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FINAL PROJECT REPORT

California Dairies Inc. (Visalia) Zero-Emissions Thermal Energy

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PREPARED BY:

Courtney McKeon
Skyven Technologies
Primary Authors

Christian Fredricks
Project Manager
California Energy Commission

Agreement Number: FPI-18-005

Alex Horangic
Branch Manager
FOOD PRODUCTION INVESTMENT PROGRAM BRANCH

Jonah Steinbuck, Ph.D.
Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Food Production Investment Program, established in 2018, encourages California food producers to reduce greenhouse gas (GHG) emissions. Funding comes from the California Climate Investments program, a statewide initiative that uses cap-and-trade dollars to help reduce GHG emissions, strengthen the economy, and improve public health and the environment.

The food processing industry is one of the largest energy users in California. It is also a large producer of GHG emissions.

The Food Production Investment Program will help producers replace high-energy-consuming equipment and systems with market-ready and advanced technologies and equipment. The program will also accelerate the adoption of state-of-the-art energy technologies that can substantially reduce energy use and costs and associated GHG emissions.

California Dairies Inc. (Visalia) Zero-Emissions Thermal Energy is the final report for project FPI-18-005 conducted by Skyven Technologies. The information from this project contributes to the Energy Research and Development Division's FPIP 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 ERDD@energy.ca.gov.

ABSTRACT

California Dairies Inc. (CDI) is the largest milk and dairy cooperative in California, producing 17 billion pounds of milk annually. CDI has set a goal to become carbon neutral by 2050, and to make strides toward this carbon neutrality goal, CDI partnered with Skyven Technologies to install a solar thermal system at their dairy plant in Visalia, California. This system consists of 1,091 solar collectors (total absorption area of 21,820 square feet) that are installed on the roof of the CDI Visalia plant and preheat boiler feedwater to provide renewable energy heat to the plant, decrease the plant natural gas usage, and decrease plant emissions. The solar thermal system is supported by funding from the California Energy Commission and addresses key elements of California's clean energy and climate goals such as public health as well as environmental and economic needs.

Twelve months of measurement and verification data has been collected and analyzed from the solar thermal system installed at CDI Visalia. The collected data show that the annual heat delivered by the system is 8,403 million British thermal units per year, the annual natural gas savings at the plant is 101,481 therms per year assuming 82.8 percent boiler efficiency, and the annual carbon dioxide emissions reduction is 539 metric tons of carbon dioxide equivalent per year.

Keywords: dairy, solar thermal, renewable energy, decarbonization, CDI, GHG, CO2, NOX, NG, IMA

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Executive Summary

Background

California Dairies Inc. (CDI), the largest member-owned milk marketing and processing cooperative in California, has pledged to reach carbon neutrality by 2050. CDI is a milk marketing and processing cooperative that is co-owned by more than 300 dairy families (family-owned member dairies located throughout California's rural landscape). CDI is a leading manufacturer of fluid milk, butter, and milk powder products producing roughly 17 billion pounds of fluid milk, 412 million pounds of butter, and 900 million pounds of milk powder annually. Partnering with Skyven Technologies (Skyven) (which provided engineering, management, and project execution services to CDI) and backed by grant funding from the California Energy Commission, CDI made strides toward its carbon neutrality goal by installing a solar thermal system aimed at reducing usage of natural gas at its CDI plant located in Visalia, California. According to CalEnviroScreen 3.0, California's Community and Environmental Health Screening Tool, CDI Visalia's dairy plant is located in an area with a pollution burden in the 81st to 90th percentile, making this a high-priority area for decarbonization efforts (OEHHA, 2018).

The installation of the solar thermal project addressed several high-impact needs of the local community, including reducing harmful effects to human health, revitalizing local economies, and reducing exposure to environmental contaminants.

Project Purpose and Approach

The purpose of the project was to design and install a solar thermal system capable of providing heat that could directly offset the heat that was being provided by burning natural gas. The solar thermal system consists of 1,061 MT-Power model panels from the manufacturer TVP Solar and is capable of preheating boiler feedwater to a setpoint of 180°F (82°C) and providing 8,403 million British thermal units of energy annually. The primary goal was to reduce carbon dioxide emissions at the CDI Visalia plant. The intended audience for this project includes industrial facilities with production processes similar to CDI Visalia's (that is, dairy facilities) as well as various other industries (such as food and beverage, chemicals, textiles, pulp and paper, hospitality, and district heating) that use thermal energy year-round and are seeking sustainable, clean energy solutions to reduce their carbon footprint.

The project approach involved designing and installing a system capable of providing the necessary heat to offset a portion of the natural gas currently used in the plant's boilers. The key steps in this approach included initial site data collection, determination and quantification of the heat sink, equipment design and procurement, site preparation, and project data monitoring and collection. The key metric needed to determine success was the amount of heat provided by the solar thermal system. Various pieces of equipment were installed on the solar thermal and boiler systems to collect the data necessary to calculate the quantity of heat provided by the solar thermal system (see Chapter 2 *Project Approach* for more information). Using the thermal heat provided by the solar thermal system, the boiler efficiency, natural gas/pollutant conversions, and some assumptions on natural gas prices, the amount of natural gas saved by the plant, the cost savings realized by the plant, and the overall reduction in pollutants such as carbon dioxide and nitrogen oxides emissions could be calculated (see Chapter 3 *Results* for more information).

Key Results

Skyven successfully installed and commissioned the solar thermal system at CDI Visalia and has been actively collecting and monitoring the data from the system since September 12, 2022.

The project application and the measurement and verification plan predicted that the solar thermal system would be capable of providing 6,650 million British thermal units of heat per year with an assumed boiler efficiency of 79.8 percent. The project team estimated the solar thermal project would reduce the emissions by a total of 443 metric tons of carbon dioxide equivalent per year. See Appendix A for detailed equations.

After a full year of data collection (from September 12, 2022, through September 12, 2023), the project team determined that the solar thermal system was providing 8,403 million British thermal units of heat per year. Using data collected from the site, the actual site boiler efficiency was calculated to be 82.8 percent (see Chapter 3 *Results* for more information on the heat provided by the solar thermal system and the boiler efficiency calculation). Therefore, the actual reduction in emissions from that plant due to the solar thermal system was 539 metric tons of carbon dioxide equivalent per year. See Appendix A for detailed equations.

Actual heat produced by the solar thermal system after one year of installation was 8,403 million British thermal units, and the predicted heat produced by the solar thermal system calculated in the application and measurement and verification plan was 6,650 million British thermal units.

Actual carbon dioxide equivalent emissions reduction by the solar thermal system after one year of operation was 539 metric tons, and the predicted carbon dioxide equivalent emissions reduction by the solar thermal system calculated in the application and measurement and verification plan was 443 metric tons.

Knowledge Transfer and Next Steps

To date, Skyven has generated and published two press releases that highlight the installation, commissioning, and successful operation of the solar thermal project at CDI Visalia (along with a few additional decarbonization projects that were completed to date at the plant). The press releases themselves, as well as the website links where the press releases reside, can be found in Appendix A of this report. Additionally, Skyven is developing an in-depth case study for this project, which will be published on the Skyven website and permanently linked to a technical resources page on the website. This case study will be completed and ready to upload to the Skyven website in 2024. For more information on this project visit https://skyven.co/resources/.

Although the installed system is performing better than anticipated, Skyven's main takeaway from the project is that solar thermal systems are not the best solution for decarbonizing industrial heat. The effectiveness of the system is limited by the inherent challenges in transferring heat over large distances and the intermittent nature of solar thermal energy, which is only available at maximum capacity during specific times of the day and year. Transferring the heat from the solar thermal system even just from one side of the plant to the other is very expensive since all the piping requires extensive insulation to minimize thermal losses. Without any grant or incentive funds, the return on investment would take more than 300 years for the system to break even (see Chapter 4 *Conclusion* for more details).

Additionally, the solar thermal system requires a substantial amount of space to make a meaningful impact, and the space must be located on site. Due to heat transfer constraints, it is not technically or financially feasible to put the system off site, and many facilities do not have the space required on site for a large solar thermal system. Given these constraints, it is Skyven's opinion that alternative technologies, such as steam-generating heat pumps, would be a more effective decarbonization solution with a wider appeal. These systems are not subject to weather-related constraints and require less space, which make them a more compelling choice for broader adoption.

CHAPTER 1: Introduction

The purpose of the project was to install a solar thermal system at California Dairies Inc. (CDI) Visalia that would reduce the natural gas usage at the plant and therefore reduce emissions at the plant. The solar thermal system was expected to produce 6,650 MMBtu of heat annually and reduce CO_2 equivalent emissions by about 443 metric tons per year. The successful installation of the solar thermal system at the Visalia, California plant was important and timely in the context of California’s clean energy and climate goals for several key reasons.

Priority Population

According to CalEnviroScreen 3.0 results from June 2018, CDI Visalia’s plant is located in an area with a pollution score of 81 to 90 percent. The pollution burden percentile, which represents the exposures to pollutants and the adverse environmental conditions caused by pollution, in the CDI Visalia’s community is the highest possible (90 to 100 percent). The population Characteristics Percentile, representing biological traits, health status, or community characteristics that can result in increased vulnerability to pollution, is in the 70 to 80 percent range, which is also very high.

Environmental and Health Benefits

Given the high pollution score and pollution burden percentile, reducing health harms and environmental contaminants in the local community is crucial for improving the well-being of residents. The project's focus on reducing on-site criteria air pollutants and toxic air contaminants by transitioning away from fossil fuel consumption is aligned with California's commitment to clean energy. Furthermore, by reducing exposure to air pollutants, the project directly contributes to public health.

Economic Development

The project aligns with California's economic goals by collaborating with local economies and supporting small businesses. Throughout various stages of the project, Skyven Technologies (Skyven) collaborated with several different California-based businesses such as Core Energy Group, E.A. Boneli, Brighton Engineering, and The Bright Group.

Reducing Air Pollutants

By promoting renewable energy resources and efficiency improvements, the project contributes to reducing greenhouse gas emissions, which is crucial for meeting the state's ambitious climate goals.

Renewable Energy

The project not only reduces emissions but also provides renewable energy sources to the plant, which is integral to California's clean energy objectives.

In summary, the CDI Visalia solar thermal system project addresses the critical environmental, health, economic, and clean energy needs of the community. It aligns with California's clean energy and climate goals by reducing emissions, providing renewable energy, and promoting economic development in high-priority population areas.

CHAPTER 2: Project Approach

Skyven's aim for this project was to design and install a high-temperature solar thermal system to offset the use of natural gas in industrial food manufacturing processes such as the CDI Visalia plant. The original project design for the solar thermal system featured Skyven's intelligent mirror array (IMA) collectors, a proprietary solar thermal collector panel that Skyven developed. Water would be run to the solar collectors to pick up heat, and the hot water from the solar collector array would then be used by the plant spray dryers in a water-to-air heat exchanger. Throughout the project, several changes were made to the original design: TVP Solar collectors were substituted for the IMA collectors, and the heat sink was changed from the spray dryer air to the boiler feedwater. At the Visalia plant, the boiler feedwater is the condensate of whey (COW) water.

The project approach is outlined in the following paragraphs in several key steps, each featuring details about the involvement of project partners and any modifications made to the original design throughout that step.

Collaborative Data Collection

Skyven worked with CDI's engineering and operations teams to collect operational data and utility usage to determine the best point of use for the solar-generated heat in the factory. As more data was collected and the design progressed, the team determined that the spray dryers, which are used at the plant to remove water from the milk powder products, were not viable as a heat sink. There were concerns from the operations team at CDI about using the spray dryer supply air as the heat source that ultimately could not be mitigated. First, preheating dryer air decreases density so the mass flow of air supplied to the dryer is decreased, which can reduce the dryer's overall capacity for water removal. Second, preheating the dryer reduces the load on the natural gas burners, which can push the burners into a lower range of operating capacity, which had presented problems in the past (mainly mechanical harmonics causing significant vibration). Due to these concerns, the decision was made to switch the heat sink, and Skyven began analyzing potential new heat sinks with CDI. The team ultimately decided that the boiler feedwater would be an optimal heat sink and that the solar collector array would create a hot water loop that preheats boiler feedwater via a water-to-water heat exchanger. In the existing boiler system at CDI Visalia, COW water is used as boiler feedwater and was therefore used as the solar thermal array heat sink. The amount of heat required for preheating the boiler feedwater was analyzed and compared to the total heat production capability of the proposed solar thermal array, and it was determined that the boiler feedwater was a sufficient heat sink for the solar thermal system.

Equipment Design and Procurement

Skyven's initial plan for the solar thermal array was to use its IMA mirror collectors: a proprietary technology for which Skyven has developed all of the control's design, programming, and specifications. However, in the wake of the COVID-19 pandemic and the supply chain issues that ensued, Skyven was forced to shift from the IMA collectors to another supplier. This was because Skyven's supply chain had not yet built the volume of collectors required for this project and was therefore facing pricing increases and decreased availability of commodity materials that would have made the production of the IMA collectors financially or technically inviable within the timeframe of the project. Skyven then began scoping other potential vendors for the solar thermal technology, including TVP Solar and SOLID California. After an assessment of mechanical, thermal, and logistical performance, Skyven and CDI decided to proceed with TVP solar thermal panels. This was determined by requesting a performance model, collector data sheets, and the Solar Rating and Certification Corporation (SRCC) rating from TVP. Skyven then requested a minimum of a year of real-time data from a system as close as possible to the proposed CDI Visalia project, and TVP provided data from two systems that were similarly sized to CDI Visalia. The British thermal unit (Btu) production per collector over the year was analyzed and compared to the data sheet and the performance model that the vendors provided for the CDI Visalia project. TVP provided the closest performance model versus actual data; therefore, TVP was selected to be the panel vendor for the project. The TVP collector datasheet can be found in Appendix B. Furthermore, Skyven collaborated with Core Energy Group, which was originally selected to do the design of the IMA, but when the supply of the panels was switched to TVP, Core Energy's services were no longer needed. Skyven also worked with The Bright Group, which designed and provided professional engineering sign off for the walkways and platforms for the solar thermal array.

Site Preparation

Skyven worked with site architects E.A. Bonelli to obtain and review structural and building drawings for the Visalia site before visiting the site. Due to the nature and quantity of obstructions on the roof area, it was determined that the panels would take up the majority of the north and south roof areas. Both sections of the roof have sheet metal decking underneath attached to the structural beams. It was determined that the roof attachments would be performed with HILTI threaded steel studs attached directly to the I-beams, and flashings would be installed for sealing to match roof type and warranty requirements. The racking for the collectors was determined to be a Hollaender racking system with cross bracing sufficient to withstand wind loading calculations and meet all applicable code requirements. It was determined that the primary control enclosure would be mounted near the pumps and heat exchanger that would power and control the programmable logic controls (PLCs), sensors, and mechanical equipment. Rooftop control enclosures would be controlled by the primary control box and mounted on the roof near the various TVP array groupings to control the mirror motors as they tracked sunlight throughout the day. Skyven and its subcontractors worked with Otto H. Rosentreter Company to get city permits approved for the installation of the system on the rooftop at the Visalia plant. Skyven also collaborated with Brighton Engineering, which was contracted to perform project management of the site installation.

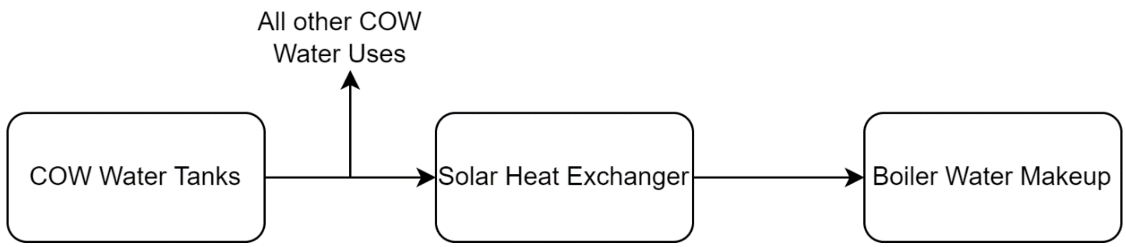
Via implementation of the previously described methodology and approach, the final system design and metering plan were developed. The subsequent paragraphs provide a comprehensive overview of this design and plan.

Final System Design

In the system that was installed at CDI Visalia, the solar collector array created a hot water loop that preheated boiler feedwater (COW water in the existing system) via a water-to-water heat exchanger. The system heated COW water to a set point of 180 degrees Fahrenheit (°F) (82 degrees Celsius [°C]) before it was fed to the boilers.

The collector array consisted of two modules. The North Module had 487 solar collectors while the South Module had 604 solar collectors. All collectors were manufactured by TVP Solar, model V4.3 with a gross area of 1.96 square meters (21.1 square feet). A simplified diagram of the system is illustrated in Figure 1.

Figure 1: Simplified System Diagram

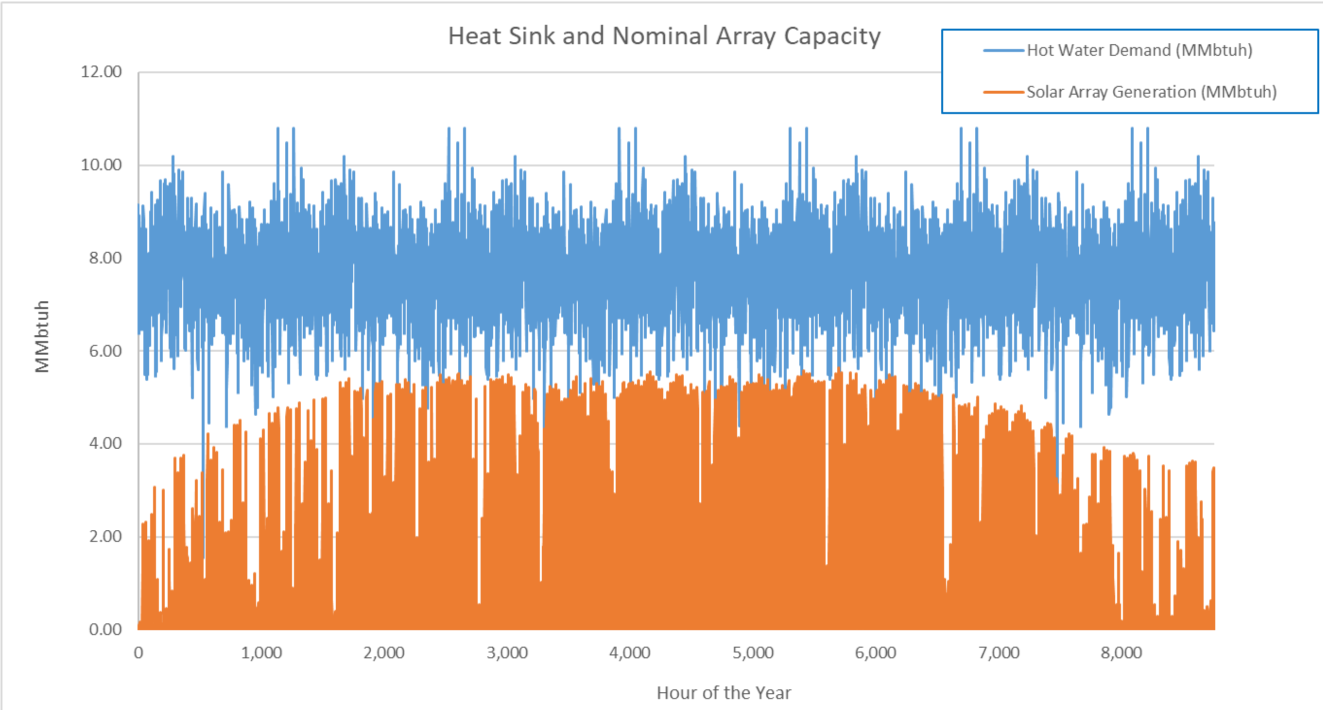


Source: Skyven Technologies, 2022

Figure 1 is three rectangles on a white background showing the progression of the COW water from the COW water tanks, to the solar heat exchanger, and then to boiler water makeup.

If there was a scenario in which excess heat was generated by the solar field, there was a heat-dump dry cooler. However, it was expected that the presence of excess heat, and therefore the operation of the dry cooler, would be extremely rare (less than 0.8 percent of the time). This was determined by calculating the magnitude of heat that the boiler feedwater could accept on an annual basis and comparing it to the heat generated by the solar array. The annual heat generated by the solar thermal system was modeled using the National Renewable Energy Lab System Advisor Model (SAM) software, Version 2021.12.02. The SAM model used TVP Solar V4.3 solar collectors - OG 100 certified system (SRCC #100002057). To calculate the magnitude of heat that the boiler feedwater could accept, metering equipment was placed on site to collect the boiler natural gas flow rate and the boiler feedwater (COW water) tank temperature. The steam meters installed at CDI were not functioning properly during the metering period, so the steam production rate was back-calculated based on natural gas input, feedwater temperature, and the thermal properties of 133 pounds per square inch steam (saturated temperature: 357°F [181°C]; Heat of Vaporization: 865 Btu per pound [Btu/lb]) with an actual boiler efficiency of 82.8 percent. The steam production flow rate was then assumed to be equal to the feedwater (COW water) flow rate. The temperature delta of the COW water temperature was calculated by subtracting the boiler feedwater (COW water) tank temperature by 180°F (27°C) (the temperature setpoint for the solar thermal array). This temperature delta was then multiplied by the COW water flow rate to get the hot water energy demand. Figure 2 shows the heat sink demand (in blue) compared to the solar thermal array generation (in orange).

Figure 2: Heat Source Capacity and Heat Sink Capacity



Source: Skyven Technologies, 2022

Figure 2 is a graph with million British thermal units per hour (MMBtu/hr) on the y-axis and hours of the year on the x-axis. In orange, the MMBtu/hr generation possible with the solar array is displayed for each hour of the year. In blue, the hot water demand in MMBtu/hr is shown for each hour of the year. Virtually all of the blue data points are above the orange, showing that the heat sink is capable of receiving all of the energy from the solar thermal field.

Load Metering Equipment with Expected Range of Temperatures/Flows

The metering equipment listed in Table 1 was used to quantify the thermal energy delivered by the solar thermal array. The temperatures and flow rates observed were within the range of the selected instrumentation.

Table 1: Metering Equipment and Expected Ranges of Temperature and Flow

Equipment	Manufacturer	Model	Accuracy	Range	Expected Range
Programable Logic Controller (PLC)	Wago	PFC100-750-8101	N/A	N/A	N/A
Resistance Temperature Detector	Omega	M12-TXSS-PT100	+/- 0.36°F (-17.6°C)	-58°F (-50°C) to 248°F (120°C)	60°F (16°C) to 190°F (88°C)

Equipment	Manufacturer	Model	Accuracy	Range	Expected Range
Flow Meter	IO-Link	FD-R50	+/- 0.10 percent	9 gallons per minute (GPM) to 150 GPM	0 GPM to 90 GPM

Source: Skyven Technologies, 2022

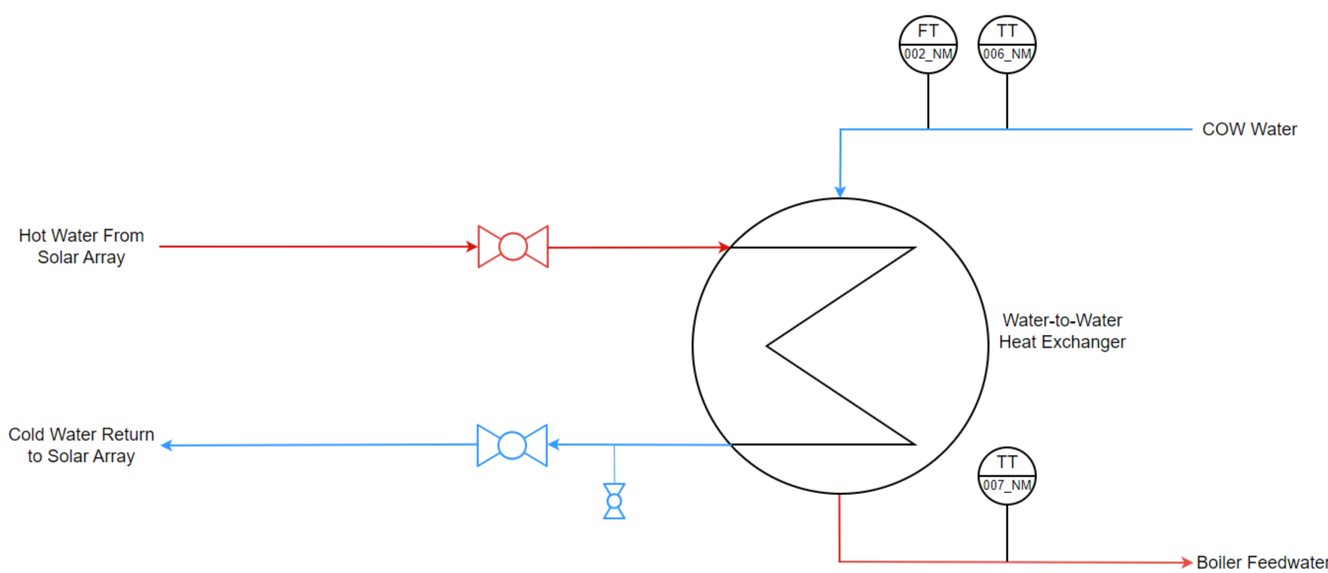
Table 1 is a list of metering equipment, the manufacturer of that equipment, the model number, the accuracy, the range, and the expected range. The list includes PLCs (made by Wago, Model PFC100-750-8101, with accuracy, range, and expected range not applicable), resistance temperature detector (made by Omega, model M12-TX22-PT100, accuracy +/- 0.36°F [-17.6°C], range of -58°F [-50°C] to 248°F [120°C], and expected range of 60°F [16°C] to 190°F [88°C]), and flow meters (made by IO-Link, model FD-R50, +/- 0.10 percent, range of 9 GPM to 150 GPM, and expected range of 0 GPM to 90 GPM).

Equipment specification sheets for this equipment can be found in Appendix C.

Piping and Instrumentation Diagrams

Figure 3 shows a condensed piping and instrumentation diagram (P&ID) of the North Module for illustration purposes. More detailed P&IDs can be found in Appendix D.

Figure 3: Solar Thermal Tie-In with COW Water and Boiler Feedwater (North Module)



Source: Skyven Technologies, 2024

Figure 3 is a simple P&ID with a water-to-water heat exchanger at the center. On one side of the heat exchanger, hot water from the solar thermal field entered and cold water left to be returned to the solar thermal field. On the other side of the heat exchanger, cold COW water entered and heated boiler feedwater left. FT-002_NM (a flow meter) and TT-006_NM (a temperature meter) were located on the cold COW water piping, and TT-007_NM (a temperature meter) was located on the hot boiler feedwater piping.

The metering points relevant to calculating the thermal energy provided by the system are listed in Table 2 below. Note that the P&IDs contain additional metering points that would be monitored to ensure proper functional control of the system but would not be used in measuring the useful thermal energy provided by the system.

Table 2: Metering Datasets

PLC Signal Description			
ID	**Module**	**Type**	**Description**
TT-006_NM	North Module	Temperature	COW Water Temperature
TT-007_NM	North Module	Temperature	Boiler Feedwater Temperature
FT-002_NM	North Module	Flow	COW Water/Boiler Feedwater Flow Rate
TT-006_SM	South Module	Temperature	COW Water Temperature
TT-007_SM	South Module	Temperature	Boiler Feedwater Temperature
FT-002_SM	South Module	Flow	COW Water/Boiler Feedwater Flow Rate

Source: Skyven Technologies, 2022

Table 2 shows the PLC metering points used to calculate the thermal energy delivered to the boiler feedwater. This included the metering points for the North Module: TT-006_NM (measured COW water temperature entering solar heat exchanger), TT-007_NM (measured boiler feedwater temperature leaving solar heat exchanger), and FT-002_NM (measured COW water/boiler feedwater flow rate). The metering points for the South Module included TT-006_SM (measured COW water temperature entering solar heat exchanger), TT-007_SM (measured boiler feedwater temperature leaving solar heat exchanger), and FT-002_SM (measured COW water/boiler feedwater flow rate).

The datapoints contained in Table 2 were sent to the PLC to calculate the thermal energy delivered to the boiler feedwater. Since the sensors were installed on the customer side, rather than the solar collector side of the heat exchangers, this configuration measured all useful energy delivered by the solar collector field. Skyven tracked the collector-side datapoints to ensure proper operation of the system, but that data was not relevant for the purpose of calculating thermal energy delivered.

CHAPTER 3: Results

Skyven has been actively monitoring the solar thermal system using the metering plan described in the project approach since September 12, 2022. The following is an analysis of a year's worth of data collected from September 12, 2022 to September 12, 2023.

The PLC calculated the instantaneous heat delivered by the solar thermal system using the values from the metering dataset in Table 6 in the following equation:

$$\dot{q} = \rho_{water} * 60\ \frac{min}{hr} * \dot{v} * c_p * (T_{Boiler\ Feedwater} - T_{COW\ Water})$$

Where: $\dot{q}$ = instantaneous heat delivered (btu/hr)

ρ_{water} = Density of water = 8.34 lb/gallon (constant)

$\dot{v}$ = COW water/boiler feedwater flow rate

c_p = Specific heat of water = 1.0 btu/lb-°F (constant)

$T_{Boiler\ Feedwater}$ = Temperature of boiler feedwater (water temperature leaving solar heat exchanger)

$T_{COW\ Water}$ = Temperature of COW water (water temperature entering solar heat exchanger)

Table 3 shows the cumulative total heat delivered from both the north and south solar modules for each month over the past year.

Table 3: Post-Installation Btus Delivered by North and South Solar Modules by Month

Month - Year	Btus Delivered
September 2022	481,989,685
October 2022	678,675,844
November 2022	495,002,111
December 2022	234,258,533
January 2023	462,286,839
February 2023	501,467,700
March 2023	836,176,752
April 2023	752,742,300

Month - Year	Btus Delivered
May 2023	786,675,766
June 2023	789,906,273
July 2023	895,684,013
August 2023	1,088,283,578
September 2023	399,510,296
Total Annual Btus Delivered	**8,402,659,690**

Source: Skyven Technologies, 2022-2023

Table 3 is on a white background and shows the Btus delivered by the system for each month starting in September 2022 and ending in September 2023. The total annual Btus delivered by the system is 8,402,659,690 Btus.

Note that September 2022 and September 2023 are partial months. The month of September 2022 included the days of September 12, 2022 to September 30, 2022. The month of September 2023 included the days of September 1, 2023 to September 12, 2023.

The total annual heat delivered by the solar thermal system was 8,402,659,690 Btus (8,403 MMBtu).

The following equation was used to convert from Btus delivered by the system to therms of natural gas (NG) saved:

$$\text{Therms NG Saved} = \text{Btus Delivered} * \frac{1\ \text{therm}}{100{,}000\ \text{Btus}} * \frac{1}{\text{Boiler Efficiency}}$$

Where: Boiler efficiency = 0.828

The boiler efficiency was calculated using data collected from the Visalia plant including the boiler gas flow rates, the temperature and flow rate of the boiler feed water, and the pressure set point of the boiler. The sensible heat needed to heat the water was calculated by subtracting the saturated liquid enthalpy of the boiler feed water (239°F [115°C]) from the saturated liquid enthalpy of the water at the pressure set point of the boiler (133 pounds per square inch gauge [psig]). This value was then added to the heat of vaporization of water at the pressure set point of the boiler (133 psig) and multiplied by the flow rate of water into the boiler (64,022 lb/hour [hr]) to get the total heat capacity of the steam (60 MMBtu/hr). The heat capacity of the natural gas was then calculated by multiplying the natural gas flow rate (63,044 standard cubic feet [SCF]/hr) by the conversion of 1,150 Btus/SCF to get the total heat capacity of the natural gas (73 MMBtu/hr). The steam capacity was then divided by the natural gas capacity to get a boiler efficiency of 82.8 percent.

Table 4 shows the combined therms of natural gas savings from both the north and south solar thermal systems for each month over the past year.

Table 4: Post-Installation Therms of NG Saved by North and South Solar Modules by Month

Month - Year	Therms of NG Saved
September 2022	5,821
October 2022	8,197
November 2022	5,978
December 2022	2,829
January 2023	5,583
February 2023	6,056
March 2023	10,099
April 2023	9,091
May 2023	9,501
June 2023	9,540
July 2023	10,817
August 2023	13,144
September 2023	4,825
Total Annual Therms Saved	**101,481**

Source: Skyven Technologies, 2022-2023

Table 4 is on a white background and shows the therms of NG saved by the system for each month starting in September 2022 and ending in September 2023. The total annual therms of NG saved was 101,481.

Note that September 2022 and September 2023 are partial months. The month of September 2022 included the days of September 12, 2022 to September 30, 2022. The month of September 2023 included the days of September 1, 2023 to September 12, 2023.

The total annual therms of natural gas saved by the solar thermal system was 101,481.

The following shows the calculations and analysis used to determine the NG cost savings, carbon dioxide (CO2) emissions reductions, and nitrogen oxides (NOx) emissions reductions from the solar thermal system.

Natural Gas Savings

Average NG cost savings was calculated using the following equation:

Annual NG Fuel Cost Savings = Annual NG Fuel Savings × CARB Price of NG

Where: California Air Resource Board (CARB) Price of NG = \$0.65/therm

$$\text{Annual NG Fuel Savings Cost} = \frac{101{,}481\ therms}{year} \times \frac{\$0.65}{therm}$$

Annual NG Fuel Savings Cost = \$65,962.65

CO2 Emissions Reductions

Average annual CO2 emissions reductions were calculated using the following equation:

CO2 Emissions Savings = Annual NG Savings × CARB Factor (NG) × Unit Conversion

Where: CARB Factor (NG) = 117.1 lbs carbon dioxide equivalent (CO2e)/MMBtu

$$\text{CO2 Emissions Reductions} = \frac{101{,}481\ therms}{year} \times \frac{117.1\ lbs\ CO_2e}{MMBtu} \times \frac{1\ MT\ CO_2e}{2{,}204.62\ lbs\ CO_2e} \times \frac{1\ MMBtu}{10\ therms}$$

Annual CO2 Emissions Reductions = 539.02 MT CO2e

NOx Emissions Reductions

Average annual NOx emissions reductions were calculated using the following equation:

Annual NOx Emissions Savings = Annual NG Savings × CARB Factor (NOx)

Where: CARB Factor (NOx) = 0.0049 lbs NOx/therm

$$\text{NOx Emisisons Reductions} = \frac{101{,}481\ therms}{year} \times \frac{0.0049\ lbs\ \mathrm{NO}_X}{therm}$$

Annual NOx Emissions Reductions = 497.26 lbs NOx

Table 5 summarizes the annual post-installation savings values observed at CDI Visalia.

Table 5: Annual Post-Installation Savings Values

Annual Natural Gas Savings at Plant	101,481	therms/year
Annual Natural Gas Cost Savings at Plant	\$65,962.65	dollars/year
Annual CO2 Emissions Reductions	539	MT CO2e/year
Annual Nox Emissions Reductions	497	lbs NO_X/year

Source: Skyven Technologies, 2022-2023

In the project application and the measurement and verification plan, it was predicted that the solar thermal system would be capable of providing 6,650 MMBtus of heat per year. It was assumed that the boiler efficiency was 79.8 percent and therefore, using the following equation, it was estimated that the solar thermal project would reduce the emissions from the plant by a total of 443 MT of CO2e per year.

Predicted GHG Emissions Offset by Solar Thermal System

$$= \frac{\text{Heat from Solar Thermal System}}{\text{Boiler Efficiency}} \times \text{CARB NG Conversion Factor} \times \text{Unit Conversion}$$

$$= \frac{6650\ \text{MMBtu/Year}}{79.8\ \text{percent}} \times \frac{117.1\ \text{lbs CO2e}}{\text{MMBtu}} \times \frac{1\ \text{MT}}{2{,}204.62\ \text{lbs}} = \frac{442.6\ \text{MT CO2e}}{\text{year}}$$

Table 6 shows the comparison between the actual and predicted annual heat delivered by the solar thermal system, and Table 7 shows the comparison between the actual and predicted annual CO2 emissions reductions.

Table 6: Actual vs. Predicted Annual Heat Delivered by the Solar Thermal System

	Actual (Post-Installation)	Predicted (Application & M&V Plan)
Annual Heat Delivered by Solar Thermal System (MMBtu/year)	8,403	6,650

Source: Skyven Technologies, 2022-2023

Table 7: Actual vs. Predicted Annual CO2 Emissions Reduction

	Actual (Post-Installation)	Predicted (Application & M&V Plan)
Annual CO2 Emissions Reductions (MT CO2e/year)	539	443

Source: Skyven Technologies, 2022-2023

Barriers/Challenges

Various barriers and challenges arose during the installation of the solar thermal system. One such challenge stemmed from a dispute between Skyven and the main contractor, TVP Solar, regarding TVP Solar's substantial and widespread breach of contract. This dispute included elements of each of the barriers and challenges described below. While the dispute was never resolved, the statute of limitations regarding construction disputes has expired.

Another challenge emerged during the process of roof penetration where it was unexpectedly discovered that a second roof deck existed. This posed a significant challenge as it required the contractor to safely penetrate through both roof decks to reach the roof girders, thus increasing the complexity of the installation. Overcoming this barrier required additional time and materials to ensure the support structures could be properly anchored. A further complication arose when the first penetrations of the roof deck were made and the number of holes that were cut immediately prior to a significant rainstorm resulted in rainwater leaking through to the plant. The holes were temporarily patched, and then the penetration process was modified to ensure that this issue did not occur again. Instead of batching penetrations and then welding, each penetration was cut, the weld was performed, and then the stanchion was booted and sealed.

Another significant challenge emerged in the form of safety restrictions that prohibited the use of tools creating sparks during the cutting process for roof penetrations. To address this issue, the project team had to procure and employ tools equipped with sparkless saw blades, which not only required additional time for tool acquisition but also prolonged the cutting process itself.

Insufficient pipe supports for certain pipe runs posed another challenge as it resulted in sagging of the pipes. This issue needed to be promptly addressed to ensure the structural integrity and functionality of the system. The solution involved installing more robust and effective pipe support systems, which could properly uphold the affected pipe runs, thus mitigating the sagging issue.

Figures 4 and 5 show the solar thermal system installed on the roof of the CDI Visalia plant. Figure 4 shows a direct aerial view of the TVP solar panels installed on the roof of the CDI Visalia plant. There are more than 50 rows and a total of 1,091 panels spanning from left to right across the roof.

Figure 4: Arial View of Solar Thermal System on the Roof of CDI Visalia

Source: Skyven Technologies, 2023

Figure 5 shows a side view of the TVP solar panels installed on the roof of the CDI Visalia plant. There are more than 50 rows and a total of 1,091 panels spanning from left to right across the roof.

Figure 5: Side View of Solar Thermal System on the Roof of CDI Visalia

Source: Skyven Technologies, 2023

CHAPTER 4: Conclusion

In conclusion, CDI, the largest milk and dairy cooperative in California, set an ambitious goal to achieve carbon neutrality by 2050. To make progress toward this goal, CDI partnered with Skyven to implement a solar thermal system at its dairy plan in Visalia, California. This system, comprised of 1,091 solar collectors installed on the plant's roof, contributes renewable energy heat to the plant, reduces natural gas consumption, and curtails emissions.

Supported by funding from the California Energy Commission, this project aligns with crucial aspects of California's clean energy and climate objectives including public health, environmental preservation, and economic development. By reducing emissions from the CDI Visalia plant, which is located in an area marked by high pollution levels, this project addressed the goal of public and environmental health. Furthermore, the collaboration with several California-based companies, including Core Energy Group, E.A. Boneli, Brighton Engineering, and Otto H. Rosentreter Company furthered the economic development goals of the California Energy Commission.

Over one year, from September 12, 2022, through September 12, 2023, Skyven collected extensive measurement and verification data since the commissioning of the project in September 2022. Skyven analyzed a year's worth of that data, from September 12, 2022, through September 12, 2023, to determine the annual performance metrics of the solar thermal system at CDI Visalia. The data revealed that the system provided an annual heat output of 8,403 MMBtu/year. Using the actual site boiler efficiency of 82.8 percent, the solar thermal system had an annual natural gas savings of 101,481 therms/year and an annual reduction of 539 MT CO2e/year.

In the project application phase, it was predicted that the solar thermal system would be capable of producing 6,650 MMBtu/year and reduce emissions by 443 MT CO2e/year. Comparatively, the actual system outperformed the predicted values by 1,753 MMBtu/year and 96 MT CO2e/year.

Notwithstanding the project's success in exceeding performance expectations, the key takeaway from the project was the limitation of solar thermal systems for industrial decarbonization. The system's effectiveness is inhibited by challenges related to heat transfer over long distances and the intermittent availability of solar thermal energy, which is only optimal at certain times of the day and year. Even the internal transfer of heat within the plant is cost prohibitive given the extensive insulation required to minimize thermal losses.

Additionally, the system would require roughly $54,000 in annual maintenance costs for tasks such as visual inspection and spot checking of the solar field, solar panels, metering equipment on a monthly basis; cleaning of the filters, dry cooler, and metering equipment annually; and replacement of all solar panel flange seals every three years. Therefore, since the system budget was $3.6 million, the system saved an average of $65,962 in fuel annually, and the system would require $54,000 in annual maintenance costs. Without any grant or incentive funds, the return on investment would be 0.33 percent. Additionally, without grant or incentive funds for this project, it would take more than 300 years for the system to break even.

Furthermore, the system demands a significant amount of onsite space, making it impractical for many facilities. Due to the constraints associated with heat transfer, off-site deployment is technically and financially unfeasible. Given these factors, Skyven recommends considering alternative technologies, such as steam-generating heat pumps, which offer a more effective decarbonization solution with broader applicability. These systems can be located off site and are not hindered by weather-related limitations, making them a more compelling choice for widespread adoption of decarbonization solutions.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
Btu	British thermal units- the amount of heat needed to raise one pound of water at maximum density through one degree Fahrenheit
Btu/lb	British thermal units per pound
Btus/SCF	British thermal units per standard cubic foot
°C	degrees Celsius
CARB	California Air Resources Board
CDI	California Dairies, Inc. - the largest milk and dairy cooperative in California. This report is in regard to a project at the California Dairies Visalia plant
CEC	California Energy Commission — California's primary energy policy and planning agency
CO2	carbon dioxide – a colorless, odorless gas produced by burning carbon and organic compounds and by respiration
CO2e	carbon dioxide equivalent – the number of metric tons of CO2 emissions with the same global warming potential as one metric ton of another greenhouse gas
COW	condensate of whey water — The condensate that is recovered from the drying process of whey production at the California Dairies Visalia plant; this is used as boiler feedwater
°F	degrees Fahrenheit
GHG	greenhouse gas – a gas the contributes to the greenhouse effect by absorbing infrared radiation
GPM	gallons per minute – unit of flow rate measurement
hr	hour
IMA	intelligent mirror array
lb	pound
lb/hr	pound per hour
MMBtu	million British thermal unit
MMBtu/hr	million British thermal unit per hour
MMBtu/year	million British thermal unit per year
MT	metric tons
MT CO2e/year	metric tons of carbon dioxide equivalent per year
M&V	movement and verification

Term	Definition
NG	natural gas
NOx	nitrogen oxides
P&ID	piping and instrumentation diagram
PLC	programmable logic controllers – industrial computers with various inputs and outputs (such as those listed in Table 2, which are used to control and monitor industrial equipment based on custom programming
psig	pounds per square inch gauge
SAM	System Advisor Model
SCF	standard cubic feet
SCF/hr	standard cubic feet per hour
Skyven	Skyven Technologies
SRCC	Solar Rating and Certification Corporation

References

CARB (California Air Resources Board). 2018. *Funding Guidelines for Agencies that Administer California Climate Investments*. August 2018. Available at https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/2018-funding-guidelines.pdf.

OEHHA (Office of Environmental Health Hazard Assessment). 2018. "Version 3.0 of the California Communities Environmental Health Screening Tool (CalEnviroScreen)." California Environmental Protection Agency. June 25, 2018. Available at https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30.

Project Deliverables

The following is a list of all of the products produced under this agreement:

- Project Design Memo
- Site Preparation and Equipment Procurement Memo
- Equipment Installation Memo
- Measurement and Verification Plan
- Pre-Installation Measurement and Verification Findings Report
- Post-Installation Measurement and Verification Findings Report
- Critical Project Review Report
- Quarterly Progress Reports

The above project deliverables, including the interim Critical Project Review and Quarterly Progress Report reports, are available upon request by submitting an email to pubs@energy.ca.gov.

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APPENDIX A: Equations

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APPENDIX A: Equations

Predicted GHG Emissions Offset by Solar Thermal System:

$$= \frac{\text{Heat from Solar Thermal System}}{\text{Boiler Efficiency}} \times \text{CARB NG Conversion Factor} \times \text{Unit Conversion}$$

$$= \frac{6650\ \text{MMBtu/Year}}{79.8\ \text{percent}} \times \frac{117.1\ \text{lbs CO2e}}{\text{MMBtu}} \times \frac{1\ \text{MT}}{2204.62\ \text{lbs}} = \frac{442.6\ \text{MT CO2e}}{\text{year}}$$

Actual GHG Emissions Offset by Solar Thermal System:

$$= \frac{\text{Heat from Solar Thermal System}}{\text{Boiler Efficiency}} \times \text{CARB NG Conversion Factor} \times \text{Unit Conversion}$$

$$= \frac{8403\ \text{MMBtu/Year}}{82.8\ \text{percent}} \times \frac{117.1\ \text{lbs CO2e}}{\text{MMBtu}} \times \frac{1\ \text{MT}}{2204.62\ \text{lbs}} = \frac{539.0\ \text{MT CO2e}}{\text{year}}$$

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APPENDIX B: Press Releases

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APPENDIX B:
Press Releases

The first press release was published in Yahoo Finance on September 28, 2023 (Figure B-1).

Figure B-1: Yahoo Finance Press Release

skyventechnologies

Skyven Technologies, Inc. Celebrates Successful Integration of Decarbonization Solutions with California Dairies, Inc.

Skyven and California Dairies, Inc have successfully eliminated over 3,500 metric tons of CO_2 emissions over the past year

VISALIA, California (September 28, 2023) -- Skyven Technologies, an Energy-as-a-Service company with a mission to decarbonize industrial process heat, and California Dairies, Inc. (CDI), the largest member-owned milk marketing and processing cooperative in California, have successfully implemented three state-of-the-art decarbonization technologies designed to increase energy efficiency and reduce emissions without affecting facility operations.

As one of the largest dairy co-ops in the nation, CDI has pledged to reach carbon neutrality by 2050, and Skyven's decarbonization solutions are helping them meet that goal.

Skyven and CDI have worked together to design, install, and replicate a first-of-its-kind integration of three decarbonization technologies at each of CDI's two largest facilities. The six total projects include two of the largest solar thermal systems for industrial process heat in the world. These renewable heat systems are each integrated with a smart steam trap solution that uses state of the art internet-connected sensors to reduce steam loss at each facility. The integration also includes a boiler heat recovery system to boost the efficiency of the boilers by nearly 10%. This innovative integration allows CDI to achieve deeper decarbonization at their processing facilities, helping them to meet their carbon neutrality goals and to contribute to the sustainable future of California's dairy industry.

In total, Skyven's innovative solutions have saved over 3,500 metric tons of CO_2 and over 65,000 MMBtu of natural gas at the two CDI facilities, the equivalent of removing 788 gasoline-powered passenger vehicles from the road annually. In a full year of operation, these installed solutions will save over 4,700 metric tons of CO_2 and over 89,000 MMBtu of natural gas. Skyven and CDI are currently working toward the implementation of additional decarbonization solutions at more facilities.

This project also represents a first-of-its-kind financial structure that leverages grant funding from the California Energy Commission's Food Production Investment Program (FPIP), utility incentive funding from Pacific Gas & Electric and Southern California Gas Company, third party project finance, and investment from Skyven's balance sheet to allow the integrated decarbonization technologies to pay for themselves from the resulted energy savings, meaning no capital outlay was required from CDI.

"We are thrilled to combine the manufacturing expertise of California Dairies, Inc with the industrial decarbonization expertise of Skyven," said Arun Gupta, CEO of Skyven Technologies. "We look forward to the continued partnership, and to supporting CDI in meeting their carbon neutrality goals."

“Skyven has played a key role in our mission to create more sustainable dairy products for a healthy world,” said Darrin Monteiro, Vice President of Sustainability and Member Relations at California Dairies, Inc. “Skyven’s ability to design and implement these successful solutions with no cost and no interruption to our process was a vital component to success.”

To learn more about Skyven Technologies, visit https://skyven.co/.

About Skyven Technologies

Skyven Technologies is an energy-as-a-service company with a mission to decarbonize industrial process heat. Skyven works with manufacturers in hard-to-decarbonize industries to reduce their onsite CO_2 emissions by delivering clean, emissions-free process heat at prices lower than natural gas. Skyven installs their latest decarbonization technology, including the Arcturus line of steam generating heat pumps, with no capital cost to the manufacturer. For more information, visit https://skyven.co/.

About California Dairies, Inc

California Dairies, Inc. is the largest member-owned milk marketing and processing cooperative in California, producing approximately 40 percent of California’s milk. Co-owned by 300 dairy producers who ship 17 billion pounds of Real California Milk annually, California Dairies, Inc. is a manufacturer of quality butter, fluid milk products, and milk powders. In addition, California Dairies, Inc. is the home of two leading and well-respected brands of butter – Challenge and Danish Creamery – and a leading global brand of milk powders - DairyAmerica. California Dairies, Inc.’s quality dairy products are available in all 50 United States and in more than 60 foreign countries.

###

Contacts:

Skyven: Chris Barnhill – chris.barnhill@skyven.co – 864-498-9288

Source: Yahoo Finance, 2023

The second press release was published in AP News on October 12, 2023 (Figure B-2). The release can be found at the following website address: https://apnews.com/press-release/pr-newswire/government-programs-8796380ae6927d21f92286ab3c85b764

Figure B-2: AP News Press Release

skyventechnologies

Skyven Technologies Transforms the Financing of Industrial Decarbonization Projects

Skyven's unique Energy-as-a-Service model demonstrates the impact of public-private funding

RICHARDSON, Texas (October 12, 2023) - Skyven Technologies, Inc., an Energy-as-a-Service company with a mission to decarbonize industrial process heat, and Kyotherm, Inc., an investment company that specializes in the third-party financing of renewable thermal projects, have demonstrated public-private funding to decarbonize America's industrial manufacturing sector. This innovative financial approach was used to successfully implement the six decarbonization projects recently announced by Skyven and California Dairies, Inc (CDI), enabling more than 3,500 metric tons of CO_2 reduction over the past year.

This public-private project financing, built on Skyven's Energy-as-a-Service (EaaS) model, combines direct financing from Skyven, third-party financing from Kyotherm, and public funding from the California Energy Commission's Food Production Investment Program (FPIP). Skyven's EaaS model is compatible with state and federal grant funding, including the FPIP program, serving a growing need for public-private partnership.

Under the EaaS model, the clean emissions-free heat delivered by Skyven's systems is measured and verified with meters and IoT data monitoring. The manufacturing facility pays for the delivered heat at prices lower than their current natural gas costs. The savings are shared by the manufacturer, third party financers, and Skyven for the life of the contract.

"When we first announced this partnership back in 2021, it was unproven - no one was doing this for industrial heat," said Arun Gupta, CEO of Skyven Technologies. "Today we're proud to report that the combination of public and private funding sources has led to fully operational industrial decarbonization projects that are outperforming original expectations - with no cost to the industrial manufacturer."

"Skyven's Energy-as-a-Service model removes the major financial barrier to industrial decarbonization projects," said Arnaud Susplugas, CEO of Kyotherm Inc. "It is great to see that Kyotherm's access to competitive capital and our dedication to energy efficiency projects are helping lead the industrial decarbonization revolution."

About Skyven Technologies

Skyven Technologies is an Energy-as-a-Service company with a mission to decarbonize industrial process heat. Skyven works with manufacturers in hard-to-decarbonize industries to reduce their onsite CO_2 emissions by delivering clean, emissions-free process heat at prices lower than natural gas. Skyven installs their latest decarbonization technology, including the Arcturus line of steam generating heat pumps, with no capital cost to the manufacturer. For more information, visit https://skyven.co/.

About Kyotherm

Kyotherm is an Energy-as-a-Service investment company and energy producer dedicated to renewable heating and energy efficiency projects, with varied technologies including waste heat recovery, solar thermal, biomass, geothermal, storage as well as district heating networks and installations allowing reduced energy consumption. As of August 2023, it has financed, owns, manages, or has committed to fund a total of 45 projects, representing an aggregate capacity of 230 MW and a production of more than 3,050,000 MMBtu per year in savings or renewable energy. More information on www.kyotherm.com/en

Contacts:

Skyven: Chris Barnhill – chris.barnhill@skyven.co – 864-498-9288

Source: AP News, 2023

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX C: TVP Collector Data Sheet

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APPENDIX C:
TVP Collector Data Sheet

Figure C-1: TVP Collector Data Sheet

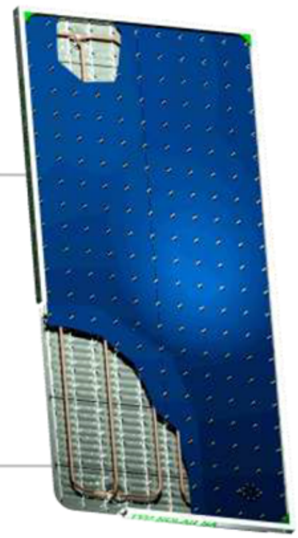
www.tvpsolar.com
Email : info@tvpsolar.com
Tel. +41 22 534 9087

PRODUCT DATASHEET

TVP SOLAR

MT-Power: Thermal Applications 100°C To 180°C

Unrivalled performance in any climate condition, without concentration



MT-Power is Thermal Vacuum Power Charged™: revolutionary, high-end, high-vacuum flat solar thermal panel designed as an ideal thermal energy source for large-scale applications between 80°C and 180°C such as: air conditioning, desalination, and process heat.

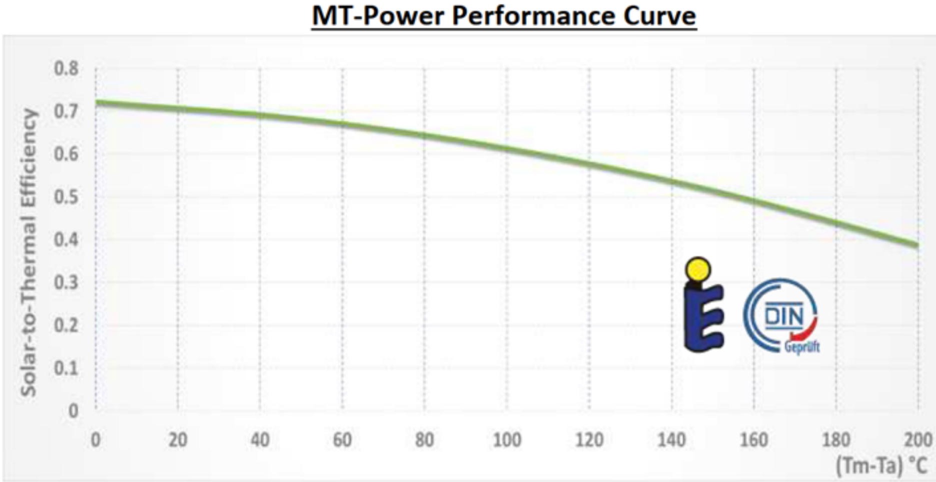
Key FEATURES

- ✓ Designed to operate above 100°C in large-scale deployments
- ✓ Flat for more active surface, high-vacuum for best performance
- ✓ Embedded return HTF flow to maximise deployment scalability
- ✓ Corrosion-proof all-metal casing for any environment
- ✓ Made with materials qualified for long-lasting high-vacuum operation
- ✓ Spot-Check™ to visually verify vacuum insulation
- ✓ 100% recyclable

Key ADVANTAGES

- ✓ **Lowest cost per Watt$_{(thermal)}$**
- ✓ **Highest peak performance:** 500 W_{th}/m^2 at 180°C (T_{amb} = 30°C)
- ✓ **Highest yearly average output**: due to maximum diffuse light capture
- ✓ **Long durability:** no degradation of performance over long-lasting product lifetime
- ✓ **Zero panel maintenance**: no need for precision cleaning and no serviceable mechanical parts
- ✓ **Superior design for solar fields:** minimizes footprint and balance of system, as well as easing installation

MT-Power Performance Curve



MT-Power is the only solar thermal panel with Solar Keymark certification to 200°C

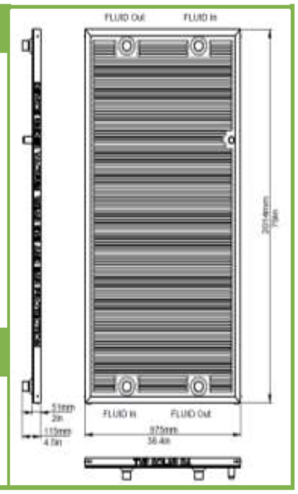
www.tvpsolar.com
Email : info@tvpsolar.com
Tel. +41 22 534 9087

PRODUCT DATASHEET

TVP SOLAR

TVP Solar MT-Power Specifications (v4 SK)

Physical Characteristics		
Dimensions	see diagram for details	
Unit Gross Area	1.96 m^2	21 sq. ft.
Aperture Area	1.84 m^2	20 sq. ft.
Weight	53 kg	117 lb
Fluid Volume	1.4 L	47 fl. oz.
Heat Absorber-Pipe	Al sheet + Cu pipe	
Absorber Coating	Alanod Mirotherm	
Back-plate	AISI 441 stainless steel	
Glass Coating	Single-sided anti-reflective (interior face)	
Connecting Ports	SMS PN16	
Operating Conditions		
Stagnation Temperature	302 °C	576 °F
Max. Operating Pressure	16 bar	232 psi
Pressure Drop H_2O @ 260 l/h ; 50°C	1.4 kPa	138 mm H_2O



MT-Power v4 Solar Keymark-Certified Thermal Performance

Application	Machinery	T_m (°C)	Peak Power
Air Conditioning / Cooling	Double-Effect Absorption Chiller	175	1.1 kW
	Single-Effect Absorption Chiller	90	1.3 kW
Desalination	MED/TVC	150	1.2 kW
	MED, and MSF	80	1.4 kW
Industrial Process Heat	HTF Heater	160	1.1 kW
	Steam Boiler Feedwater	130	1.2 kW
	Dryers / Ovens	110	1.3 kW
	Tank Temperature Control	90	1.3 kW
	District Heating	80	1.4 kW

Built On Thermal Vacuum Power Charged™ Technology

Thermal Vacuum Power Charged™ family of technologies are designed to make, maintain, and inspect the high-vacuum in TVP flat panels, key to the industry-best sun-to-thermal efficiency. Make: innovations in manufacturing process & equipment, as well as materials such as the patented inorganic, flexible glass/metal seal to resist mechanical stresses and contain the vacuum. Maintain: novel use of materials qualified for long-lasting high-vacuum products, and a patented self-regenerating getter pump assembly to preserve high-vacuum insulation and high performance over panel lifetime. Inspect: patented visual verification tool inside TVP panels showing high-vacuum state for easy deployment troubleshooting.

Thermal Vacuum Power Charged™ panels harness the full power of solar thermal technology – providing unrivalled performance for any thermal application in any climate condition, without concentration.

Source: TVP Solar, 2017

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APPENDIX D: Metering Equipment Data Sheets

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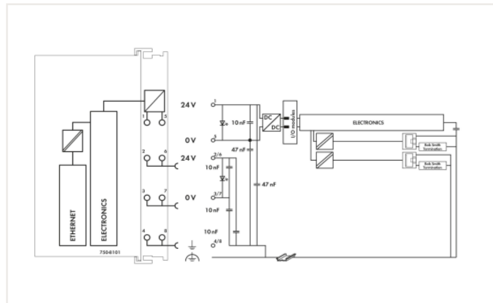
APPENDIX D:
Metering Equipment Data Sheets

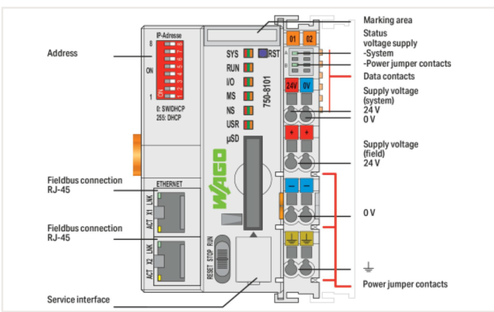
Figure D-1: WAGO PFC 100-750-8101 Data Sheet

| : 750-8101
Controller PFC100; 2 x ETHERNET
https://www.wago.com/750-8101

WAGO



: light gray



The PFC100 Controller is a compact PLC for the modular WAGO I/O System. Besides network and fieldbus interfaces, the controller supports all digital, analog and specialty I/O modules found within the 750/753 Series.
Two ETHERNET interfaces and an integrated switch enable line topology wiring.
An integrated Webserver provides user configuration options, while displaying PFC100 status information.
Besides the processing industry and building automation, typical applications for the PFC100 include standard machinery and equipment control (e.g., packaging, bottling and manufacturing systems, as well as textile, metal and wood processing machines).
The DIP switch configures the last byte of the IP address and may be used for IP address assignment.
Programming per IEC 61131-3

- Programmable via ***e!****COCKPIT*
- Direct connection of WAGO's I/O modules
- 2 x ETHERNET (configurable)
- Linux 3.18 operating system with RT-Preempt patch
- Configuration via ***e!****COCKPIT* or Web-Based Management interface
- Maintenance-free

Technical data	
Communication	Modbus (TCP, UDP) ETHERNET EtherNet/IP™ Adapter (slave), library for ***e!****RUNTIME* MQTT
ETHERNET protocols	DHCP DNS NTP FTP FTPS SNMP HTTP HTTPS SSH
Visualization	Web-Visu
Operating system	Real-time Linux 3.18 (with RT-Preempt patch)

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Source: WAGO, 2022

Figure D-2: Omega M12-TXSS-PT100 Data Sheet

M12 Stainless Steel RTD Temperature Transmitters

NEW

C

M12TXSS Series

1 YEAR WARRANTY CE RoHS

- **Programmable Transmitter**
- **M12 Connection**
- **4 to 20 mA Output**
- **-50 to 120°C (-58 to 248°F)**

M12TXSS-PT100-13MM-1/8NPT

M12TXSS-PT100-24MM-1/8NPT

Both models shown actual size.

RTD 100 Ω sensor with built-in transmitter is programmable by a computer. The configuration kit required for programming is M12TX-CONFIG. This unique probe is ideal for areas with space limitations where traditional head connections are too large to fit. The M12 thread design offers a secure industrial connection.

Specifications

Body: Stainless steel AISI 316L

Probe Length: 13 mm (0.51") and 24 mm (0.94")

Diameter: Ø3 mm (0.1")

Probe Type: Thermowell AISI 316L SS

Probe Minimum Bending Radius: Three-times the outer diameter [except the sensing tip which length is 30 mm (1.2")]

Connection: ⅛ NPT male thread

Sensor: RTD PT100 class A up to 300°C in accordance to IEC751

Range: -50 to 120°C (-58 to 248°F)

Tmax. Electronic: 80°C (176°F)

Sensor Break Monitoring:

- **Selectable:** Upscale (>21.0 mA) or downscale (<3.6 mA) action
- **Sensor Short-Circuit:** Fixed to downscale (<3.6 mA) action

Output:

- **Signal:** 4 to 20 mA
- **Factory Default:** 4 to 20 mA = 0 to 100°C (32 to 212°F)
- **Permissible Load:** 700 @ 24 Vdc [RLo= (Vsupply-8,5)/0,020]

Response Time (90%): <50 ms

Isolation In-Out: Non-isolated

Power Supply: 8.5 to 32 Vdc (polarity protected)

Environment Conditions:

- **Temperature:** -40 to 80°C (-40 to 176°F) for plastic body
- **Relative Humidity:** 0 to 100%
- **EMC:** In accordance to EN 61326

Degree of Protection: IP65 and IP67 in accordance to IEC60529

Accuracy:

- **Transmitter:** Maximum of ±0.2°C or ±0.2% of span
- **Sensor:** Class A in accordance to IEC751

Temperature Influence [Deviation from 20°C (68°F)]: Maximum of ±0.3°C/25°C (77°F) or ±0.3% of span/25°C (77°F)

Supply Voltage Influence: Negligible

Range Configurations: It is possible set the input temperature range (span) by the M12TX-CONFIG configuration kit (PC with OS Windows required)

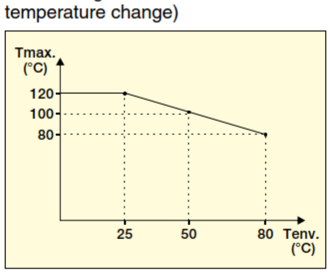
Zero Adjustments: Any value between -50 to 50°C

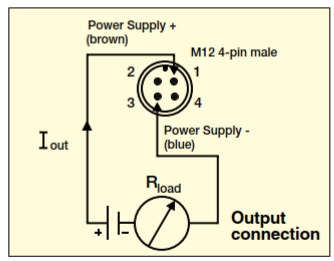
Minimum Span: 50°C (122°F) [if the zero value is set between one of these values: -40°C (-40°F), -20°C (-4°F), 0°C (32°F), 20°C (68°F), 40°C (104°F), the minimum span is 20°C (68°F) rather than 50°C (122°F)]

Sensor Error Compensation: Over 2 points (maximum 1% of span)

Factory Setting: 0 to 100°C/sensor break >21 mA (upscale)

Response Time: Diameter 3 mm <3.5 seconds, diameter 6 mm <13 seconds (test in water to IEC751- time for reaching 63.2% of instantaneous temperature change)





M12TX-CONFIG Specifications

Interface: PC connection through the USB port with connection cable included in the kit

M12TX + Connection: Through extension cable with M12 female connector included in the kit

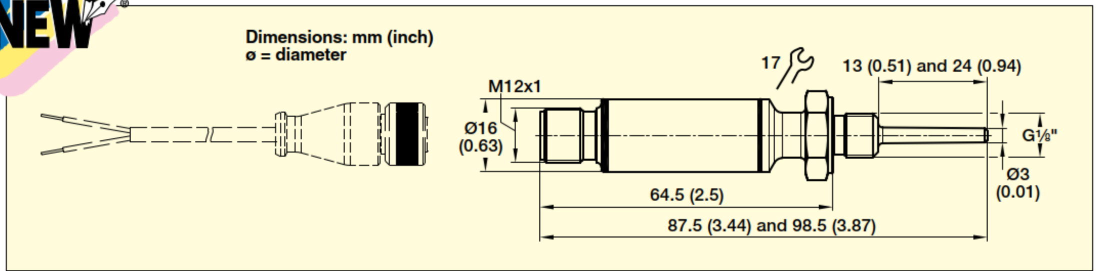
Note: The transmitter is powered from the USB interface

Programming Software: M12TX + Configurator for Windows® 2000 (SP3), XP (SP2), Vista (32 and 64 bit), 7 (32 and 64 bit)

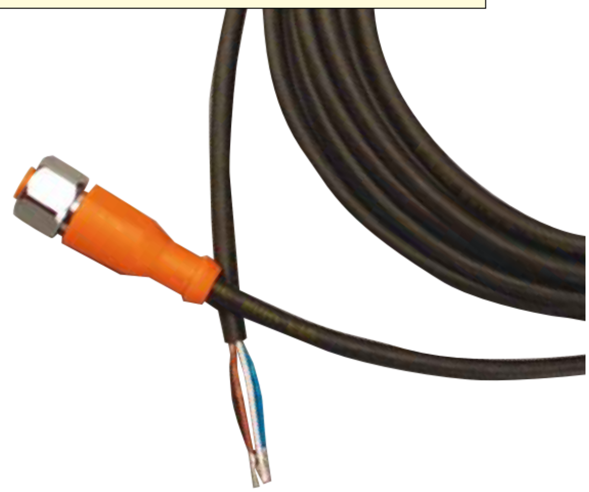
Configurable Parameters: Temperature range (-50 to 800°C), measurement unit (°C/°F/°K), sensor break monitoring (upscale/downscale), identifying name of the transmitter (16 alphanumeric characters), input sensor error compensation over one or two points

Supported Languages: Italian, English, French, German, Swedish

Included in the Kit: Interface USB, connection cable between USB port and interface, connection cable between interface and M12TX + transmitter, memory-stick USB with installation software, introductive manual for software installation and USB



M12TX-CONFIG shown smaller than actual size.



M12C-PUR-4-S-F-5 shown smaller than actual size.

Standard

To Order

Model No.	Description
M12TXSS-PT100-13MM-1/8NPT	Temperature transmitter with M12 input connector for Pt100, output 4 to 20 mA standard, 3 mm (0.118") diameter, 13 mm (0.51") long, ⅛ NPT
M12TXSS-PT100-24MM-1/8NPT	Temperature transmitter with M12 input connector for Pt100, output 4 to 20 mA standard, 3 mm (0.118") diameter, 24 mm (0.94") long, ⅛ NPT

Metric

Model No.	Description
M12TXSS-PT100-13MM-G1/8	Temperature transmitter with M12 input connector for Pt100, output 4 to 20 mA standard, 3 mm (0.118") diameter, 13 mm (0.51") long, G⅛ thread
M12TXSS-PT100-24MM-G1/8	Temperature transmitter with M12 input connector for Pt100, output 4 to 20 mA standard, 3 mm (0.118") diameter, 24 mm (0.94") long, G⅛ thread

Comes complete with operator's manual.

Accessories

Model No.	Description
M12C-PUR-4-S-F-10	Polyurethane cable, straight 4-pin M12 female connector one end, flying leads one end, 10 m (32.8') long
M12TX-CONFIG	Configuration kit for M12TXSS, USB serial interface, connection cables, programming software for Windows®

C-2

Source: Omega, 2023

Figure D-3: IO-Link FD-R50

Data Sheet

KEYENCE

FD-R50

Sensor Main Unit 40A/50A Type

Specifications

Model		FD-R50
Supported pipe diameter		1 1/2" (40 A), ø44 to ø55 1.73" to 2.17" 2" (50 A), ø55 to ø64 2.17" to 2.52"
Supported pipe materials		Metal / resin[*1]
Supported fluids		Various liquids (i.e. water, oils, chemicals)[*1]
Supported fluid temperature		- 20 to + 120°C - 4.0 to + 248 °F (no freezing on the pipe surface)[*2]
Maximum rated flow		Rated flow velocity range: 5.0 m/s Flow rate range (Typical): 1 1/2" (40 A): 400 L / min 100 gal / min 24 m^3/ h) 2" (50 A): 600 L / min 150 gal / min 36 m^3 / h
Zero cut flow rate		Zero cut: 0.3 m/s (default)[*3] Flow rate (Typical): 36 L / min 9 gal / min 2.4 m^3 / h
Display method		Dual row, 5-digit display with white, 14-segment LED; Large status indicator; Output indicators; Stability indicator; Unit indicator
Display update cycle		Approx. 3 Hz
Display resolution		0.1 / 1 (L / min)
Response time		0.5 s / 1.0 s / 2.5 s / 5.0 s / 10.0 s / 30.0 s / 60.0 s / 120.0 s / 200.0 s (variable)
Measurement accuracy		Between 20 and 100% of F.S. : ±2.0% of RD[*4*5] Between 6 and 20% of F.S. : ±0.4% of F.S. [*4*5]
Protection circuit		Power supply reverse connection protection, Power supply surge protection, Short-circuit protection for each output, Surge protection for each output
Zero point error		±0.5% of F.S.[*4*6]
Hysteresis		Variable
Flow units		L / min, m^3 / h, gal / min
Integrated flow unit display		1 / 10 / 100 / 1000 / 10000 (L)
Pipe temperature measurement accuracy		±3°C ±5.4°F (liquid temperature of - 20 to + 50°C, - 4 to + 122°F) ±5°C ±9°F (liquid temperature of 50 to + 120°C, 122 to 248°F) (ambient operating temperature of 25°C 77°F)[*4]
Wiring specifications	Power supply	DC power supply: M12 4-pin connector / AC power supply: M4 screw terminal block (selectable)
	I/O	When using a DC power supply: M12 4-pin connector / when using an AC power supply: M3 screw terminal block
Input/Output (Selectable)	Output (ch.1/ch.2)	Control output / Integrated pulse output / Error output / Temperature alarm, NPN / PNP setting switchable,open collector output 30 VDC or less, max. 100 mA / ch., residual voltage: 2.5 V or less[*7]
	Analog output (ch.1/ch.2)	Flow rate analog output / Temperature analog output and 4 - 20 mA / 0 - 20 mA (selectable), load resistance: 500 Ω or less[*7]
	External input (ch.2)	Integrated flow reset input / Flow rate zero input / Origin adjustment input (selectable), short-circuit current: 1.5 mA or less, input time: 20 ms or more[*7]
Rating	Power voltage	20 to 30 VDC including 10% ripple (P-P), Class 2 / 100 to 240 VAC - 15% or + 10% (50 / 60 Hz)

Environmental resistance	Current consumption	When using a DC power supply: 200 mA or less (load current excluded), 400 mA or less (load current included) When using an AC power supply: 15 VA or less
	Enclosure rating	IP65 / 67 (IEC60259), IP69K (ISO20653), Enclosure Type 4X (NEMA250)
	Ambient temperature	- 20 to + 60°C - 4.0 to 140 °F (no freezing)*2
	Relative humidity	5 to 90%RH (no condensation)
	Vibration resistance	10 to 55 Hz, compound amplitude 1.5 mm 0.06", XYZ axes 2 hours for each axis
	Shock resistance	100 m/s^2 , 16 ms pulse, XYZ axes, 1000 times for each axis
Dimensions		Main unit size: 218.5 mm × 66.9 mm × 70.7 mm 8.60" × 2.63" × 2.78"
Material	Main unit	Body: aluminum die-casting + coating / PPS, display: reinforced glass, connectors: SUS304-equivalent
	Unit rear	Rubber
	Upper/lower bracket	SUS304
Weight		Main unit: Approx. 1.0 kg Upper/lower bracket: Approx.1.5 kg (including sub unit)

*1 Liquid must allow for the passage of an ultrasonic pulse, as well as not contain large air pockets or excessive bubbles. Detection may be unstable due to the type and status of the pipes.
*2 Perform derating depending on the ambient temperature and liquid temperature when using an AC power supply.
*3 The zero cut flow rate can be changed in the settings.
*4 This value is guaranteed by KEYENCE inspection facilities. Errors will be introduced by the type and status of the pipes, the type and temperature of the fluid, and the zero cut flow rate.
*5 This is the value when considering linearity + span error + repeatability in a stable environment of 25°C 77°F.
*6 It is possible to enhance the precision of zero point error by performing an origin adjustment.
*7 IO-Link: Compatible with Specification v1.1 / COM2 (38.4 kbps) The setting file can be downloaded from the KEYENCE website. If using the unit in an environment where downloading the file is not accessible via Internet, contact your nearest KEYENCE office. IO-Link is either registered trademarks or trademarks of PROFIBUS Nutzerorganisation e.V. (PNO)

Source: Keyence, 2023

CALIFORNIA ENERGY COMMISSION

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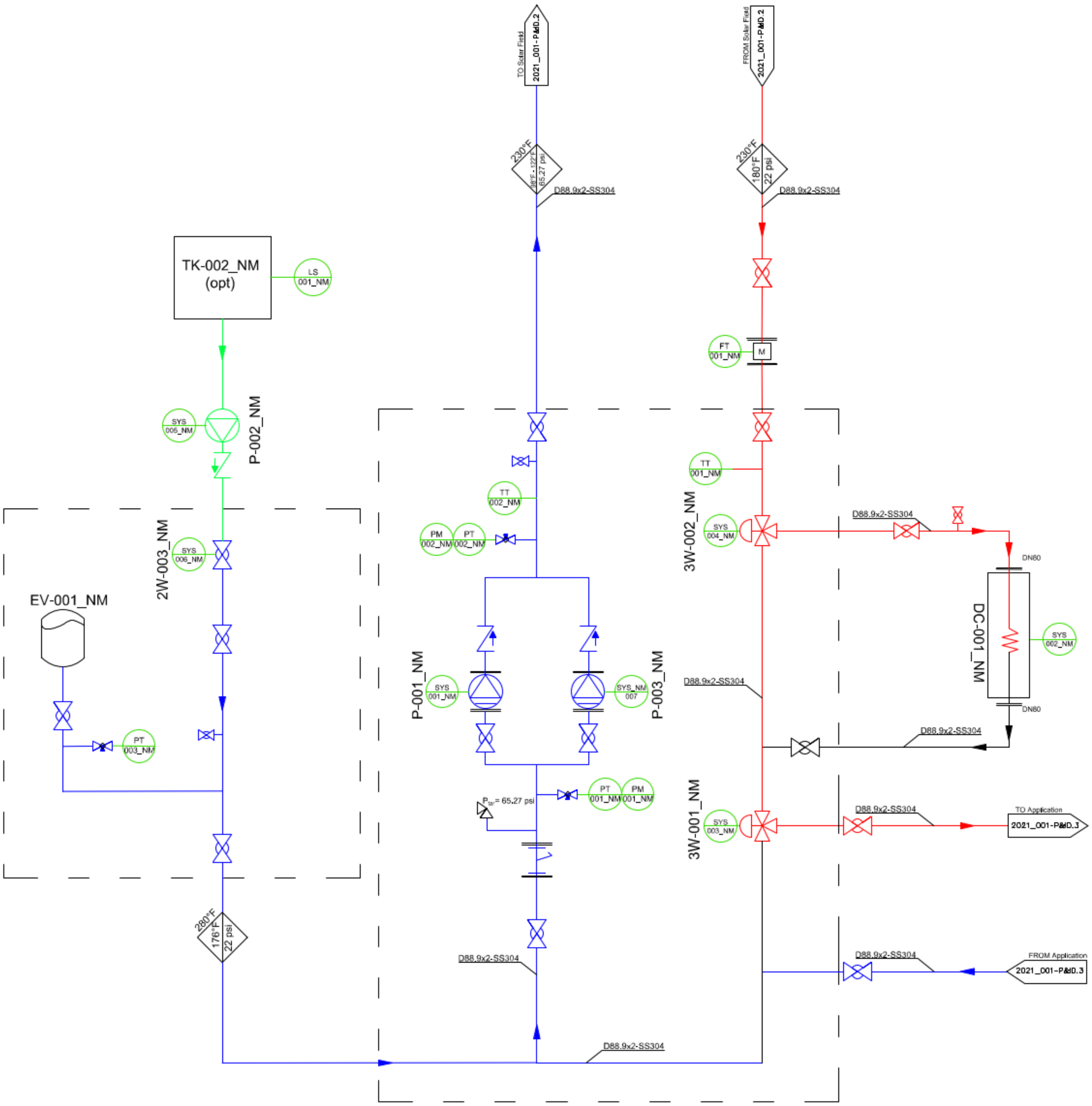
ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX E: Detailed P&IDs

May 2025 | CEC-500-2025-025

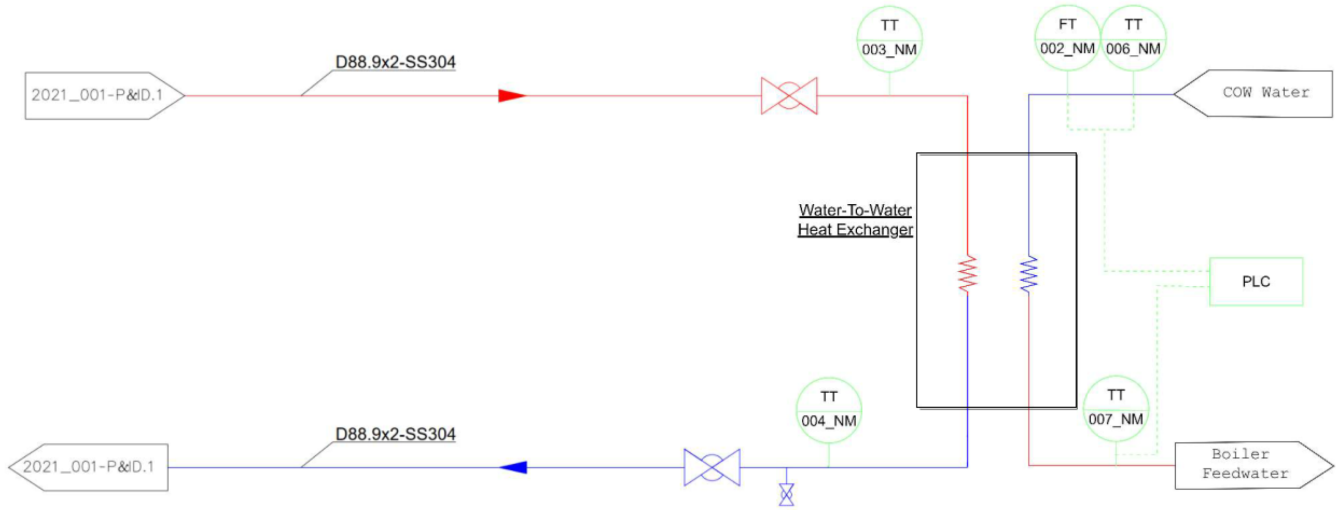
APPENDIX E: Detailed P&IDs

Figure E-1: Solar Field – P&ID



Source: TVP, 2021

Figure E-2: Solar Field – Application Side



Source: TVP, 2021