ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

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

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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. (Turlock) Zero-Emissions Thermal Energy is the final report for project FPI-19-015 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 co-op in California, producing 17 billion pounds of milk annually. CDI declared 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 its dairy plant in Turlock, California. The system consists of 300 solar collectors (total absorption area of 39,945 square feet) installed at the CDI Turlock plant, which preheats the dryer air to provide renewable energy heat to the plant, decreases the plant's natural gas usage, and decreases plant emissions. The solar thermal system was backed by funding from the California Energy Commission and addresses key elements of California's clean energy and climate goals such as public health, environmental, and economic needs.

Twelve months of measurement and verification data were collected and analyzed from the installed solar thermal system. The extrapolated data show that the annual heat delivered by the system was 10,508 million British thermal units per year, the annual natural gas savings at the plant was 127,683 therms per year, and the annual carbon dioxide emissions reduction was 678 metric tons of carbon dioxide per year.

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

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 Turlock plant located in Turlock, California. According to CalEnviroScreen 3.0, California's Community and Environmental Health screening tool, CDI Turlock's dairy plant is located in an area with a pollution burden in the 91st to 100th 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 threats to public health, revitalizing local economies, and reducing exposure to environmental contaminants. The project supports California's clean energy and climate goals by addressing the following common community needs listed in Table 5 of the California Air Resources Board's Funding Guidelines (CARB, 2018):

- Public health needs: reduce threats to public health suffered disproportionately by priority populations due to air pollutants.
- Economic needs: revitalize local economies and support California-based small businesses and create quality jobs.
- Environmental needs: reduce exposure to local air pollutants.

Project Purpose and Approach

The purpose of the project was to design and install a solar thermal system capable of providing heat that can directly offset natural gas provided heat. The solar thermal system consists of 300 GREENoneTEC panels from the distributor, SOLID California, and is capable of preheating the dryer air, which is removing moisture from the milk product to produce milk powder, to a setpoint of 138°F (59°C). The primary goal of the project was to reduce carbon dioxide emissions at the CDI Turlock plant. The intended audience for this project includes industrial facilities with production processes similar to CDI Turlock's (that is, dairy facilities) as well as various other industries that use thermal energy year-round and are seeking sustainable, clean energy solutions to reduce their carbon footprint — industries such as food and beverage, chemicals, textiles, pulp and paper, hospitality, district heating, and wastewater treatment.

The project approach involved designing and installing a solar thermal system capable of providing the necessary heat to offset natural gas currently used in the facility's manufacturing processes. 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 Turlock and has been actively collecting and monitoring the data from the system since December 1, 2022.

In the project application and the measurement and verification plan, it was predicted that the solar thermal system would be capable of providing 11,970 million British thermal units of heat per year with an assumed boiler efficiency of 83.0 percent. Calculations estimated that the solar thermal project would reduce the emissions from the plant by a total of 766 metric tons of carbon dioxide per year.

After a full year of data collection (from December 1, 2022, through November 30, 2023), it was observed that the solar thermal system provided 5,872 million British thermal units of heat per year. However, the solar thermal system operated with technical and mechanical problems until late October 2023 (see Chapter 3 *Results* for more information). Therefore, Skyven extrapolated the performance data from late October 2023 to early January 2024 (when the system was operating without issues) to determine that the solar thermal system would have provided 10,508 million British thermal units of heat per year had it been operating without issues for the entire year. Using data collected from the site, the actual site boiler efficiency was calculated to be 82.3 percent (see Chapter 3 *Results* for more information on both the observed and extrapolated heat provided by the solar thermal system and the boiler efficiency calculation). The difference between the extrapolated and predicted values was due to issues with the dryer unrelated to the solar thermal system that caused CDI to decrease the operating hours of the dryer, thereby decreasing the heat that could be provided to the dryers.

Actual (extrapolated) heat produced by the solar thermal system after one year of installation was 10,508 million British thermal units, and the predicted heat produced by the solar thermal system calculated in the application and measurement and verification plan was 11,970 million British thermal units.

Actual (extrapolated) carbon dioxide equivalent emissions reduction by the solar thermal system after one year of operation was 678 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 766 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 Turlock. 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 developed an in-depth case study for this project, which was published and is available on the Skyven website (https://skyven.co/).

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 of the piping requires extensive insulation to minimize the thermal losses. Without any grant or incentive funds, the return on investment would take more than 2,300 years for the system to break even with the observed results and more than 125 years for the system to break even with the extrapolated results (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 restrictions, it is Skyven's opinion that alternative technologies, such as steam-generating heat pumps, would be a more effective decarbonization solution with wider appeal. These systems are not subject to weather-related constraints and require less space, which makes 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) Turlock that would reduce the natural gas usage at the plant and therefore reduce emissions at the plant. In the project application phase, it was predicted that the solar thermal system would be capable of producing 11,970 million British thermal unit (MMBtu)/year and of reducing emissions by 766 Metric Tons (MT) carbon dioxide equivalent ($CO2e$)/year. The successful installation of the solar thermal system at the Turlock, California plant is 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, CDI Turlock's plant is located in an area with a pollution score of 91 to 100 percent. The pollution burden percentile, which represents the exposures to pollutants and the adverse environmental conditions caused by pollution, in the CDI Turlock community is the highest possible (90 to 100). The population Characteristics Percentile, representing biological traits, health status, or community characteristics that can result in increased vulnerability to pollution, is in the 60 to 70 range, which is also very high (OEHHA, 2018).

Environmental and Health Benefits: Given the high pollution score and pollution burden percentile, reducing threats to human health 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 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 Solar Thermal Construction Inc. and JPR Systems.

Reducing Air Pollutants: By promoting renewable resources and efficiency improvements, the project contributed to reducing greenhouse gas emissions, which is crucial for the state's ambitious climate goals.

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

In summary, the CDI Turlock solar thermal system project addressed 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 Technologies' aim for this project was to design and install a solar thermal system to offset the use of natural gas in industrial food manufacturing processes such as that at the CDI Turlock 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 clean-in-place (CIP) water via a water-to-water heat exchanger. Throughout the project, several changes were made to the original design: GREENoneTEC collectors (distributed and installed by the company SOLID California) were substituted for the IMA collectors, and the heat sink was changed from the CIP water to the dryer air, as detailed in the following paragraphs.

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 and utility usage data 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 CIP water, which is used to clean process equipment, was determined to be not viable as a heat sink for several reasons. First, the CIP water demand was determined to be not continuous and therefore not an ideal heat sink. Second, evaluation of the site showed that the location for the heat exchanger to transfer heat from the solar thermal system to the CIP water would have been directly in the way of the facility's trucking and loading station. Third, concerns about fouling in the heat exchanger and maintenance blowdown could not be mitigated. It was ultimately decided that the dryer air, which is used for generating milk powder, would be an optimal heat sink and that the solar collector array would create a hot water loop that preheated dryer air via a heat exchanger. The amount of heat required for pre-heating the dryer air was analyzed and compared to the total heat production capability of the proposed solar thermal array, and it was determined that the dryer air was a sufficient heat sink for the solar thermal system. More details on this analysis can be found below in this section.

Equipment Design and Procurement: Skyven's initial plan for the solar thermal array was to use the IMA mirror collectors, a proprietary technology for which Skyven has developed all of the controls' 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 as 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. These factors would have made the production of the IMA collectors not financially or technically viable within the timeframe of the project. Skyven then began scoping other potential vendors for solar thermal technology, including TVP Solar and

SOLID California. After an assessment of mechanical, thermal, and logistical performance, Skyven and CDI selected to proceed with SOLID as the panel distributor. This was determined by evaluating a performance model, collector data sheets, and the Solar Rating and Certification Corporation rating from the panels SOLID proposed in addition to real-time data from two systems that were similarly sized to CDI Turlock. The British thermal unit (Btu) production per collector over the year was analyzed and compared to the data sheet and the performance models that the vendors provided for the CDI Turlock project. SOLID provided reliable data and, given that the project team had used TVP Solar already as a panel supplier for a solar thermal system installed at CDI's plant in Visalia, California, Skyven selected SOLID to be the panel vendor for the project to create more diversity in the portfolio. The collector data sheet provided by SOLID can be found in Appendix B.

Skyven collaborated with Solar Thermal Construction and did the project management, design, permitting, and drawings for the solar thermal system. Skyven also worked with JPR Systems for the collection of site data.

Site Preparation: Skyven and its subcontractor Solar Thermal Construction worked with site architect E.A. Bonelli to obtain and review structural and building drawings for the Turlock site. It was determined that the solar panels would be installed on the ground outside a warehouse. To support the panels, support frames tie into piles that were driven into the ground. The panels were connected hydraulically to a heat exchanger that completes the solar field loop of the system. The other ports of the heat exchanger were tied into the storage tanks. These storage tanks required the installation of a foundation to support the load. The storage tanks then tie into the customer use point (the dryer air). To do this tie-in at the Turlock site, a tunnel underneath the existing railroad at the site was needed. Skyven worked with Solar Thermal Construction to get railroad permits approved for the tunnel. Additionally, piping had to be run along an existing building, which required the installation of necessary pipe supports. Finally, to facilitate the flow of fluids through the various loops, an equipment trailer was fabricated that contains the various pumping systems. A new concrete pad was designed that could support the trailer equipment load.

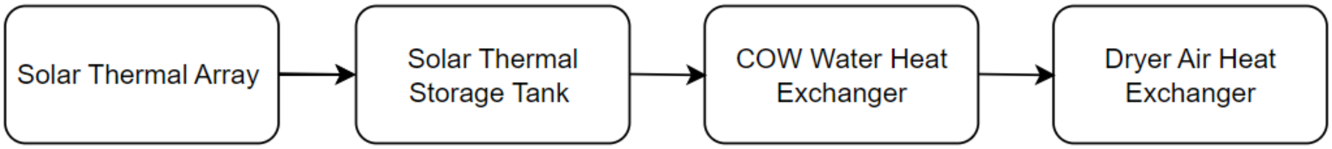
Via implementation of the previously described methodology and approach, the final system design and metering plan were developed. The subsequent paragraphs provide a comprehensive overview of this design and plan.

Final System Design

In the system that was installed at CDI Turlock, the solar collector array created a closed loop where a water/glycol mixture was sent to the solar system and then to a heat exchanger where it dumped the heat into the storage tank water. The storage tank water was then used to heat condensate of whey (COW) water that was then sent to a water-to-air heat exchanger that preheats dryer air to a setpoint of 138 degrees Fahrenheit (°F) (59 degrees Celsius [°C]).

The collector array consists of 300 solar collectors. All collectors were manufactured by GREENoneTEC c (distributed by SOLID), model GK 3133, with an absorber area of 12.37 square meters (133 square feet) per collector for a total absorption area of 3,711 square meters (39,945 square feet). The storage tanks contained 45,610 gallons of water and were used to store thermal energy during periods of reduced irradiance (that is, nighttime, cloudy days) so that the system could provide heat to the dryer air as continuously as possible. Figure 1 illustrates a simplified diagram of the system.

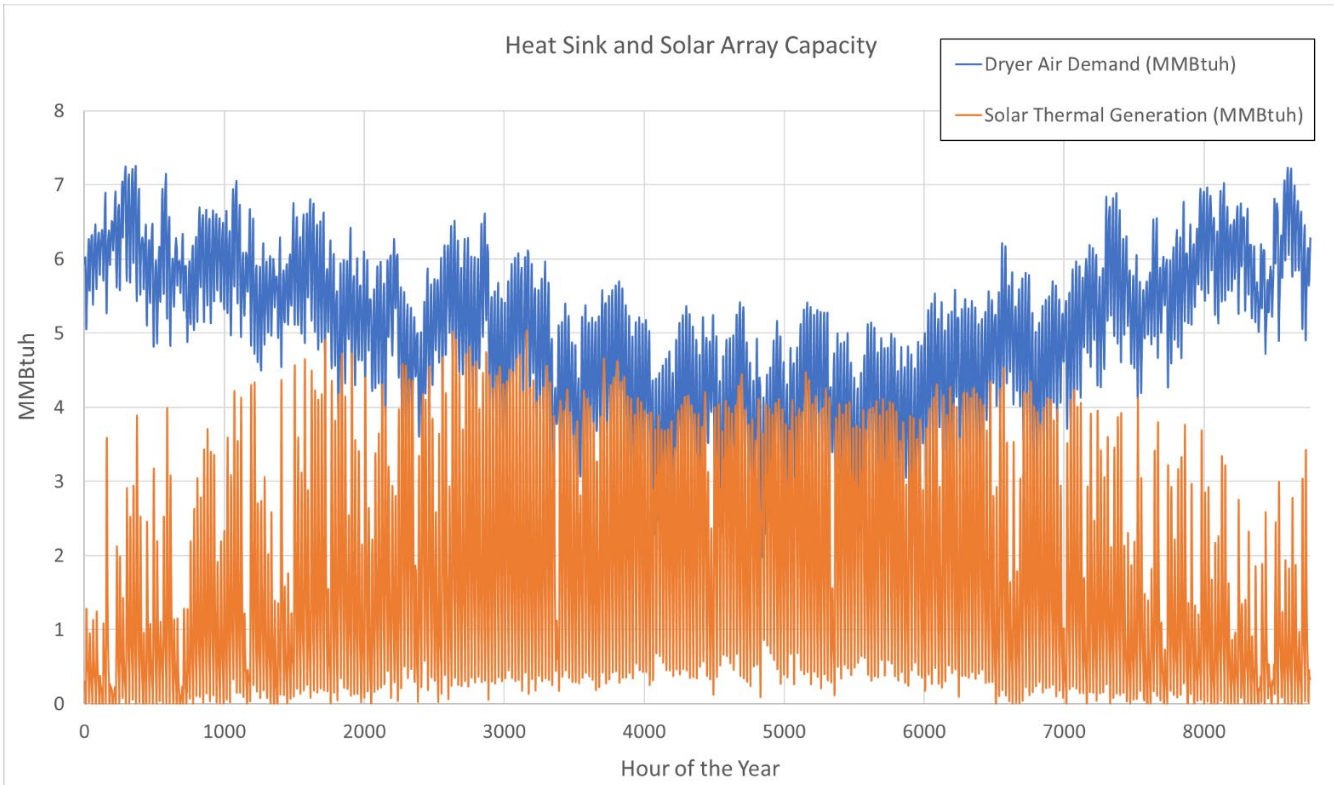
Figure 1: Simplified System Diagram



Source: Skyven Technologies, 2023

If there is a scenario in which the heat generated by the solar field exceeds the heating needs of the air stream and storage capacity, there is a heat-dump dry cooler that can reject heat to the atmosphere. However, it was expected that the presence of excess heat, and therefore the operation of the dry cooler, would be extremely rare. This was determined by creating an annual performance model of the magnitude of heat that the dryer air can accept and comparing it to the heat generated by the solar array. The annual heat generated by the solar thermal system was modeled using the solar radiation observed at the site for each hour of the year. Using this relationship, a value for the heat generated by the solar system for each hour of the year was calculated. To calculate the magnitude of heat that the dryer air could accept, metering equipment was used to characterize the dryer air preheating heat exchanger performance. The modeled temperature of the air heated by the solar thermal system was subtracted from the dryer air setpoint of 138°F (59°C) and multiplied by the ambient air flow rate of 90,000 cubic feet per minute to calculate the heat needed to preheat the dryer air to the process setpoint. Figure 2 shows the heat sink demand (in blue) compared to the solar thermal array generation (in orange) over a year.

Figure 2: Heat Source and Heat Sink Capacity



Source: Skyven Technologies, 2023

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	Manufac turer	Model	Accuracy	Range	Expected Range
Programable Logic Controller (PLC)	Kamstrup	Multical 603	N/A	N/A	N/A
Temperature Sensor	TGH	PT1000 1/3 DIN	+/- 0.18°F (0.1°C)	–58°F (-50°C) to 356°F (180°C)	50°F (10°C) to 190°F (88°C)
Flow Meter	Keyence	FD-R125	+/- 2.0% of reading (136 to 660 GPM) +/- 0.4% of reading (60 to 132 GPM)	60 gallons per minute (GPM) to 660 GPM	0 GPM to 500 GPM

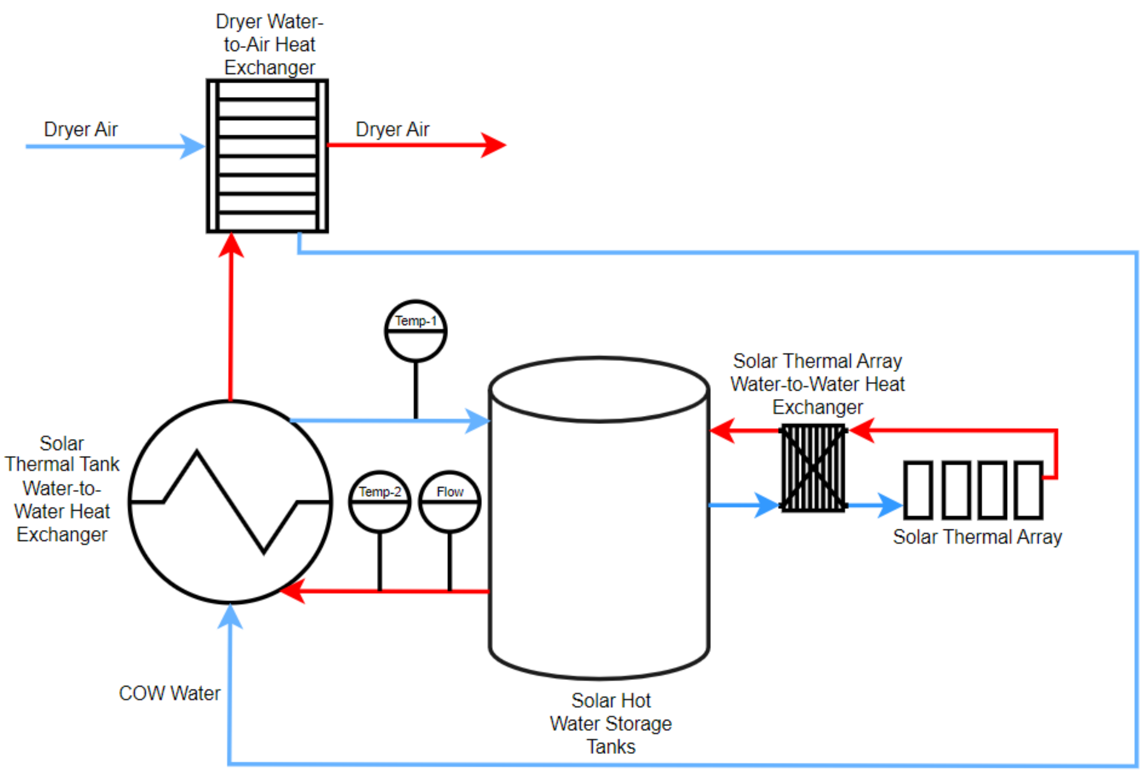
Source: Skyven Technologies, 2023

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) diagram of the North Module for illustration purposes. More detailed P&ID diagrams can be found in Appendix D.

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



Source: Skyven Technologies, 2023

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

Table 2: Metering Datasets

PLC Signal Description		
Label	**Type**	**Description**
Temp-1	Temperature	Load Supply Temperature
Temp-2	Temperature	Load Return Temperature
Flow	Flow	Load Flow Rate

Source: Skyven Technologies, 2023

The data points contained in Table 2 were sent to the programmable logic controller (PLC) to calculate the thermal energy delivered to the dryer air. 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 Technologies tracked the collector-side data points to ensure proper operation of the system, but that data is not relevant for calculating the 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 December 1, 2022. The following is an analysis of a year's worth of data collected from December 1, 2022 to November 30, 2023.

The PLC calculated the instantaneous heat delivered by the solar thermal system using the values from the metering dataset in Table 2 in the following equation:

$$\dot{q} = \rho_{water} * 60\,\frac{min}{hr} * \dot{v} * c_p * (T_{Hot\,Water\,from\,Tank} - T_{Cold\,Water\,Return\,to\,Tank})$$

Where: $\dot{q}$ = Instantaneous heat delivered (Btu/hr)

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

$\dot{v}$ = Volumetric Flowrate of Water from Solar Tank to Heat Exchanger / Meter Label: Flow

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

$T_{Hot\,Water\,from\,Tank}$ = Temperature of hot water leaving the tank (water temperature going to the heat exchanger) / Meter Label: Temp-2

$T_{Cold\,Water\,return\,to\,Tank}$ = Temperature of cold water returning to the tank (water temperature entering solar heat exchanger) / Meter Label: Temp-1

Table 3 shows the observed cumulative total heat delivered from the solar thermal system for each month over the past year.

Actual (Observed) Data

Table 3: Post-Installation Btus Delivered by Solar Thermal System by Month (Observed)

Month - Year	Btus Delivered
December 2022	254,712,279
January 2023	403,339,746
February 2023	487,385,956
March 2023	524,175,699
April 2023	433,167,145
May 2023	414,021,308
June 2023	308,156,620

Month - Year	Btus Delivered
July 2023	497,860,125
August 2023	461,675,262
September 2023	724,120,942
October 2023	619,795,954
November 2023	743,761,330
Total Annual Btus Delivered	**5,872,172,366**

Source: Skyven Technologies, 2023

The total annual heat delivered by the solar thermal system was 5,872,172,366 Btu (5,872 MMBtu).

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

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

Where: Boiler efficiency = 0.823

The boiler efficiency was calculated using the average boiler stack temperature (T_{stack}) observed at the site (300°F [149°C]), the dry oxygen in flue gas ($O_{2,Dry,\%}$) percentage (8 percent), and the following equations from American Society of Mechanical Engineers Performance Test Codes 4 (Boiler Efficiency Stack Loss Method):

1. Calculation of Mass of Dry Gas per Standard Cubic Feet of Fuel:

$$DG = 14.7365\left(\frac{O_{2,\%}}{21\% - O_{2,\%}}\right) + 15.371$$

$$DG = 14.7365\left(\frac{8\%}{21\% - 8\%}\right) + 15.371$$
$$DG = 24.44$$

2. Calculation of Dry Losses in Stack:

$$L_{DG}[\%] = 0.001044 \text{ x } DG\ x\ (T_{stack} - 70)$$

$$L_{DG}[\%] = 0.001044 \text{ x } 24.44\ x\ (300 - 70)$$

$$L_{DG}[\%] = 5.868\ \%$$

3. Calculation of Wet Losses in Stack:

$$L_{WG}[\%] = 9.482 + 0.004351\ x\ T_{stack}$$

$$L_{WG}[\%] = 9.482 + 0.004351\ x\ 300$$

$$L_{WG}[\%] = 10.787\ \%$$

4. Boiler Efficiency:

$$BE = 100\% - L_{DG} - L_{WG} - 1\%_{Other\ Losses}$$

$$BE = 100\% - 5.868\% - 10.787\% - 1\%$$

$$BE = 82.3\ \%$$

Table 4 shows the observed combined therms of natural gas savings from the solar thermal system for each month over the past year.

Table 4: Post-Installation Therms of NG Saved by Solar Thermal System by Month (Observed)

Month - Year	Therms of NG Saved
December 2022	3,095
January 2023	4,901
February 2023	5,922
March 2023	6,369
April 2023	5,263
May 2023	5,031
June 2023	3,744
July 2023	6,049
August 2023	5,610
September 2023	8,799
October 2023	7,531
November 2023	9,037
Total Annual Therms Saved	**71,351**

Source: Skyven Technologies, 2023

The total annual therms of natural gas saved by the solar thermal system was 71,351 therms.

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

Natural Gas Savings:

Average annual NG cost savings was calculated using the following equation:

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

Where: CARB Price of NG = $0.65/therm

Annual NG Fuel Savings Cost = $\frac{71{,}351\ therms}{year} \times \frac{\$0.65}{therm}$

*CARB = California Air Resources Board

Annual NG Fuel Savings Cost = $46,378.15

CO2 Emissions Reductions:

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

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

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

CO2 Emissions Reductions = $\frac{71{,}351\ therms}{year} \times \frac{117.1\ lbs\ CO_2e}{MMBtu} \times \frac{1\ MT\ CO_2e}{2{,}204.62\ lbs\ CO_2e} \times \frac{1\ MMBtu}{10\ therms}$

Annual CO2 Emissions Reductions = 379 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

NOx Emisisons Reductions = $\frac{71{,}351\ therms}{year} \times \frac{0.0049\ lbs\ \mathrm{NO}_X}{therm}$

Annual NOx Emissions Reductions = 350 lbs NOx

Actual (Extrapolated) Data

There were issues at the site that were being masked by a calculation error in Skyven's reporting spreadsheet, so it was believed the system was operating as expected. As part of Skyven's standard operating procedure, in late summer of 2023, an audit was conducted that resulted in the discovery of the reporting spreadsheet error and the realization that the system had issues and was underperforming.

Various issues at the site caused the solar thermal system to underperform including a heat exchanger that was installed backwards and the solar thermal storage system controls that were limiting the amount of heat that storage could absorb during the day. These issues were resolved, and the solar thermal system began operating without issues on October 20, 2023.

Therefore, to determine the annual natural gas and greenhouse gas (GHG) emissions savings the solar thermal system was capable of when operating without issues, the radiation data and the solar thermal Btus produced by the system from October 20, 2023 to January 8, 2024, (during which the system was operating without issues) were compiled. Since the solar thermal Btus produced by the system were essentially a direct correlation to the amount of radiation, a linear relationship between the radiation and solar thermal Btus produced was established. This equation was then used in conjunction with the radiation data to determine the solar thermal Btus that would have been produced over the year had the solar thermal system been operating without issues for the entire year.

Table 5 shows the extrapolated cumulative total heat delivered from the solar thermal system for each month over the past year.

Table 5: Post-Installation Btus Delivered by Solar Thermal System by Month (Extrapolated)

Month - Year	Btus Delivered
December 2022	527,471,427
January 2023	693,474,120
February 2023	631,555,367
March 2023	753,610,528
April 2023	1,067,625,999
May 2023	1,039,655,813
June 2023	1,076,884,137
July 2023	1,123,029,939
August 2023	1,044,172,604
September 2023	952,737,304
October 2023	890,811,826
November 2023	707,253,688
Total Annual Btus Delivered	**10,508,282,752**

Source: Skyven Technologies, 2023

The extrapolated total annual heat delivered by the solar thermal system was 10,508,282,752 Btus (10,508 MMBtu).

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

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

Where: Boiler efficiency = 0.823

Table 6 below shows the extrapolated combined therms of natural gas savings from the solar thermal system for each month over the past year.

Table 6: Post-Installation Therms of NG Saved by Solar Thermal System by Month (Extrapolated)

Month - Year	Therms of NG Saved
December 2022	6,409
January 2023	8,426
February 2023	7,674
March 2023	9,157
April 2023	12,972
May 2023	12,633
June 2023	13,085
July 2023	13,646
August 2023	12,687
September 2023	11,576
October 2023	10,824
November 2023	8,594
Total Annual Therms Saved	**127,683**

Source: Skyven Technologies, 2023

The extrapolated total annual therms of natural gas saved by the solar thermal system was 127,683 therms.

The following shows the calculations and analysis used to determine the natural gas cost savings, CO2 emissions reductions, and NOx emissions reductions from the solar thermal system.

Natural Gas Savings:

Average annual NG cost savings was calculated using the following equation:

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

Where: CARB Price of NG = $0.65/therm

Annual NG Fuel Savings Cost = $\frac{127{,}683\ therms}{year} \times \frac{\$0.65}{therm}$

Annual NG Fuel Savings Cost = $82,993.95

CO2 Emissions Reductions:

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

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

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

$$\text{CO2 Emissions Reductions} = \frac{127{,}683\ therms}{year} \times \frac{117.1\ lbs\ CO_2e}{MMBtu} \times \frac{1\ MT\ CO_2e}{2{,}204.62\ lbs\ CO_2e} \times \frac{1\ MMBtu}{10\ therms}$$

Annual CO2 Emissions Reductions = 678 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

$$\text{NOx Emissions Reductions} = \frac{127{,}683\ therms}{year} \times \frac{0.0049\ lbs\ \mathrm{NO}_X}{therm}$$

Annual NOx Emissions Reductions = 626 lbs NOx

Table 7 summarizes the annual post-installation savings values observed at CDI Turlock.

Table 7: Annual Post-Installation Savings Values (Observed)

Annual Natural Gas Savings at Plant	71,351	therms/year
Annual Natural Gas Cost Savings at Plant	$46,378.15	dollars/year
Annual CO2 Emissions Reductions	379	MT CO2e/year
Annual Nox Emissions Reductions	350	lbs NO_X/year

lbs NOx/year=pounds of nitrogen oxides per year; MT CO2e/year=metric tons of carbon dioxide equivalent per year
Source: Skyven Technologies, 2023

Table 8 summarizes the annual post-installation savings values extrapolated at CDI Turlock.

Table 8: Annual Post-Installation Savings Values (Extrapolated)

Annual Natural Gas Savings at Plant	127,683	therms/year
Annual Natural Gas Cost Savings at Plant	$82,993.95	dollars/year
Annual CO2 Emissions Reductions	678	MT CO2e/year
Annual Nox Emissions Reductions	626	lbs NO_X/year

Source: Skyven Technologies, 2023

In the project application and the measurement and verification (M&V) plan, it was predicted that the solar thermal system would be capable of providing 11,970 MMBtus of heat per year with an assumed boiler efficiency of 83.0 percent. The following equation estimated the solar thermal project would reduce the emissions from the plant by a total of 766 MT of CO2e per year.

Predicted GHG Emissions Offset by Solar Thermal System

Table 9 shows the comparison between the actual and predicted annual heat delivered by the solar thermal system, and Table 10 shows the comparison between the actual and predicted annual CO_2 emissions reductions.

Table 9: Actual (Observed) vs. Actual (Extrapolated) vs. Predicted Annual Heat Delivered by the Solar Thermal System

	Actual (Observed)	Actual (Extrapolated)	Predicted (M&V Plan)
Annual Heat Delivered by Solar Thermal System (MMBtu/year)	5,872	10,508	11,970

Source: Skyven Technologies, 2023

Table 10: Actual (Observed) vs. Actual (Extrapolated) vs. Predicted Annual CO2 Emissions Reduction

	Actual (Observed)	Actual (Extrapolated)	Predicted (M&V Plan)
Annual CO2 Emissions Reductions (MT CO2e/year)	379	678	766

Source: Skyven Technologies, 2023

The delta in the extrapolated and predicted values was due to the fact that the dryer had issues unrelated to the solar thermal system, which caused CDI to decrease the operating hours of the dryer thereby decreasing the overall amount of heat that could be provided to the dryers.

Barriers/Challenges

Several challenges emerged during the project's design phase. Initially, the absence of crucial site engineering information led to an unexpected delay in the design process. Drawings such as P&IDs and site layout drawings that typically would have been available to review were not. To overcome this barrier, two actions were taken. First, sound engineering assumptions were made based on the available data, ensuring progress toward the final design. Additionally, extra site visits were conducted to gather field information that was not obtainable through the engineering drawings. Through these actions, Skyven and its subvendors were able to overcome the lack of engineering drawings.

Another significant challenge was the time difference between Skyven and the panel distributor, SOLID, based in Austria. There were concerns about delays and backlogs in communication and the flow of information given the large time difference. Recognizing the potential communication difficulties, weekly meetings with SOLID were scheduled at suitable times to accommodate both parties. This approach not only facilitated smoother communication but also ensured timely review and commentary on shared information.

The cumbersome process of obtaining permits for digging beneath the railway posed another barrier that required attention and detail. To surmount this challenge, the Solar Thermal Construction subcontractor actively pushed forward the permit application, contributing to the overall success of the project.

Figure 4 shows the solar thermal system installed on the ground at CDI Turlock plant.

Figure 4: View of Solar Thermal System on the Ground at CDI Turlock

Source: Skyven Technologies, 2023

Return on Investment

The system would require roughly $44,300 in annual maintenance costs for tasks such as visual inspection and spot checking of the solar field, solar panels, and metering equipment every quarter and cleaning and spot checking of the filters, dry cooler, and metering equipment quarterly. The system budget was $4.9 million. The system requires $44,300 in annual maintenance costs and was observed to save an average of $46,378 in fuel annually but should now save an average of $82,994 in fuel annually. Without any grant or incentive funds, the return on investment would take more than 2,300 years for the system to break even with the observed results and more than 125 years for the system to break even with the extrapolated results.

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 CDI's dairy plant in Turlock, California. This system, comprised of 300 solar collectors installed on the grounds of the plant, contributes renewable energy heat to the plant, reduces natural gas consumption, and curtails emissions.

Supported by funding from the CEC, 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 Turlock plant, which is in an area marked by high pollution levels, this project addresses the goal of public and environmental health. Furthermore, the collaboration with several California-based companies, including Solar Thermal Construction and JPR Systems furthers the economic development goals of the CEC.

Over one year, from December 1, 2022, through November 30, 2023, Skyven collected extensive measurement and verification data since the commissioning of the project in December 2022 and analyzed that data to determine the annual performance metrics of the solar thermal system at CDI Turlock. The observed data revealed that the system provided an annual heat output of 5,872 MMBtu/year. Using the actual site boiler efficiency of 82.3 percent, the solar thermal system provided an annual natural gas savings of 71,351 therms/year and an annual reduction of 379 MT CO2e/year. The data was extrapolated to reveal that, without any technical or mechanical problems, the system could provide an annual heat output of 10,508 MMBtu/year. Using the actual site boiler efficiency of 82.3 percent, the solar thermal system provided an annual natural gas savings of 127,683 therms/year and an annual reduction of 678 MT CO2e/year. Without any grants or incentives, the return on investment would take more than 2,300 years for the system to break even with the observed results and more than 125 years for the system to break even with the extrapolated results

In the project application phase, it was predicted that the solar thermal system would be capable of producing 11,970 MMBtu/year and of reducing emissions by 766 MT CO2e/year. Comparatively, the observed actual system was producing roughly half the predicted amount, but the extrapolated data showed the system would be within 11 percent of the predicted values. The difference is due to problems with the dryer unrelated to the solar thermal system that caused CDI to decrease the operating hours of the dryer, thereby decreasing the heat that could be provided to the dryers.

The key takeaway from the project is 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.

Furthermore, the system demands a significant amount of on-site 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
Btu/hr	British thermal units per hour
°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 Turlock plant
CEC	California Energy Commission — California's primary energy policy and planning agency
CIP	clean-in-place — an automated method of cleaning the interior surfaces of pipes, vessels, equipment, filters, and associated fittings, without major disassembly
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 Turlock 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
IMA	intelligent mirror array
lb	pound
lb CO2e/MMBtu	pounds of carbon dioxide equivalent per million British thermal unit
lb NOx/year	pounds of nitrogen oxides per year
lb NOx/therm	pounds of nitrogen oxides per therm
lb/gallon	pound per gallon
MMBtu	million British thermal unit
MMBtu/year	million British thermal unit per year

Term	Definition
MT	metric tons
MT CO2e/year	metric tons of carbon dioxide equivalent per year
M&V	movement and verification
NG	natural gas
NOx	nitrogen oxides
P&ID	piping and instrumentation diagram — a detailed schematic or drawing that shows the interconnection of process equipment, piping, and instrumentation devices in an industrial facility
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
Skyven	Skyven Technologies

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 Reports, are available upon request by submitting an email to pubs@energy.ca.gov.

CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: Press Releases

May 2025 | CEC-500-2025-024

APPENDIX A:
Press Releases

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

Figure A-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.

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Contacts:

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Source: Yahoo Finance, 2023

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

Figure A-2: AP News Press Release

skyventechnologies

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Source: AP News, 2023

CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX B: Collector Data Sheet

May 2025 | CEC-500-2025-024

APPENDIX B:
Collector Data Sheet

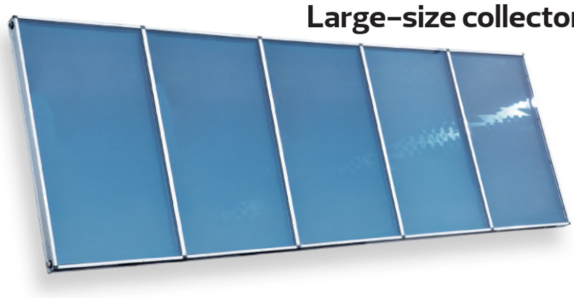
Figure B-1: GREENoneTEC Solar Collector Data Sheet

AALBORG CSP - Changing Energy
Exclusive Danish distributor

GREENoneTEC 1
SOLAR COLLECTORS

GK 3003 Series single & double glazed

Large-size collectors



GREENoneTEC manufactures large-size collectors in the GK 3003 series.
A special design of the absorber and the attractive performance data make these collectors ideal for large solar thermal systems working at higher temperature.
The optimized mounting system, which permits time-saving installation by crane, and hydraulic connection considerably reduce the overall time and effort required to install the system.

Collector installation options

Mounting angle, 30° | Mounting angle, 30° | Mounting angle, 30° | Foundation possibility

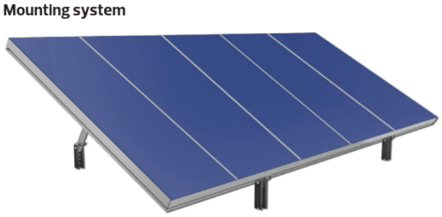
- rammed profiles
- concrete

Technical data	GK 3133 / GK 3133 S	GK 3803 / GK 3803 S
Collector type	Large-size collector	
Overall area [m²]	13.17	7.91
Absorber area [m²]	12.37	7.41
Aperture area [m²]	12.35	7.42
L x W x H [mm]	5920 x 2224 x 135	3557 x 2224 x 135
Weight [kg]	333	202
Weight [kg] - GK/S	232	141
Absorber capacity [l]	11,35	6,81
Housing	Al-frame	
Surface	Al-natural	
Back plate	Al-sheet	
Absorber	Al, highly selective vacuum coating	
Absorption [%]	95	
Emission [%]	5	
Ø manifold [mm]	28	
Ø risers [mm]	8	
Connections	1¼" external thread	
Glass	3.2 mm tempered solar safety glass (double glazing)	
Transmittance of glass [%]	95 - AR glass	
Insulation	70 mm mineral wool plate	
Max. stagnation temperature	218 °C under norm conditions	
Max. operating pressure	10 bar	
Heat transfer medium	Polypropylene glycol / water mixture	
Packaging	for truck and container optimized	

GK 3003 product benefits

- Up to 16 collectors can be connected in parallel / seriel with each other with minimum pressure loss (Low Flow / Tichelmann)
- Optimal stagnation and venting behaviour thanks to the serpentine absorber designed for large systems
- Aluminium frame collector with a high degree of long-term stability satisfies all static requirements as per EN 1991
- Time-saving collector installation thanks optimized support rails as well as simple collector connections
- Excellent value for money thanks to aluminium absorber with highly selective coating as well as minimum crane use and installation time to set up the system
- Easy to service since glass covers and modules can be individually replaced
- High performance panel with double glazing anti-reflex glass

Mounting system



To find out more about our large-size collector go to: www.greenonetec.com

Source: GREENoneTEC, 2015

CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX C: Metering Equipment Data Sheets

May 2025 | CEC-500-2025-024

APPENDIX C: Metering Equipment Data Sheets

Figure C-1: Kamstrup Multical 603 Data Sheet

kamstrup

Data sheet

MULTICAL® 603

The future-proof heat and cooling meter with full flexibility

- Fully programmable data logger with minute loggers
- 2 second integration interval
- 16 years battery lifetime at a reading interval down to 10 seconds
- Possibility of built-in M-Bus
- 2 communication modules
- 7 or 8 digit display resolution
- User-friendly interface with 3 push buttons
- Possibility of backlit display
- Auto Detect of ULTRAFLOW®
- Mixed fluid compatible

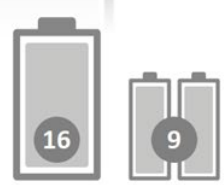
MID 2014/32/EU

CE M21 0200

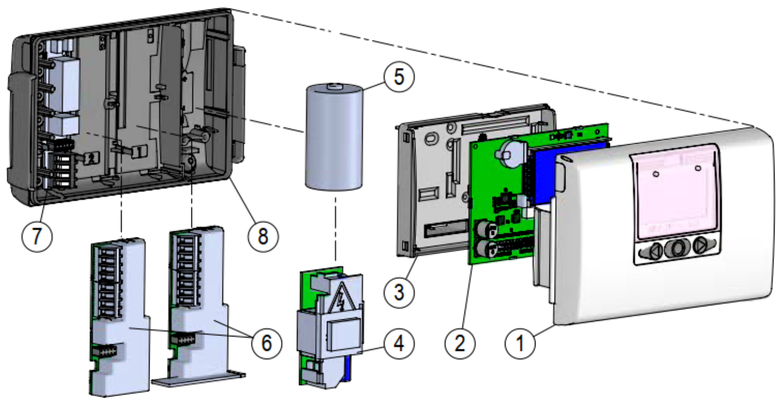
EN 1434

DK-BEK 1178 – 06/11/2014

EN 1434



Mechanical construction



1 Calculator top with front keys and laser engraving
2 PCB with microcontroller, display, etc.
3 Verification cover (may only be opened at an authorised laboratory)
4 Either a power supply module can be mounted...
5 ... or a battery can be mounted
6 1 or 2 communication modules
7 Connection of temperature sensors and flow sensors
8 Calculator base

Mechanical data

Weight	450 g	
Ambient temperature	5...55 °C. Non-condensing, closed location (indoor installation)	
Protection class	IP65	
Medium temperatures ULTRAFLOW®	2...130 °C	At medium temperatures below ambient temperature or above 90 °C in the flow sensor, we recommend that the calculator is wall-mounted.
Medium in ULTRAFLOW®	Water (district heating water as described in AGFW FW510)	
Storage temperature	-25...60 °C (drained flow sensor)	
Connection cable	ø3.5...6 mm	
Supply cable	ø5...8 mm	

Materials

Calculator case – Top and base – Verification cover	 Thermoplastic, PC 10 % GF with TPE (thermoplastic elastomer) ABS
Cables	Silicone cable with inner Teflon insulation

Approved meter data

Approvals	
– Heat meter	DK-0200-MI004-040
- Temperature range	θ: 2 °C...180 °C
- Differential area	ΔΘ: 3 K...178 K
– Cooling meter	TS 27.02 012
- Temperature range	θ: 2 °C...180 °C
- Differential area	ΔΘ: 3 K...178 K
– Bifunctional heat/cooling meter	Marked with DK-0200-MI004-040 and TS 27.02 012 as well as yearly mark of MID
- Temperature range	θ: 2 °C...180 °C
- Differential area	ΔΘ: 3 K...178 K
Standard	EN 1434:2015
EU directives	Measuring Instrument Directive, Low Voltage Directive, Electromagnetic Compatibility Directive, Radio Equipment Directive, RoHS directive, Pressurised Equipment Directive
EN 1434 designation	Environmental class A and C
MID designation	
– Mechanical environment	Class M1 and M2
– Electromagnetic environment	Class E1 and E2
Temperature sensor connection	
– Type 603-A	Pt100 – EN 60751, 2-wire connection
– Type 603-B	Pt100 – EN 60751, 4-wire connection
– Type 603-C/E/F/M	Pt500 – EN 60751, 2-wire connection
– Type 603-D/G/H	Pt500 – EN 60751, 4-wire connection

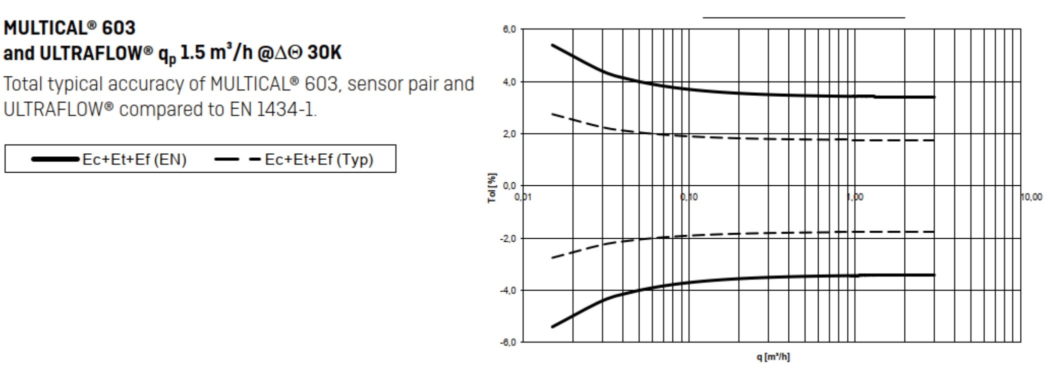
The stated minimum temperatures apply to the type approval only. The meter has no cutoff for low temperature and thus measures as low temperatures as 0.01 °C and 0.01 K.

Measurement accuracy

Heat meter components	MPE according to EN 1434-1	Typical accuracy
MULTICAL® 603	$E_c = \pm (0.5 + \Delta\Theta \text{ min}/\Delta\Theta)$ %	$E_c = \pm (0.15 + 2/\Delta\Theta)$ %
ULTRAFLOW®	$E_f = \pm (2 + 0.02\ q_p/q)$, but not above ± 5 %	$E_f = \pm (1 + 0.01\ q_p/q)$ %
Temperature sensor set	$E_t = \pm (0.5 + 3\ \Delta\Theta \text{ min}/\Delta\Theta)$ %	$E_t = \pm (0.4 + 4/\Delta\Theta)$ %

MULTICAL® 603
and ULTRAFLOW® q_p 1.5 m³/h @ΔΘ 30K

Total typical accuracy of MULTICAL® 603, sensor pair and ULTRAFLOW® compared to EN 1434-1.



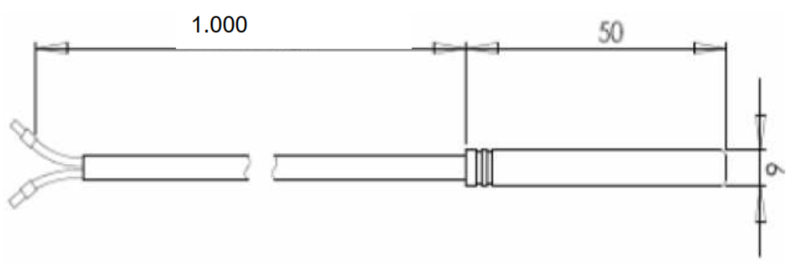
Source: Kamstrup, 2021

Figure C-2: TGH PT1000 Data Sheet

TGH
Technik G. Himbsel GmbH

CABLE TEMPERATURE SENSOR

Sensor:	PT1000 1/3 DIN (DIN EN 60751)
Cable:	Silicon cable (length 1.000 mm)
Wiring:	2-wire
Material:	Stainless steel 1.4571
Sensor size:	6x50 mm
Protection:	IP65
Range:	-50℃…+180℃



Source: TGH, 2022

Figure C-3: Keyence FD-R125 Data Sheet

FD-R125

Sensor Main Unit 100A/125A Type

Specifications

Model		FD-R125
Supported pipe diameter		4" (100 A), ø100 to ø127 3.94" to 5.00" 5" (125 A), ø127 to ø152 5.00" to 5.98"
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): 4"(100 A): 2500 L/min 660 gal/min 150 m^3 /h 5" (125 A): 3700 L/min 990 gal/min 220 m^3/h)
Zero cut flow rate		Zero cut: 0.3 m/s (default)[*3] Flow rate (Typical): 220 L / min 60 gal / min 12 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		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/s² , 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.2.3 kg (including sub unit)

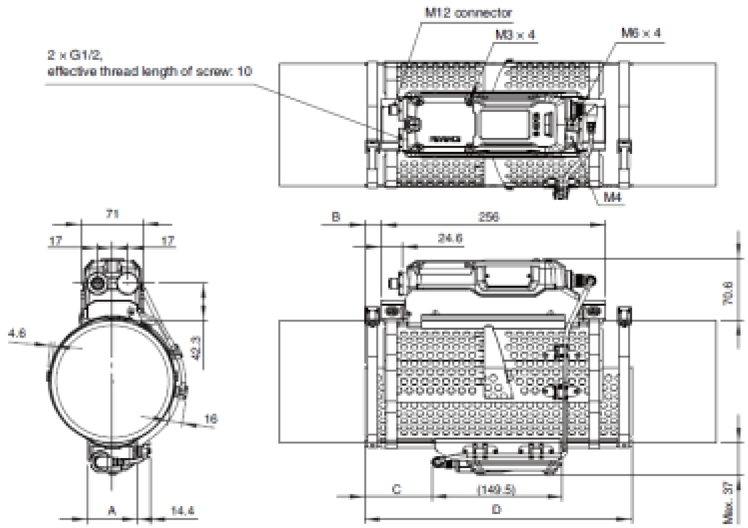
*1 Liquid must allow for the passage of an ultrasonic pulse, as well as not contain large air pockets or excessive bubbles. Detection may be unstable due to the type and status of the pipes.
*2 Perform derating depending on the ambient temperature and liquid temperature when using an AC power supply.
*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)

Dimensions

* Download CAD file or product manual for larger image/text and more detail.

FD-R125_200_dimension_01.gif

● FD-R125/FD-R200



	FD-R125	FD-R200
A	57	62
B	14.1 to 34.6 4" (100A): 29 5" (125A): 19	17.1 to 42.9 6" (150A): 37.6 8" (200A): 18.5
C	(76.9)	(104.3)
D	306	315

Source: Keyence, 2022

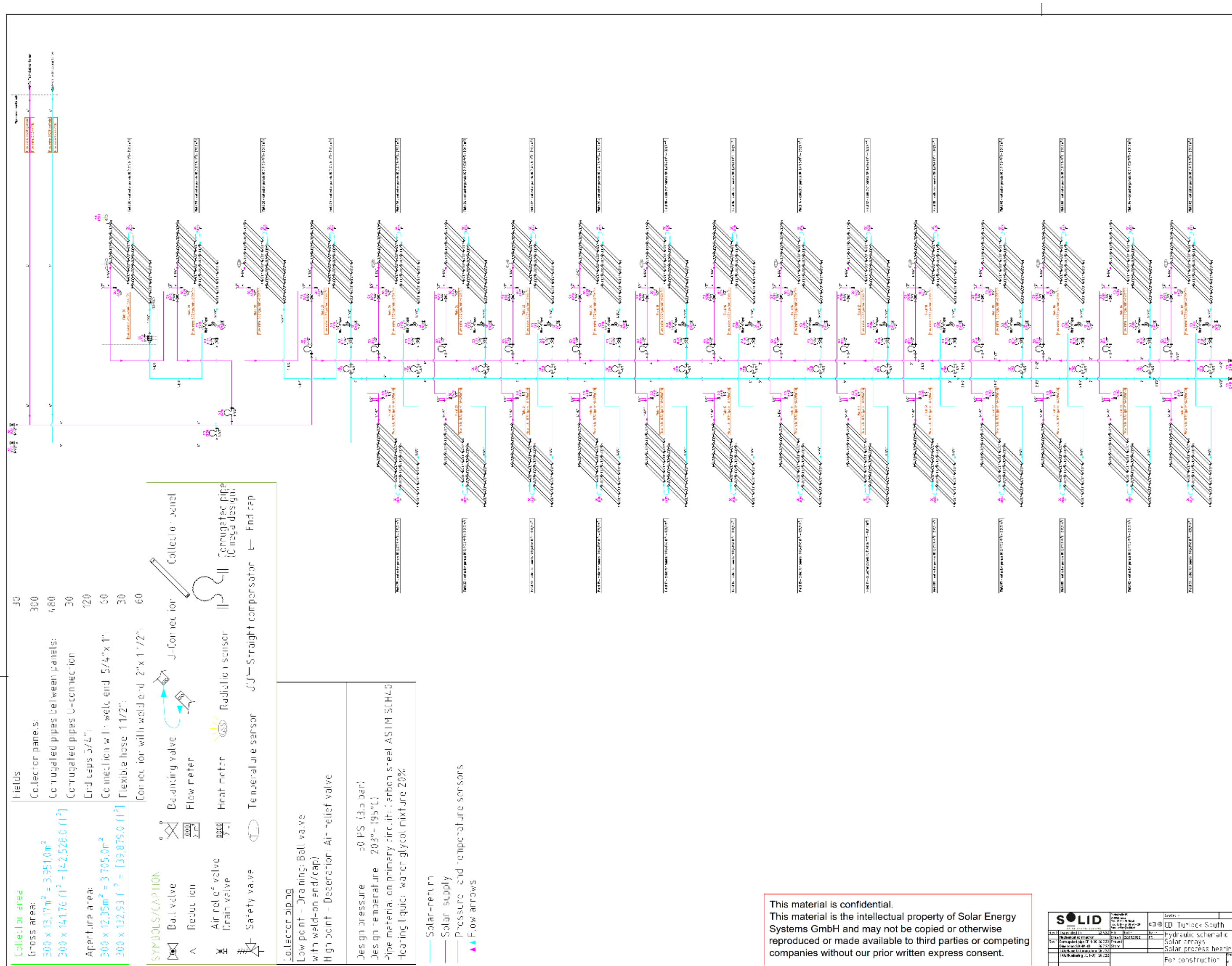
ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX D: Detailed P&IDs

May 2025 | CEC-500-2025-024

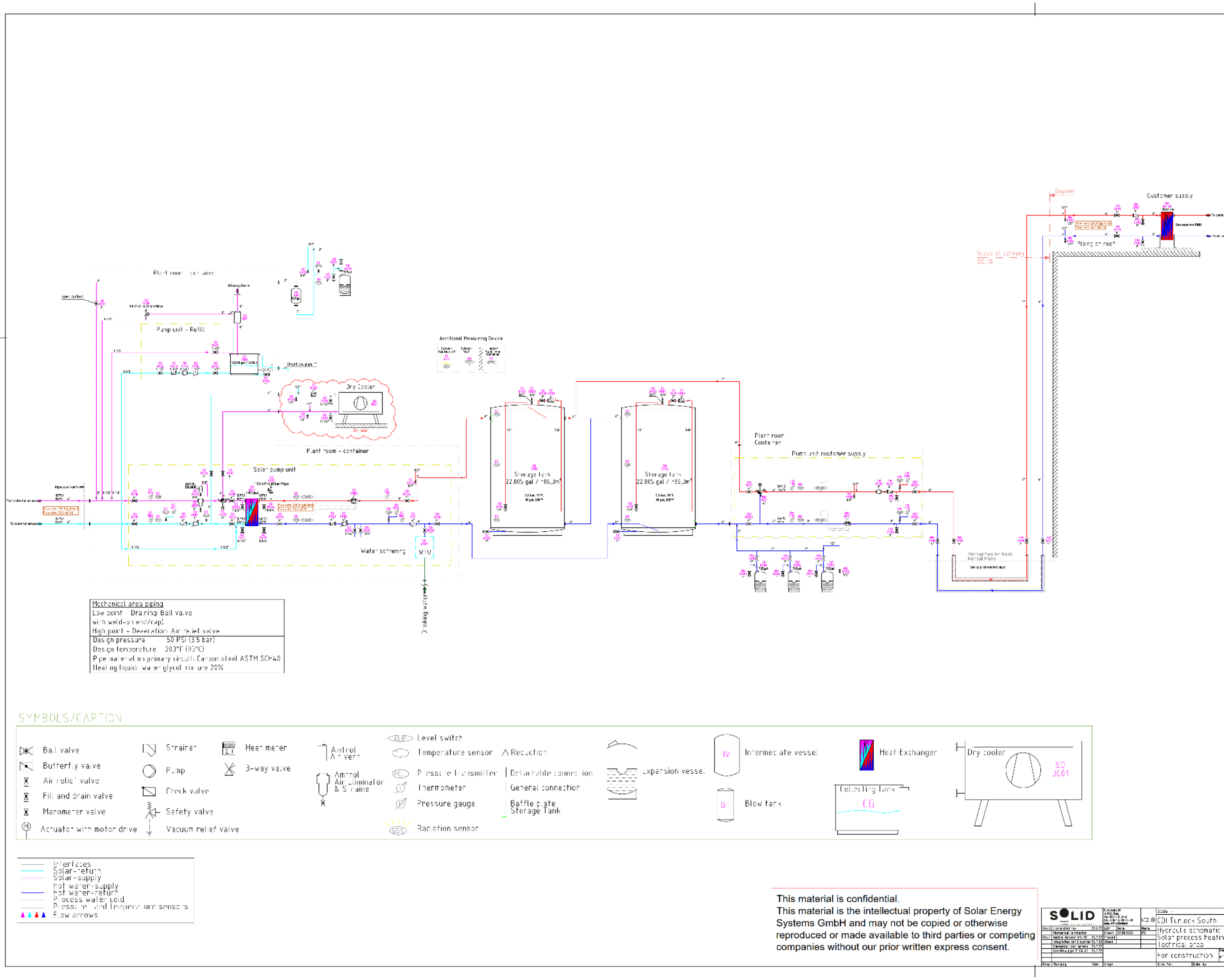
APPENDIX D: Detailed P&IDs

Figure D-1: Solar Array Hydraulic Schematic



Source: SOLID, 2022

Figure D-2: Solar Process Hydraulic Schematic



Source: SOLID, 2022