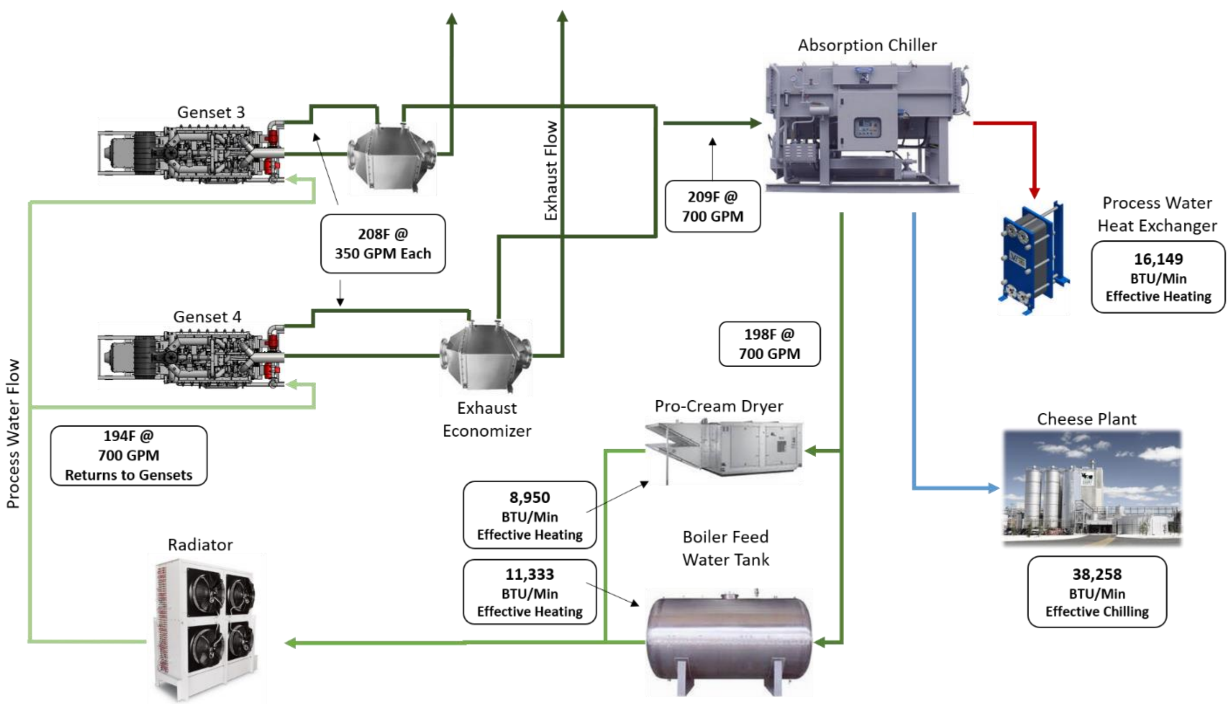
The project design proposed to deviate from normal operations in a couple ways to maximize the value of this waste heat stream. First, the jacket water temperature was increased to enter each genset at a starting temperature of 190°F. This temperature increase required that the flow rate of the jacket water be increased to a peak flow rate of 400 GPM. Furthermore, the project team had to upgrade the oil coolers of each engine to ensure that the engines didn't overheat with the new higher-operating temperatures. The resulting wastewater stream exiting each genset was estimated to be 200°F-208°F.

The next step of the design was to capture heat from the exhaust of each engine and add it to the water stream. The design called for an additional exhaust economizer to be installed atop each genset to capture and transfer the heat from the exhaust to the jacket water. This task would increase the temperature of the waste heat stream to temperatures greater than 209°F.

Waste-Heat Implementation

To employ the recovered energy, the project used a four-stage energy employment system to maximize the environmental and financial benefits obtained from the waste heat sources (Figure 4).

Figure 4: Waste Heat Stream Sources and Uses



Source: Maas Energy Works, Inc.

The project team piped the process water stream to an ammonia-water ThermoSorber absorption chiller from the point of highest temperature to produce up to 250 tons of chilling, depending on time of day, for the Joseph Gallo Farms cheese plant. The plant will receive chilling at 32°F-38°F, the lowest and therefore highest value the facility can employ. The team modified Joseph Gallo Farms' existing chilled glycol tank to be able to receive the new chilling provided by the ThermoSorber equipment. A stream of hot water was also produced from the absorption chiller. This stream went to a heat exchanger at 87°F in the cheese plant to offset 16,150 Btu/minute of natural gas heating.

After exiting the absorption chiller, the process water still contained significant energy at about 198ºF. A portion of the waste-heat stream was piped to the newly installed heat exchangers to preheat the water in the boiler feed tank for the natural gas-powered steam boilers of the plant.

The remaining portion of the process stream was cycled through the procream dryer of the plant to preheat air for a natural-gas fired process dryer, resulting in additional natural gas savings. The resulting process water was then pumped through a backup radiator and back to the gensets, where the cycle started again without venting much, if any, heat to the atmosphere. The innovative design of the project to maintain the engine and waste heat employments in this high-temperature range enabled it for more beneficial uses.

In addition to chilling, the ThermoSorber created a separate low-value stream of 90°F-95°F waste heat. Initial designs planned to pump this water to the cheese plant to preheat the milk being fed into the milk pasteurization equipment. However, the California Department of Food and Agriculture had concerns about milk contamination, so the project team changed the design to instead preheat well water being fed into the cheese plant for additional natural gas savings. Due to the energy balance of the system, the process water returning to the gensets at 194ºF cannot be used to also preheat the well water.

Energy Balance Transfer

A key element of the design was tracking the balance of energy including calculating the correct amount of energy available, deciding on the best design to effectively capture that available energy, and designing the most efficient way to use that energy.

As discussed above, the jacket water temperature was allowed to run hotter than normal at an average input temperature of 194°F. The water stream entered the genset at an average flow rate of 350 GPM. Assuming an average engine load of 80%, the jacket water recovered up 37,875 BTU/min per genset, which increased the water temperature to an average 207.5°F.

After exiting the gensets, the water was then sent to the exhaust economizer, where it recovered an additional 5,250 BTU/min per genset. This increased the water temperature to an average temperature of 209.3°F. See Figure 5 for calculations.

This "hot water" loop was then pumped via insulated stainless-steel piping to the ThermoSorber. The absorption chiller converted the heat to 38,258 Btus of effective chilling for the cheese plant that was transferred to the "chilling loop" within the ThermoSorber. The chilling loop was pumped underground via high-density polyethylene (HDPE) piping to the glycol tank-chilling reservoir for the cheese plant.

Figure 5: Energy Balance – Waste Heat Sources

Jacket Water (JW) Cycle – **Waste Heat Sources**

Genset	JW Flow Rate (GPM)	JW Temp In (F)	Engine Load (%)	JW Temp Out (F)	Exhaust Economizer Outlet (F)
Genset 3	350	194.0	80%	207.5	209.3
Genset 4	350	194.0	80%	207.5	209.3

Waste Heat Sources

Engine Jacket Water (Heat Source)

Genset	JW Flow Rate	Input Deg (F)	Engine Load (%)	BTU/min Recovered
Genset #3	350	194	80%	**37,875**
Genset #4	350	194	80%	**37,875**

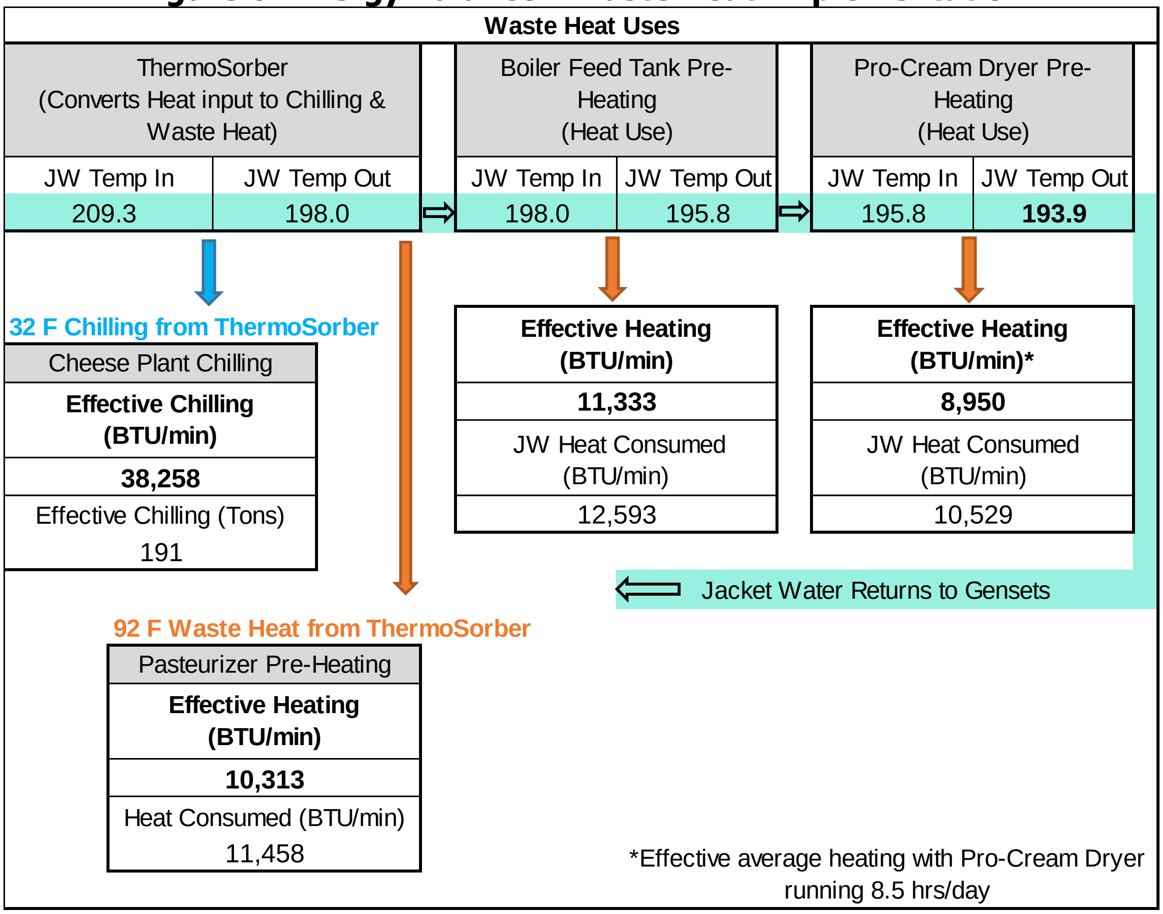
Engine Exhaust (Heat Source)

Genset	Temp In (F)	Temp Out (F)	Flow Rate (DSCFM)	BTU/min Recovered
Genset #3	375	250	2112	**5,250**
Genset #4	375	250	2112	**5,250**

Source: Maas Energy Works, Inc.

The hot-water loop exited the ThermoSorber at an average temperature of 198°F and was cycled to the boiler feed tank and the procream dryer. Using a standard heat exchanger unit from MEGS LLC, an average of 11,333 Btus/min was transferred to the boiler feed water. Moreover, the hot-water loop was cycled through the procream dryer to preheat the air, providing an additional 8,950 Btu/min. of heating for that unit. As demonstrated in Figure 6, once the hot water loop cycles through all three sources, the water returned to the starting temperature of 194°F and was pumped back to the gensets to restart the loop.

Figure 6: Energy Balance - Waste Heat Implementation



Source: Maas Energy Works, Inc.

Technical Advisory Committee

Once the CEC approved the initial design, the project team presented it to the technical advisory committee (TAC). The committee consisted of Craig Hartman, P.E., of Hartman Engineering; Kamesh Gupta, P.E., of GTech Global; and Vince Furtado with F&R Ag Services. The TAC meeting was held November 1, 2016. Committee members approved the overall design and gave feedback regarding project operational safety and the potential water savings benefits of the absorption chiller technology if installed at California dairies. Their suggestions were incorporated into the final design.

CHAPTER 3: Project Implementation

Implementation Plan and Project Team

The authors constructed the project using proven engineers and contractors, each with extensive experience for their respective project role. Gallo Cattle Company (dba Joseph Gallo Farms) was the project owner. Gallo's on-site project manager was Kenneth Weaver who worked with all contractors to coordinate facilitate construction of the project.

- Weaver contracted Daryl Maas of Maas Energy Works Inc. to help secure project funding, prepare project design, work on procurement, coordinate third-party monitoring, track the budget, report the project, and transfer knowledge.
- The project engineer was Michael Hayes, P.E., of VVH Consulting, with assistance from Aaron Casados, P.E. They were responsible for surveying and drafting construction drawings.
- Harelson Mechanical was hired as the mechanical construction contractor, including earthwork and piping.
- The project team contracted Phase 1 Construction to do excavation and construction of the concrete pad where the equipment will be installed.
- PetroChem was responsible to insulate the newly installed pipe to ensure the least amount of energy was lost to the atmosphere.
- Industrial Electric assisted the project team with installing electrical controls, sensors, and automation controls.
- Enovity Inc. was hired as the third-party monitor who was responsible for providing the project team with baseline electrical and natural gas measurements prior to construction and providing monthly monitoring after project startup.
- Finally, Electric Innovations, the California distributor for Energy Concepts Inc., manufactured and designed the prime technology of the project, the 250-ton, ammonia-based, industrial-grade ThermoSorber absorption chiller.

Project Schedule

The CEC project schedule for all tasks and products was:

in Table 4, along with all dates of submission and completion.

Table 4: Schedule of Deliverable Energy Commission Products and Meetings

Task #	Task Name	Product	Due Date	Submitted / Completed
1.2	Kick-off Meeting	Kick-off Meeting Agenda	7 days prior to the kick-off meeting	6/20/2017
1.2	Kick-off Meeting	Kick-off Meeting • Updated Project Schedule (if applicable) • Updated List of Match Funds (if applicable) • Updated List of Permits (if applicable)	Meeting: 6/22/2016 Products: 7 days after determination of the need to update the documents	Meeting: 6/22/2016 Products: 8/23/2016
1.3	CPR Meeting	CPR Meeting #1	7/20/2017	7/20/2017
1.3	CPR Meeting	CPR Report	15 days prior to the CPR meeting	7/31/2017
1.3	CPR Meeting	CPR Agenda	5 days prior to the CPR meeting	7/17/2017
1.3	CPR Meeting	List of Expected CPR Participants		7/17/2017
1.3	CPR Meeting	Schedule for Providing a Progress Determination	8/4/2017	8/4/2017
1.3	CPR Meeting	Progress Determination	8/4/2017	8/4/2017
1.4	Final Meeting	Final Meeting	2/7/2019	
1.4	Final Meeting	Final Meeting Agreement Summary (if applicable)	7 days after the final meeting	
1.4	Final Meeting	Schedule for Completing Agreement Closeout Activities		
1.4	Final Meeting	All Draft and Final Written Products		
1.5	Progress Reports and Invoices	Progress Reports	10 days after the first of each month	Sept, 2016 - July, 2018
1.5	Progress Reports and Invoices	Invoices	10 days after the first of each month or quarter	Sept, 2016 - July, 2018

Task #	Task Name	Product	Due Date	Submitted / Completed
1.6.1	Final Report Outline	Draft Final Report Outline	6/1/2018	6/1/2018
1.6.1	Final Report Outline	Final Report Outline	As determined by the CAM	
1.6.1	Final Report Outline	Style Manual	At least 2 months prior to the final report outline due date	
1.6.1	Final Report Outline	Comments on Draft Final Report Outline	10 days after receipt of the Draft Final Report Outline	
1.6.1	Final Report Outline	Approval of Final Report Outline	10 days after receipt of the Final Report Outline	
1.6.2	Final Report	Draft Final Report	8/1/2018	
1.6.2	Final Report	Final Report	10/1/2018	
1.6.2	Final Report	Comments on Draft Final Report	30 days after receipt of the Draft Final Report	
1.7	Match Funds	Match Funds Status Letter	2 days prior to the kick-off meeting	6/22/2016
1.7	Match Funds	Supplemental Match Funds Notification Letter (if applicable)	10 days after receipt of additional match funds	N/A
1.7	Match Funds	Match Funds Reduction Notification Letter (if applicable)	10 days after any reduction of match funds	N/A
1.8	Permits	Permit Status Letter	2 days prior to the kick-off meeting	6/22/2016
1.8	Permits	Updated List of Permits (if applicable)	10 days after determination of the need for a new permit	N/A
1.8	Permits	Copy of Each Approved Permit (if applicable)	7 days after receipt of each permit	As received

Task #	Task Name	Product	Due Date	Submitted / Completed
1.9	Subcontracts	Draft Subcontracts (if required by the CAM)	As determined by the CAM	As received
1.9	Subcontracts	Final Subcontracts		As received
1.10	Technical Advisory Committee (TAC)	List of Potential TAC Members	2 days prior to the kick-off meeting	6/22/2017
1.10	Technical Advisory Committee (TAC)	List of TAC Members	7 days after finalization of the TAC	9/9/2016
1.10	Technical Advisory Committee (TAC)	Documentation of TAC Member Commitment	7 days after receipt of the documentation	9/9/2016
1.11	TAC Meetings	TAC Meeting #1	11/3/2016	11/2/2016
2.0	Contract Execution			
2.1	Execution of a Contract with the Demonstration Site(s)	Contract with Each Demonstration Site	4/15/2016	N/A
2.2	Execution of a Contract with the Selected M&V Contractor	Contract with the M&V Contractor	4/15/2016	4/15/2016
3.0	Pre-Installation Design	Installation Site Plan	5/2/2016	5/2/2016
3.0	Pre-Installation Design	Installation Parts and Instrumentation Diagram	5/2/2016	5/2/2016
3.0	Pre-Installation Design	Quotations/Contracts	9/1/2016	9/1/2016
3.0	Pre-Installation Design	Permits (if any)	9/1/2016	9/1/2016
3.0	Pre-Installation Design	CPR Report (pre-installation)	4/7/2017	4/7/2017
4.0	Installation	As Built Site Plan	7/14/2017	7/14/2017
4.0	Installation	As -Built Parts and Instrumentation Diagram	7/14/2017	7/14/2017
5.0	Monitoring	Data Logs and M&V Report	7/16/2018	7/16/2018
6.0	Evaluation of Project Benefits	Kick-off Meeting Benefits Questionnaire	8/1/2016	9/9/2016

Task #	Task Name	Product	Due Date	Submitted / Completed
6.0	Evaluation of Project Benefits	Mid-term Benefits Questionnaire	TBD	N/A
6.0	Evaluation of Project Benefits	Final Meeting Benefits Questionnaire	TBD	N/A
7.0	Technology/Knowledge Transfer Activities	Draft Initial Fact Sheet	10/3/2018	
7.0	Technology/Knowledge Transfer Activities	Final Initial Fact Sheet	11/2/2018	
7.0	Technology/Knowledge Transfer Activities	Draft Final Project Fact Sheet	12/3/2018	
7.0	Technology/Knowledge Transfer Activities	Final Project Fact Sheet	1/11/2019	
7.0	Technology/Knowledge Transfer Activities	Draft Presentation Materials	11/15/2018	
7.0	Technology/Knowledge Transfer Activities	Final Presentation Materials	12/3/2018	
7.0	Technology/Knowledge Transfer Activities	Draft Technology/Knowledge Transfer Plan	10/2/2018	
7.0	Technology/Knowledge Transfer Activities	Final Technology/Knowledge Transfer Plan	11/2/2018	
7.0	Technology/Knowledge Transfer Activities	Draft Technology/Knowledge Transfer Report	1/31/2019	
7.0	Technology/Knowledge Transfer Activities	Final Technology/Knowledge Transfer Report	2/1/2019	

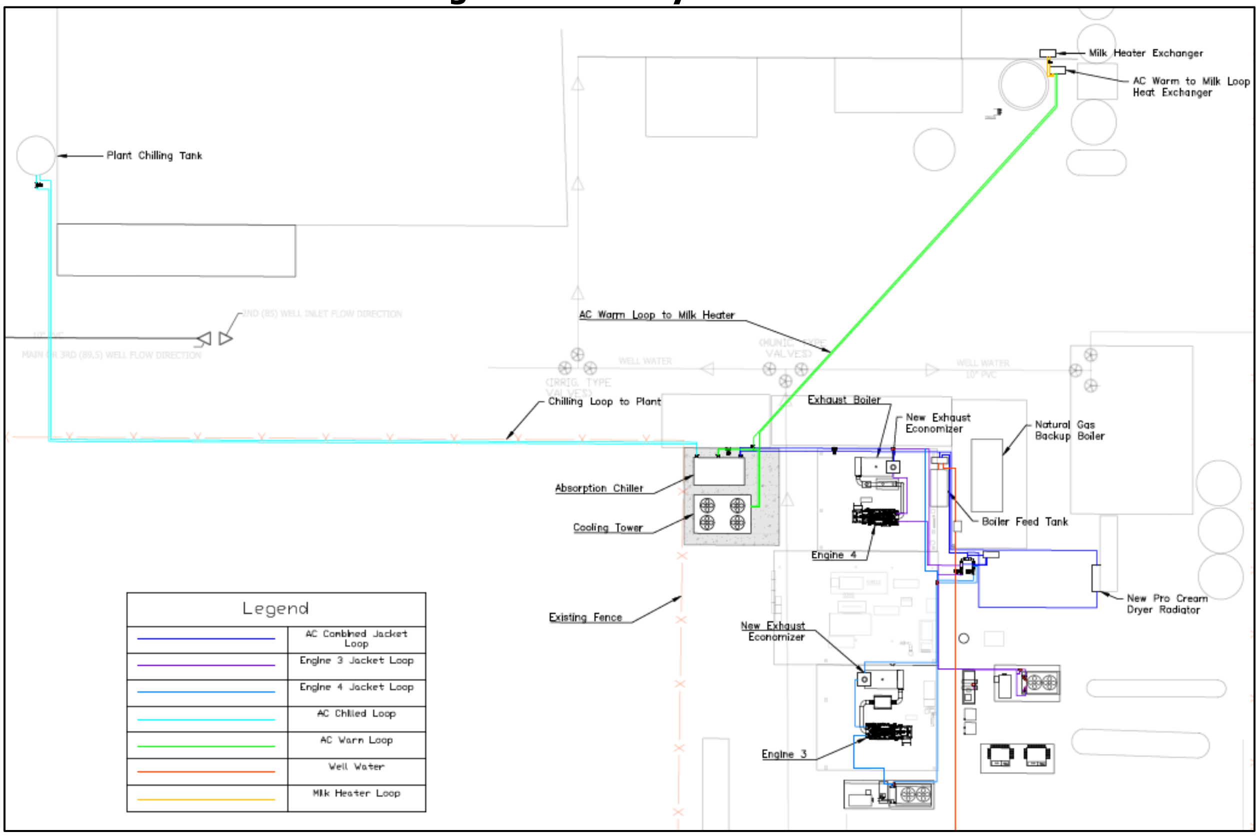
Source: Maas Energy Works, Inc.

Project construction was finished on time, as shown above, and on budget, as discussed and shown below.

Equipment Installation

Figure 7 shows a site plan with the location of the existing and newly installed equipment. A more detailed description of the equipment installed follows.

Figure 7: Facility Site Plan



Source: Maas Energy Works, Inc.

Oil Coolers

To ensure that the biogas gensets would not overheat due to the higher operating temperatures of the project design, the oil coolers of the engine had to be upgraded. These brazed oil coolers were ordered from WCR Incorporated and installed by Kenneth Weaver at Joseph Gallo Farms (Figure 8).

Figure 8: Oil Coolers Upgraded for Each 800 KW Genset

Source: Maas Energy Works, Inc.

Exhaust Economizers

California Boiler custom built and installed the exhaust economizers of the project. T&R Enterprises was contracted to custom build a stand for each economizer so that each could be installed above the boiler (Figure 9).

Figure 9: Exhaust Economizer Installed Above Boiler

Source: Maas Energy Works, Inc.

Absorption Chiller and Evaporative Cooling Towers

The largest and most expensive piece of technology was the 250-ton ThermoSorber absorption chiller ordered through Electric Innovations Inc. and manufactured by Energy Concepts (Figure 10). The equipment was delivered to the project site in April 2017 and fully installed by end of May 2017. The water streams from both gensets were combined and then piped via insulated stainless-steel piping to the ThermoSorber.

Figure 10: ThermoSorber Absorption Chiller Installed at Joseph Gallo Farms

Source: Maas Energy Works, Inc.

Two additional loops from the ThermoSorber were installed – the “chilling loop” and the “warm water loop.” The chilling loop was constructed by Harelson Mechanical using HDPE piping that was installed underground. It was filled with a 50/50 glycol/water mixture, and the loop connected the ThermoSorber to the chilled glycol tank reservoir of the plant. The necessary glycol tank modifications are shown in Figure 11.

Figure 11: Existing Glycol Tank Modified to Receive Chilled Glycol from the ThermoSorber

Source: Maas Energy Works, Inc.

The ThermoSorber also produces a warm-water waste stream at about 90°F. This additional water stream was piped to the cheese plant to preheat the process well water for additional natural gas savings. The water returning from the cheese plant is around 80°F, which is still too warm for the feed to the ThermoSorber. Evaporative coolers were purchased from Air Treatment Corporation and installed on a stand above the ThermoSorber to cool the water stream to the required 70°F for proper absorption chiller operations (Figure 12).

Figure 12: Cooling Tower Installed Above ThermoSorber for Warm-Water Loop

Source: Maas Energy Works, Inc.

Process Water Heat Exchanger

The warm-water loop from the absorption chiller was cycled to a newly installed standard heat exchanger ordered from California Stainless for additional natural gas savings before being cycled back to the evaporative coolers and absorption chiller (Figure 13).

Figure 13: Process Water Heat Exchanger from California Stainless

Source: Maas Energy Works, Inc.

Procream Dryer Heat Exchanger

The final waste heat implementation for the hot-water loop was at the procream dryer. Gallo staff repurposed an existing radiator to transfer heat from the hot-water loop to preheat the air inside the procream dryer providing additional natural gas savings. See Figure 14.

Figure 14: Repurposed Radiator Used to Transfer Heat from the Hot-Water Loop to the Procream Dryer

Source: Maas Energy Works, Inc.

Capital Budget

The initial proposed project budget total was $1,609,515 with matching funds of $402,379 and Energy Commission share of $1,207,136. Specific budget categories are shown in Table 5.

Table 5: Initial Capital Budget

Cost Category	CEC Share	Match Share	Total
Direct Labor	$109,200	$0	$109,200
Fringe Benefits	$0	$0	$0
Total Labor	**$109,200**	**$0**	**$109,200**
Travel	$0	$0	$0
Equipment	$640,916	$278,079	$918,995
Materials/Misc.	$120,550	$0	$120,550
Subcontractors	$336,470	$124,300	$460,770
Total Other Direct Costs	**$1,097,936**	**$402,379**	**$1,500,315**
Indirect Costs	$0	$0	$0
Profit	$0	$0	$0
Total Indirect and Profit	**$0**	**$0**	**$0**
Grand Totals	**$1,207,136**	**$402,379**	**$1,609,515**

Source: Gallo Cattle Company and Maas Energy Works Inc.

At the time of application to the Energy Commission, Joseph Gallo Farms intended to construct most of the pipe work using existing employees. However, Gallo's management team decided to outsource most of the work instead to subcontractors, requiring a budget amendment to move funds from Direct Labor to accommodate. Furthermore, some items that were initially budgeted in Equipment did not end up meeting the $5,000 threshold to qualify for that cost category and were instead applied to Materials/Misc. Details of the project's final budget are shown in Table 6. Total project cost was $1,623,721, with match funding of $420,994 and the Energy Commission's share of $1,207,050.

Table 6: Final Project Budget

Cost Category	CEC Share	Match Share	Total
Direct Labor	$25,985	$0	$25,985
Fringe Benefits	$0	$0	$0
Total Labor	**$25,985**	**$0**	**$25,985**
Travel	$0	$0	$0
Equipment	$610,648	$278,079	$888,727
Materials/Misc.	$192,114	$0	$192,114
Subcontractors	$378,303	$138,592	$516,895
Total Other Direct Costs	**$1,181,065**	**$420,994**	**$1,589,447**
Indirect Costs	$0	$0	$0
Profit	$0	$0	$0
Total Indirect and Profit	**$0**	**$0**	**$0**
Grand Totals	**$1,207,050**	**$420,994**	**$1,623,721**

Source: Gallo Cattle Company and Maas Energy Works

CHAPTER 4: Project Operations, Results, and Analysis

Description

Kenneth Weaver and his team at Joseph Gallo Farms are responsible for day-to-day operations at the newly constructed site. Commissioning of the absorption chiller occurred during the week of June 12, 2017. Adjustments were made to the system through the end of July 2017. Engineers from Energy Concepts provided absorption chiller operations training to Gallo's technicians and the Maas Energy Works staff involved to ensure optimal equipment oversight. To date, the project has had uptime of greater than 95 percent while providing substantial electrical and natural gas savings, as shown and discussed in the third-party monitoring results.

Project Monitoring and Results

The project team selected Tim Huang, P.E. (Enovity, Inc.) as the third-party monitor for this project. Enovity established a 12-month baseline for the natural gas usage of the boiler and procream dryer in 2016 through existing data loggers. Enovity also installed data loggers to track the average electrical consumption, average load, and the percentage of time that existing chillers ran at Joseph Gallo Farms to establish a baseline of electricity used by the chillers. Enovity then collected natural gas and electrical usage each month after startup and reported it to the project team from July 2017 to June 2018. The results were substantial, as discussed below.

Natural Gas Savings

The CEC asked the project team to report natural gas savings in therms per unit of product. For Joseph Gallo Farms, the team compared monthly natural gas usage for the boiler and procream dryer in the baseline and production years and divided the result by total pounds of cheese the plant produced each month. The results showed a six-month average natural gas savings of 8 percent for the boiler and 12 percent for the procream dryer in the last half of 2017. The Gallo facility was facing technical issues with its boiler in October and November 2017, which may have skewed the results of the natural gas savings for the first six months. The first half of 2018 showed even better natural gas savings for the boiler and pro-cream dryer at 22% and 17% when compared to baseline, respectively. These savings resulted in an annual average of 1.45 therms of natural gas per 100 pounds of cheese produced, or 19,527 MMBtus per year (Table 7 and 8).

Electrical Savings

Enovity recorded the electrical usage of the chillers from March 25, 2016, to June 14, 2016, to establish a baseline. The results established that the chillers were running 87% of the time with an average electrical load of 225 kW for an average monthly electrical consumption of 145,840 kWh. After the ThermoSorber was installed and fully operating, Enovity measured the same average power, chiller percentage on time, and average monthly kWh of the existing chillers to compare to baseline. The difference between current monthly consumption of the chillers compared to the monthly baseline electrical consumption was used to calculate the percentage savings. The results were substantial, with the average monthly electrical usage decreasing from 145,840 kWh to 30,404 kWh. This decrease is an average monthly savings of 115,436 kWh or 1,385,227 kWh per year. See Table 9.

Table 7: Project Natural Gas Savings per Pound of Cheese (2017)

	Jul	Aug	Sep	Oct	Nov	Dec	6-Mo. Avg.
Pre-Install Boiler Gas Therms/Unit Cheese (2016)	0.0154	0.0130	0.0146	0.0129	0.0133	0.0155	0.0141
Post-Install Boiler Gas Therms/Unit Cheese (2017)	0.0142	0.0121	0.0122	0.0131	0.0139	0.0121	0.0129
Natural Gas Savings	8%	7%	16%	-2%	-5%	22%	8%
Preinstall Dryer Gas Therms/ Unit Procream (2016)	0.081	0.073	0.075	0.086	0.090	0.104	0.085
Post-Install Dryer Gas Therms/Unit Procream (2017)	0.078	0.075	0.064	0.077	0.078	0.077	0.075
Procream Dryer Natural Gas Savings	3%	-2%	14%	10%	13%	26%	12%

Source: Tim Huang, P.E. with Enovity Inc.

Table 8: Project Natural Gas Savings per Pound of Cheese (2018)

	Jan	Feb	Mar	Apr	May	Jun	6-Mo. Avg.
Pre-Install Boiler Gas Therms/Unit Cheese (2016)	0.0126	0.0140	0.0140	0.0144	0.0131	0.0152	0.0139
Post-Install Boiler Gas Therms/Unit Cheese (2018)	0.0115	0.0119	0.0103	0.0102	0.0106	0.0107	0.0109
Natural Gas Savings	9%	15%	27%	29%	19%	29%	22%
Preinstall Dryer Gas Therms/ Unit Procream (2016)	0.091	0.095	0.083	0.089	0.091	0.082	0.088
Post-Install Dryer Gas Therms/Unit Procream (2018)	0.077	0.072	0.077	0.067	0.070	0.079	0.074
Procream Dryer Natural Gas Savings	15%	25%	8%	25%	23%	4%	17%

Source: Tim Huang, P.E. with Enovity Inc.

Table 9: Monthly Electrical Monitoring Compared to Baseline

	2016 Baseline	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	6-Mo Avg	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	6-Mo Avg
Avg Mthly kWh	145,840	52,660	33,788	27,849	31,709	37,055	26,600	34,944	21,099	20,632	18,041	22,754	29,662	43,003	25,685
Avg Power (kW)	225	165	155	147	145	137	81	138	70	81	48	60	51	71	63
Chiller % ON Time	87%	43%	29%	26%	29%	38%	44%	35%	40%	38%	51%	52%	79%	84%	57%
Electrical Savings	0%	64%	77%	81%	78%	75%	82%	76%	86%	86%	88%	84%	80%	71%	82%

Source: Tim Huang, P.E. with Enovity Inc.

Analysis

Project Objectives Compared to Project Results

This project had four measurable objectives:

1. Capture 86,250 Btu/min. of waste heat.
2. Reduce onsite natural gas consumption by 18,600 MMBtu per year.
3. Reduce onsite electrical consumption by 1.3 million kWh.
4. Reduce total site greenhouse gas emissions by 2,000 metric tons of CO_2e per year.

As shown in Table 10, the project team accurately predicted and reached each of these objectives. These results demonstrate to the industry at large that ammonia-based absorption chiller technology is predictable and measurable with significant economic benefits available. It also demonstrates that the project has a high level of replicability, which leads to ease in permitting, planning, and obtaining financing.

Table 10: Project Objectives (Estimated vs. Achieved)

Description	Estimated	Achieved	%
Reduce Natural Gas Consumption (MMBtu/yr)	18,624	19.527	105%
Reduce Electrical Consumption (kWh/yr)	1.307,432	1,385,227	106%
Reduce GHG Emissions ($MTCO_2e$/yr)	1,913	2,016	105%

Source: Maas Energy Works, Inc.

Economic Sustainability

The project saw energy savings of 19,527 MMBtu of natural gas and 1,385,227 kWh of electrical savings in the first year of operations. Using the same cost assumptions used in the grant application of $4.49 per MMBtu of natural gas and $0.28 per kWh of electricity, the project team can calculate the economic sustainability of the project. The resulting annual natural gas savings is $87,676, and electrical savings are $387,863 for total gross annual savings of $475,540. The operational expenses of the project are minimal at $25,568 per year. Total net annual savings of the project are **$**449,972 (Table 11). These savings yield an extremely favorable cost-benefit ratio that highly encourages the Gallo cheese plant to continue long-term project operations and upkeep.

Table 11: Project Economic Analysis

Savings	Amount
Total Natural Gas Reductions (MMBtu/yr)	19,527
Avg Natural Gas Cost ($/MMBtu)	$4.49
Natural Gas Savings ($/yr)	$87,676.23
Total Electricity Reduction (kWh/yr)	1,385,227
Avg Electricitgy Cost	$0.28
Electrical Savings ($/yr)	$387,863.56
Total Gross Annual Savings	$475,539.79
Estimated Project Labor	$18,263
Materials and Maintenance	$7,305
Total Annual Project Expense	$25,568
Total Net Annual Savings	$449,971.79

Source: Maas Energy Works, Inc.

Simple Payback

As discussed above, the total capital investment of the project was $1,623,721. The project has produced estimated natural gas savings of $87,676 per year and electric savings of $387,863 per year. Thus, the simple payback formula for the project is as follows:

$1,623,721/ ($87,676 + $387,864) = 3.4 years

Environmental Impact

The annual natural gas savings of the project are 19,527 MMBtu and 1,385,227 kWh per year, as discussed above. Using a conversion rate of 117.08 lbs. CO_2e per MMBtu (per EPA) and 1,559 lbs. per MWh, the total resulting greenhouse gas reductions are 4,445,790 lbs. CO_2e per year (Table 12).

Table 12: Greenhouse Gas Reductions for Project

Energy Reduction	Total	Conversion (lbs.)	CO_2e Reduced (lbs.)
Natural Gas Reduction (MMBtu)	19,527.00	117.08	2,286,221
Energy Reduction (MWh)	1,385.23	1,559.00	2,159,569
Total GHG Reduction (lbs)			4,445,790

Source: Maas Energy Works Inc.

Possibilities

The project demonstrated that absorption chilling can work on a farm, and that the benefits of absorption chilling can be estimated with remarkable accuracy before project installation (as shown in Table 10). The most natural expansion of this demonstration would be to implement absorption chillers at all dairy farms, since all such farms have manure (to create generator fuel) and milk (which needs to be chilled). However, this project was at a large cheese processing plant with a very large chilling demand. The site was able to use all the available waste energy to create savings – enough savings that the project payback is commercially compelling. Most dairy farms do not demand nearly as much electricity or natural gas for their on-site processes, so a smaller, less expensive system must be developed to collect the same benefits on a more limited scale.

Scalability

This project used waste heat from two-biogas powered 800 kW engine-generators to produce 250 tons of 32°F refrigeration. Smaller dairy operations have similar energy streams (biogas, chilling demand), but most often at less capacity. Ammonia absorption chillers rated at 3 to 5 tons are commercially available for small-scale air-conditioning applications. Economic feasibility at this scale depends on standardized design and mass production. Industrial applications require more robust design and controls. Furthermore, "balance-of-plant" costs have to be factored in. Energy Concepts estimates that economically viable units can be provided at capacities larger than 20 tons. The smaller units still need to be standardized and serial-/mass-produced to minimize cost. Moreover, the unit can be factory-packaged with the heat source (engine, boiler, and so forth) and cooling tower to minimize cost. For larger applications, the absorption chillers can and have been designed for thousands of tons. Price per unit capacity will be higher for smaller units, with a projected price of $2,500 per ton of chilling for serially manufactured 20-ton units to less than $1,500 per ton of chilling for larger units.

The ThermoSorber can use any waste heat stream, so the absorption chiller can be powered by waste heat from thermal oxidizers, natural gas reciprocating engines (the thermal component of a combined heat and power [CHP] plant), natural gas turbines (such as Capstones), solar thermal, biogas boiler, or other process waste heat streams. The scalability and breadth of market applicability indicate substantial energy savings potential for this technology.

Future Markets

The future applications are very broad for food processors and other industrial customers. In the KEMA Incorporated study, more than 26,000 industrial and commercial establishments could be relevant market sectors for the ThermoSorber market nationwide based on their need for both heating and cooling.[1] The total estimated electrical demand at these facilities is 25,985 GWh per year, of which 19,280 GWh per year is used is in the industrial sector. Similarly, these facilities consume 303 million therms per year, of which 246 million therms is used in the industrial sector. The study did not break down the 26,000 potential facilities by state, but a reliable estimate can be created based on the fact that California consumes 10.3

[1] Rosenberg, Mitchell. KEMA, Inc. 2008. *Assessment of the Benefits and Costs of Seven PIER-Sponsored Projects.* California Energy Commission. Publication Number: CEC-500-2014-023. https://www.energy.ca.gov/2014publications/CEC-500-2014-023/CEC-500-2014-023.pdf

percent of U.S. natural gas demand in the industrial sector.[2] Applying that percentage to Table 13, the project team can infer that the potential California industrial market for absorption chiller technology includes more than 25.4 million therms of natural gas demand and 1,785 GWh of electrical chilling demand – not counting any new construction.

Table 13: Potential Future ThermoSorber Markets

Building Type	# of Estab.	GWh/Year	Million Therms/Year
Hospital	3,206	1,941	26
Hotel	6,386	4,764	32
Meat & Poultry Processor	3,973	13,428	74
Dairy	4,681	N/A	N/A
Breweries/Beverages	2,908	2,052	4
Fruit & Vegetable Canning	1,090	615	7
Frozen fruit juice, and vegetable manufacturing	237	1,465	4
Industrial Laundries	2,636	N/A	N/A
Swimming Pools	3,405	N/A	N/A
Ice Rinks	443	N/A	N/A
Paper	561	1,720	157
Subtotal Commercial	13,441	6,705	58
Subtotal Industrial	13,086	19,280	246
Total	26,527	25,985	304

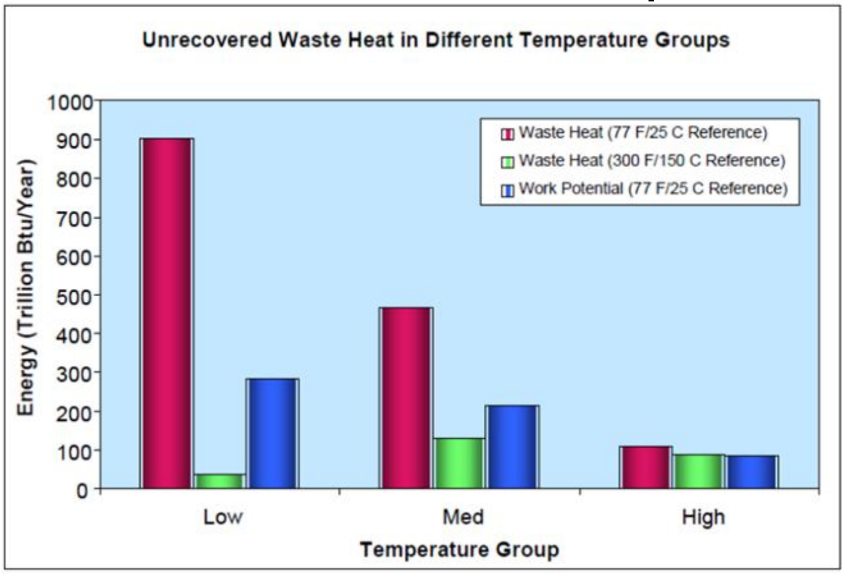
Source: Rosenberg et. al.

The potential absorption chiller market is large. v. ThermoSorber can supply the intermittent duty cycles and low chilling temperatures necessary to satisfy the industrial market and can r connect the chilling and heating demand with the ability to use the industrial waste heat to satisfy those loads. Furthermore, ThermoSorber has the unique ability to make use of not just high-value waste heat sources such as steam, but lower-temperature waste energy sources as well. Figure 15 from USDOE illustrates that, by far, the largest source of untapped waste heat

2 U.S. Energy Information Administration. 2014. "Natural Gas Consumption by End Use." http://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SCA_a.htm.

is in the low-temperature range targeted by this project's demonstration of ThermoSorber technology.[3]

Since the project was completed, the project team has marketed the ThermoSorber technology to several food processors. This industry has the most potential for cost effectiveness if it has unused, low grade waste heat and a need for both heating and cooling. Despite the marketing and the potential for grants through various state and utility programs, uptake of the technology has been slow. Recently, a California food processor indicated interest in installing a ThermoSorber. The plan is to capture the waste heat from internal combustion engine exhausts to operate two absorption chillers. The project is planned for completion in 2021. TFigure 15: Unrecovered Waste Heat in Different Temperature Groups



Source: U.S. Department of Energy

3 U.S. Department of Energy. 2015. *Waste Heat Recovery Technology Assessment.* http://energy.gov/sites/prod/files/2015/02/f19/QTR%20Ch8%20-%20Waste%20Heat%20Recovery%20TA%20Feb-13-2015.pdf.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
Absorption Chiller	A type of chiller that uses hot fluid streams to cool process waters
Btus	British Thermal Units - A unit of heat
CEC	California Energy Commission
CHP	Combined heat and power
CO2e	Carbon dioxide equivalent - a unit of greenhouse gas intensity
CPUC	California Public Utilities Commission
EPA	Environmental Protection Agency
Exhaust Economizer	Equipment used to capture waste heat from engine exhaust gases
Genset	Pairing of an internal combustion engine with an electrical generator
GPM	Gallons per minute
GWh	Gigawatt Hours - a unit of energy
HDPE	High-Density Polyethylene
kW	Kilowatt - a unit of power
kWh	Kilowatt-Hour - a unit of energy
MMBtus	A unit of heat equal to 1,000,000 Btus
Procream	A protein-cream milk product
TAC	Technical Advisory Committee
Therms	A unit of heat equal to 99,976 Btus
U.S.	United States

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