CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Implementation and Verification of a Condensing Heat Recovery System at Dairy Farmers of America Facility

A Detailed Analysis of Energy Savings and Environmental Benefits

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PREPARED BY:

La Gussi Kanane
Thermal Energy International
Primary Authors

Claire Sweeney
Project Manager
California Energy Commission

Agreement Number: FPI-19-025

Alex Horangic
Office Manager
SUSTAINABILITY AND RESILIENCE 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.

Implementation and Verification of Condensing Heat Recovery System at Dairy Farmers of America Ventura Facility is the final report for the Boiler Heat Recovery project (Grant Number: FPI-19-025) conducted by Thermal Energy International. 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

Beverage production is an energy intensive process involving substantial natural gas use to produce steam for heating and cleaning. Approximately 18 percent of the heat energy is lost when superheated gases leave the boiler exhaust stack. Without the use of economizers to recover this energy, waste gases are exhausted at high temperatures, representing a significant amount of wasted energy and excess greenhouse gas emissions.

The primary objective of the Condensing Heat Recovery Project was to install a condensing heat recovery system to capture and reuse waste heat from the boiler exhaust, thereby improving energy efficiency and reducing greenhouse gas emissions. PepsiCo partnered with the Dairy Farmers of America facility in Ventura, California, to implement this advanced technology.

Prior to this project, the facility's steam boilers operated at an efficiency level of 80 percent with significant energy losses through the boiler stack. The newly installed heat recovery system captured both latent (heat energy required for a substance to change phases without changing temperature) and sensible heat (heat energy that causes a change in temperature of a substance without a phase change) from the exhaust gases that were then used to preheat boiler make-up water and process water, resulting in a notable reduction in natural gas consumption and greenhouse gas emissions.

Based on limited operational data due to the facility's unanticipated closure, the system demonstrated annual savings of 57,282 therms of natural gas and a reduction of 304 metric tons of carbon dioxide equivalent emissions. By annualizing data from a month that was less impacted by the shutdown, estimated savings increased to 107,063 therms and an approximate reduction of 567 metric tons of carbon dioxide equivalent per year.

The project demonstrated the viability of heat recovery technologies in the food production sector, providing a model for similar initiatives. It highlighted the importance of integrating advanced monitoring and control systems to optimize energy use and performance and also had positive economic impacts on the local community.

Keywords: Energy efficiency, condensing heat recovery system, Dairy Farmers of America, natural gas savings, greenhouse gas reduction, food production industry, environmental sustainability, energy management, California Energy Commission

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Introduction/Project Purpose

Beverage production is an energy intensive process involving substantial natural gas use to produce steam for heating and cleaning. Steam systems have the potential to operate at up to 90 percent efficiency but typically operate around 55 to 60 percent efficiency. Approximately 18 percent of the heat energy is lost when superheated gases leave the boiler exhaust stack. Without the use of economizers to recover this energy, waste gases are exhausted at high temperature (between 280-380 degrees Fahrenheit [138-193 degrees Celsius]) representing a significant amount of wasted energy and excess greenhouse gas emissions.

The Dairy Farmers of America facility in Ventura, California, is a beverage manufacturing plant producing various dairy-based products, including Starbucks-brand ready-to-drink Frappuccino beverages produced in partnership with PepsiCo. This project aimed to install a condensing heat recovery system to capture and reuse waste heat from the boiler exhaust, addressing the inefficiency of the steam generation process by reducing natural gas consumption and greenhouse gas emissions.

Project Goals and Objectives

The project sought to:

- Reduce natural gas consumption by 139,962 therms per year.
- Lower GHG emissions by 743 metric tons of carbon dioxide equivalent per year.
- Demonstrate the viability of energy-efficient technologies in the food production sector.
- Support local low-income communities through economic benefits from involving local vendors and contractors.

Project Approach

A dedicated team from Dairy Farmers of America, PepsiCo, and Thermal Energy International executed the project.

The Measurement and Verification Plan (see Appendix A) included pre-installation baseline measurements and continuous post-installation monitoring. Prior to installation, the project team completed detailed engineering design, including mechanical, structural, and electrical drawings, and procured all necessary components to prepare the site.

Project Results

During the installation and commissioning phase, the system successfully demonstrated its ability to capture and reuse waste heat, resulting in reduced natural gas consumption and lower greenhouse gas emissions. Despite the facility's closure shortly after project completion, the project achieved an annual reduction of 57,282 therms of natural gas and 304 metric tons of carbon dioxide equivalent in greenhouse gas emissions. While these savings were lower than originally projected due to the facility's closure and reduced operations, the project still delivered meaningful environmental benefits. Notably, data from April 2023, a month that was less impacted by the shutdown, suggest that annualized savings could have reached approximately 107,063 therms and 567 metric tons of carbon dioxide equivalent had the system operated under normal conditions. These findings highlight the project's strong potential and reinforce the value of similar waste heat recovery technologies in the food production sector.

Technology/Knowledge Transfer/Market Adoption

Despite the closure of the facility, Dairy Farmers of America and PepsiCo have valuable opportunities to support broad knowledge transfer through internal dissemination, industry engagement, academic collaborations, and media outreach. These efforts are intended to promote the successful implementation of energy-efficient technologies and encourage their wider adoption across the food processing industry.

Future Recommendations

Since the equipment remains on site, Thermal Energy International plans to re-engage if the facility is purchased by another company. This would include notifying the new owner about the system, resuming training, recommissioning the equipment, and continuing planned knowledge transfer activities to maximize the project's impact. Efforts would focus on optimizing the system for the new operational context and ensuring that staff are properly trained to operate and maintain it efficiently.

CHAPTER 1: Introduction/Project Purpose

Beverage production is an energy intensive process involving substantial natural gas use to produce steam for heating and cleaning. Steam systems have the potential to operate at up to 90 percent efficiency but typically operate around 55 to 60 percent efficiency. Approximately 18 percent of the heat energy is lost when superheated gases leave the boiler exhaust stack. Without the use of economizers to recover this energy, waste gases are exhausted at high temperature (between 280-380 degrees Fahrenheit [138-193 degrees Celsius]) representing a significant amount of wasted energy and excess greenhouse gas (GHG) emissions. This project aimed to install a condensing heat recovery system to capture and reuse waste heat from the boiler exhaust, addressing the inefficiency of the steam generation process by reducing natural gas consumption and GHG emissions.

Facility Overview

The project facility is a beverage manufacturing plant in Ventura, California operated by Dairy Farmers of America (DFA). It is part of a joint marketing partnership with PepsiCo and Starbucks through the North American Coffee Partnership. The plant processes a variety of dairy-based products, including Starbucks-brand ready-to-drink Frappuccino beverages. Steam generation is a critical part of the manufacturing process, used for pasteurization, coffee retorts, and clean in place (CIP) processes.

Project Overview

The purpose of this project was to install a condensing heat recovery system to capture and reuse waste heat from the boiler exhaust. This initiative aimed to address the inefficiency in the steam generation process and reduce the facility's natural gas consumption and greenhouse gas (GHG) emissions. Figure 1 shows the boiler and Figure 2 shows the boiler flue.

Figure 1: Boiler at DFA's Facility

Source: Thermal Energy International Inc.

Figure 2: Boiler Exhaust at DFA Facility

Source: Thermal Energy International Inc.

Problem

Steam boilers at the facility typically operated at 80 percent efficiency, with approximately 18 percent of energy being lost through the boiler stack as superheated gases. The absence of economizers exacerbated this issue, resulting in significant energy loss and increased GHG emissions.

Solution

A condensing heat recovery system was installed to capture both latent (heat energy required for a substance to change phases without changing temperature) and sensible heat (heat energy that causes a change in temperature of a substance without a phase change) from the boiler exhaust gases. The recovered heat was used to preheat boiler make-up water and process water, significantly improving the system's overall efficiency.

Goals and Objectives

- **Reduce Natural Gas Consumption:** By capturing waste heat, the project aimed to reduce the facility's natural gas usage by approximately 139,962 therms per year.
- **Lower GHG Emissions:** The project was expected to reduce GHG emissions by 743 metric tons of carbon dioxide equivalent ($MTCO_2e$) annually.
- **Demonstrate Market Potential:** The project aimed to showcase the viability of energy-efficient technologies in the food industry, encouraging wider adoption.

CHAPTER 2: Project Approach

Project Description

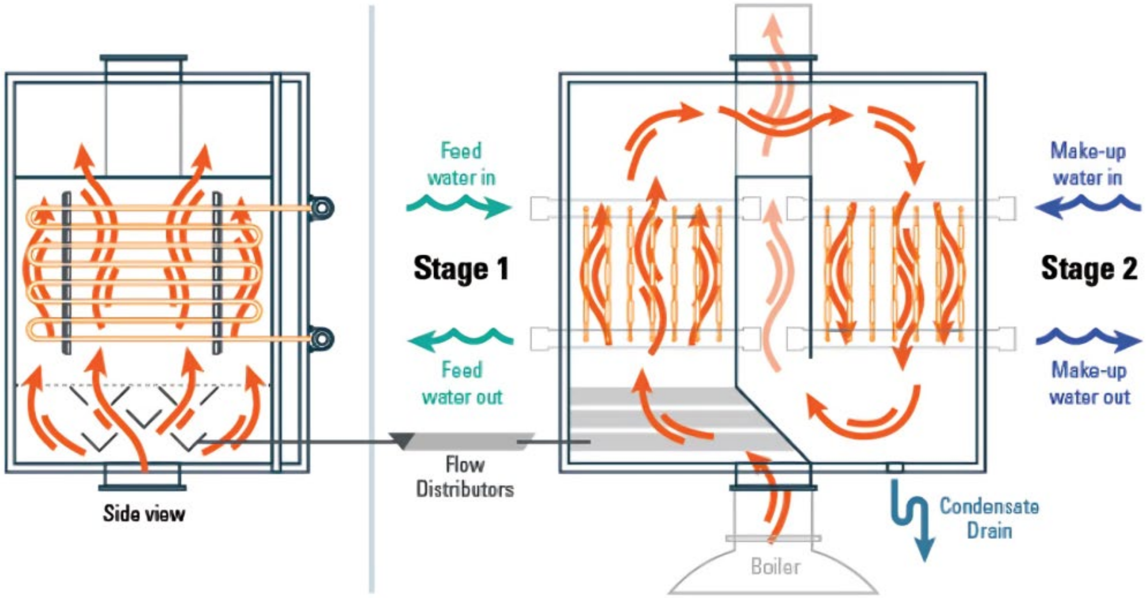
Prior to project installation, the facility's steam boiler system operated at an efficiency of approximately 80 percent. The absence of economizers meant that approximately 18 percent of the energy was lost through the boiler stack as superheated gases. The facility used three natural gas-fired boilers to support essential processes.

The project's primary objective was to install a condensing heat recovery system designed to capture both latent and sensible heat from the exhaust gases produced by these boilers. The installation involved several key components: the condensing heat recovery unit to capture waste heat, the exhaust fan to facilitate the movement of exhaust gases through the heat recovery unit, and the primary pump to circulate water through the system. Additionally, heat exchangers were installed to preheat boiler make-up water and process water using the recovered heat. Control dampers were also included to regulate airflow and optimize heat recovery. A control panel equipped with variable frequency drives and sensors was implemented to monitor and control the system's operations.

Condensing Heat Recovery Unit

Thermal Energy's HeatSponge technology (see Figure 3) is an indirect contact gas-to-liquid condensing heat exchange device. The HeatSponge is a two-stage economizer whereby the first stage pre-heats feedwater and the second stage is a condensing stage responsible for pre-heating cold boiler make-up water. The water circuits run perpendicular to the boiler exhaust gases indirectly contacting one another and cooling the exhaust to below its dew point temperature. By cooling boiler exhaust gas to below its dew point temperature, water vapor present in the products of combustion is condensed, releasing its latent heat of vaporization. These recoverable latent heat losses account for roughly 10 percent of the higher heating value of natural gas. Natural gas savings are derived from preheating boiler make-up water upstream from the deaerator, thereby lowering steam demand and boiler fuel consumption.

Figure 3: Typical HeatSponge Flow Diagram



Source: Boilerroom Equipment Inc.

Exhaust Fan

The exhaust fan (Figure 4) facilitates the movement of exhaust gases through the heat recovery unit. This fan was designed to handle high-temperature exhaust gases and maintain a steady flow rate, ensuring that the heat recovery unit operated efficiently. By controlling the flow of exhaust gases, the fan ensures that the gases spend sufficient time in the heat exchanger to transfer maximum heat to the water circuits. The exhaust fan is essential for maintaining the system's overall pressure balance and preventing back pressure on the boilers.

Figure 4: Industrial Centrifugal Fan

Source: Thermal Energy International Inc.

Primary Pump

The primary pump (Figure 5) circulates water through the heat recovery system. It moves preheated boiler make-up water and process water through the heat exchangers and into the boiler system. The pump was equipped with variable speed controls to adjust the flow rate based on the system's demand, optimizing energy use and ensuring consistent water temperatures. Efficient circulation is critical for maximizing heat recovery and maintaining the desired temperature differentials.

Figure 5: Centrifugal Close-Coupled Pump

Source: Thermal Energy International Inc.

Heat Exchangers (HX-01 and HX-02)

Heat exchangers (HX-01 and HX-02) (Figure 6) were installed to preheat boiler make-up water and process water using the recovered heat. HX-01 handled the initial preheating of feedwater using sensible heat from the exhaust gases, while HX-02 was responsible for further heating using the latent heat captured during the condensation process. These heat exchangers were designed to maximize thermal transfer efficiency, reducing the overall energy required for steam generation and improving the boiler system's efficiency.

Figure 6: Plate and Frame Heat Exchanger

Source: Thermal Energy International Inc.

Control Dampers

Control dampers (Figure 7) regulate airflow within the heat recovery system, optimizing heat transfer and maintaining system balance. These dampers are adjustable, allowing for precise control of exhaust gas flow through the heat exchangers. By modulating the airflow, the dampers help maintain optimal temperature and pressure conditions within the system, enhancing overall efficiency and performance.

Figure 7: Control Damper

Source: Thermal Energy International Inc.

Control Panel (PLC-01) with Variable Frequency Drives (VFDs) and Sensors

The control panel (PLC-01) was equipped with variable frequency drives (VFDs) and sensors to monitor and control the system's operations. The programmable logic controller (PLC) in the control panel collected data from various sensors throughout the system, including temperature, pressure, and flow rate sensors (Figure 8). It used this data to adjust the operation of the VFDs, which control the speed of the exhaust fan and primary pump, ensuring optimal performance. The control panel provided real-time monitoring and allowed for automated adjustments, improving the system's reliability and efficiency.

Figure 8: Boiler Room Flue Gas Heat Recovery System Programmable Logic Controller

Source: Thermal Energy International Inc.

Project Team

This initiative, driven by PepsiCo's sustainability vision, united key partners to deliver innovative energy solutions. While DFA benefited as the facility owner, PepsiCo's leadership and co-funding were central to the project's success.

Thermal Energy International handled system design, heat recovery implementation, and performance tracking. Local contractors executed the installation under PepsiCo's coordination.

The project highlights PepsiCo's role in advancing eco-friendly partnerships and achieving shared sustainability goals.

Projected Benefits

Initial estimates of the project's benefits, calculated using the FPIP Calculator Tool, highlighted the potential for substantial energy and environmental savings. The system was designed to reduce the facility's natural gas consumption by approximately 139,962 therms per year, with an expected annual reduction of 743 $MTCO_2e$ in GHG emissions. Electricity usage was not anticipated to be significantly affected. Although actual savings were lower due to the facility's early closure, adjusted estimates based on representative data from April 2023, a month that was less impacted by shutdown conditions, suggested the system could have achieved up to 107,063 therms in annual natural gas savings and 567 $MTCO_2e$. These values demonstrated the system's strong performance potential under normal operating conditions.

Measurement and Verification Plan

The Measurement and Verification (M&V) Plan was integral to ensuring the project's success and accountability. The plan began with pre-installation baseline measurements from May to July 2021. The measurements involved recording natural gas consumption and GHG emissions from the boilers. Flow meters and temperature probes were also installed to capture accurate baseline data on make-up water and steam flow and their respective temperatures. For the full M&V plan, refer to Appendix A.

Post-installation, the plan involved continuous monitoring of natural gas and GHG reduction for at least 12 months. However, the data collection period was shortened to nine months due to the closure of the facility. The post-installation monitoring period occurred from March to November 2023 and included regular calibration of the equipment to maintain the accuracy of the data collected. Data analysis was conducted to determine the actual reduction in natural gas consumption and GHG emissions, and the results were compiled into a comprehensive post-installation M&V report (see Appendix D).

Project Implementation

The project was implemented through a well-structured approach that included detailed planning, site preparation, equipment procurement, installation, and commissioning. The implementation began with securing the necessary permits, followed by a series of coordinated activities to ensure the successful deployment of the condensing heat recovery system. Key stages in the implementation process included general project tasks, site preparation, equipment procurement, and installation and commissioning.

Site Preparation and Equipment Procurement

Site preparation involved several critical activities to ensure the facility was ready for the installation of the new heat recovery system. Detailed engineering work was conducted to verify equipment sizing and to prepare mechanical, structural, and electrical drawings for construction. Specific tasks are shown in Table 1.

Table 1: Site Preparation and Equipment Procurement Timeline

Task	Duration	Start Date	End Date	Purpose
Detailed Engineering	104 days	March 23, 2021	August 13, 2021	Verify equipment sizes and prepare necessary drawings.
Mechanical Drawings for Construction	6 weeks	March 29, 2021	May 7, 2021	Prepare mechanical drawings for construction.
Structural and Civil Drawings	7 weeks	May 6, 2021	June 23, 2021	Prepare structural and civil drawings.
Electrical and Controls Engineering	4 weeks	July 19, 2021	August 13, 2021	Finalize electrical and controls engineering.

Source: Thermal Energy International Inc.

Equipment procurement involved sourcing all components necessary for the heat recovery system. This phase spanned 166 days, from April 5, 2021, to November 22, 2021, and included the procurement of the indirect contact heat recovery unit, exhaust fan, primary pump, heat exchangers, control dampers, control valves, and the PLC/VFDs and starters. Additionally, control devices, sensors, and ductwork were fabricated and installed to support the system.

Equipment Installation and Commissioning

The equipment installation and commissioning phase was critical to ensuring the system was operational and met the project's objectives. This phase was meticulously planned and executed, involving several key activities:

- **Construction Kick-Off Meeting:** Held on September 1, 2021, to establish the project's initiation.
- **Mechanical Mobilization:** Conducted from September 6 to September 10, 2021, to prepare the site for installation.
- **Primary Circuit Piping Installation:** Spanned 7 weeks, from September 27, 2021, to November 12, 2021, achieving 80 percent completion.
- **Heat Recovery Equipment Installation:** Installation took place between April 19 and May 2, 2022.
- **Process Piping and Exhaust Stacks Tie-Ins:** Completed in May 2022 to integrate the new system with existing infrastructure.
- **Electrical Mobilization and Wiring Installation:** Conducted in May 2022 to connect the control panel and sensors, ensuring full system integration.
- **System Startup and Commissioning:** Commissioning took place May 31 to June 13, 2022, including input and output checks, equipment startup, controls commissioning, and optimization.

The heat recovery system setup was successful. All components were installed according to the project plan and the system was tested for operational efficiency. This phase confirmed the system's ability to capture and reuse waste heat, reducing natural gas consumption and GHG emissions. The successful commissioning of the system marked the completion of the installation phase, ensuring that the facility could immediately benefit from the enhanced energy efficiency and environmental performance of the new heat recovery system.

Project Changes and Challenges

The project was documented through a series of progress reports that provided insights into the implementation process, challenges encountered, and actions taken to overcome these challenges.

Initial Phase and Early Challenges

The project commenced with detailed planning and engineering, which included verifying equipment sizes and preparing mechanical, structural, and electrical drawings. One of the early challenges encountered was the alignment of project activities with the facility's ongoing operations. Ensuring minimal disruption to the food production schedule required careful coordination and flexibility in planning. Additionally, obtaining necessary permits and compliance with California Environmental Quality Act (CEQA) requirements posed administrative hurdles that needed to be addressed promptly.

To overcome these challenges, the project team held regular coordination meetings with facility management to align installation activities with production schedules. The team also worked closely with local authorities to expedite the permitting process, ensuring that all regulatory requirements were met without significant delays.

Impact of COVID-19

The COVID-19 pandemic introduced a new set of challenges, particularly in terms of labor availability and supply chain disruptions. Restrictions and safety protocols limited the number of workers on site, which slowed some of the installation activities. Additionally, delays in the delivery of critical components affected the project timeline.

The project team responded by implementing strict health and safety protocols to protect workers and minimize the risk of COVID-19 transmission. They also adjusted the project schedule to accommodate delays, prioritizing tasks that could be completed with available resources and rescheduling those that required delayed components. Communication with suppliers was increased to manage and expedite deliveries where possible.

Site Preparation and Equipment Procurement

During the site preparation phase, unexpected issues with the site's infrastructure were encountered. The existing piping and ductwork were not sufficient to support the new equipment. This required unplanned structural adjustments and additional procurement of materials, leading to slight deviations from the original schedule.

The project team addressed these issues by conducting thorough site assessments and bringing in structural experts to design the necessary reinforcements. These adjustments were communicated to all stakeholders, ensuring that the project remained on track despite the unforeseen challenges.

Installation and Commissioning

The installation phase presented its own set of challenges, primarily related to integrating the new heat recovery system with the existing infrastructure. Aligning the new components with the old systems required precise engineering and occasionally led to minor delays.

To mitigate these challenges, the team used detailed engineering plans and conducted rigorous testing at each stage of the installation. This iterative process ensured that any issues were identified and resolved promptly, maintaining the integrity and performance of the overall system.

Adjustments and Project Changes

Throughout the project, adjustments were made to enhance efficiency and address emerging challenges. For example, additional sensors and control systems were integrated into the heat recovery system to improve monitoring and performance. These changes were made to ensure the system could adapt to varying operational conditions and provide consistent energy savings.

Funding and Support

Funding limitations posed another potential barrier, but strong internal and corporate support from PepsiCo and DFA, along with the FPIP grant, ensured that financial constraints did not hinder progress. The project team effectively managed the budget, reallocating resources as needed to address priority areas and ensure successful project completion.

CHAPTER 3:
Project Results

Measurement and Verification Findings

Measurement and Verification Methodology

The M&V process followed the International Performance Measurement and Verification Protocol (IPMVP) Option B (Retrofit Isolation), which focused on isolating energy savings attributable to the economizer. Key variables measured included water flow rate (FT-01) and inlet (TT-11) and outlet (TT-12) temperatures. These measurements were used to calculate the heat recovered, natural gas savings, and GHG reductions. The same methodology and calculations were used for pre- and post-installation M&V analysis.

Calculations

1. **Heat Recovered:**
   The heat recovered was calculated using the water flow rate and the temperature difference between the inlet and outlet.

This equation quantified the energy captured from the flue gases and transferred to the water.

2. **Natural Gas Savings:**
   The natural gas savings were derived by dividing the heat recovered by the product of the distribution efficiency and boiler efficiency.

This calculation estimated the amount of natural gas that would have been required to generate the equivalent amount of heat without the economizer.

3. **GHG Reductions:**
   The GHG savings were calculated by multiplying the natural gas savings by the emissions factor for natural gas. This step translated the energy savings into equivalent reductions in carbon dioxide emissions.

Baseline data included natural gas usage and GHG emissions for May, June, and July 2021, prior to implementing the energy conservation measure. The total natural gas usage during the three months was 252,225 therms, while the total GHG emissions from the therms consumed during this period were 1,337 $MTCO_2e$. To reflect an annual estimate, both natural gas consumption and GHG emissions were annualized by multiplying the three-month totals by 4. This results in an estimated annual natural gas consumption of 1,008,900 therms and corresponding GHG emissions of 5,348 $MTCO_2e$ per year.

Post-installation data was collected over 251 days, with 10-second sensor readings, and annualized for reporting purposes.

Data Collection Results

Table 2 presents the heat recovered and corresponding carbon reduction for each month during the 251-day operational period of the plant.

Table 2: Monthly Heat Recovery and Carbon Reduction

Month	Heat Recovered (therms)	CO2 Reduction ($MTCO_2e$)
Mar-23	3349.89	17.75
Apr-23	6135.36	32.52
May-23	5390.49	28.57
Jun-23	4854.74	25.73
Jul-23	3647.19	19.33
Aug-23	4193.13	22.22
Sep-23	4549.00	24.11
Oct-23	4830.15	25.60
Nov-23	2441.37	12.94
Total	**39,391.31**	**208.77**

Source: Thermal Energy International Inc.

To represent an annualized total, the monthly heat recovered data was scaled using a factor of 365/251. Since the CO_2 reduction was directly derived from the heat recovered, this annualization is reflected in both values. For an example of daily heat recovery data, refer to Appendix E. The total annualized heat recovered was 57,282 therms and the total annualized CO_2 reduction was 304 $MTCO_2e$.

Notably, April 2023 showed the highest level of heat recovery and carbon reduction during the 251-day operational period, with 6,135 therms recovered and a corresponding reduction of 32.52 $MTCO_2e$. This month was less affected by the facility's operational disruptions, making it a useful reference point for estimating the system's potential under more typical conditions. When annualized based on April's performance, projected savings increased to approximately 107,063 therms of natural gas and 567 $MTCO_2e$. These adjusted figures provide a clearer indication of the system's capability and reinforce the benefits that could be achieved in a fully operational setting.

Issues in Findings

1. Facility Closure: The most significant factor impacting the M&V findings was the phased closure of the DFA Ventura facility shortly after project completion. As production gradually diminished during decommissioning, normal heat usage declined, leading to lower-than-expected energy savings. While the project initially aimed to achieve annual savings of 139,962 therms and reduce GHG emissions by 743 $MTCO_2e$, actual savings were 57,282 therms per year with a GHG reduction of 304 $MTCO_2e$ (Table 3). Despite this, the project successfully demonstrated the effectiveness of

condensing heat recovery technology in food production and provided valuable insights for future applications.

2. Data Gaps: Occasional short-term data gaps occurred due to sensor malfunctions or system maintenance. These interruptions, typically lasting less than 24 hours, were mitigated by interpolating data from adjacent time periods to ensure continuity in energy performance analysis.
3. Production Fluctuations: As the project involved heating both boiler make-up water and process water, energy consumption was directly influenced by production rates. Routine variations in production, such as equipment troubleshooting, plant-wide shutdowns, or equipment replacements, led to fluctuations in energy savings. These variations were a normal part of facility operations and did not reflect system underperformance. Future implementations should consider normalizing energy data against production metrics for more accurate comparisons.

Despite these challenges, the M&V process provided valuable insights into the performance of the condensing heat recovery system and its impact on facility operations.

Table 3: Results

Key Finding	Grant Application Reduction Estimates	Pre-Installation Consumption Measurements (Annualized)	Post-Installation Reduction Measurements (Annualized)
Natural Gas (therms/yr)	139,962	1,008,900	57,282
GHG ($MTCO_2e$/yr)	743	5,348	304

Source: Thermal Energy International Inc.

The observed savings were lower than the original estimates. This discrepancy resulted from unforeseen circumstances that led to the facility's early closure. The shutdown required substantial modifications to normal operating processes, significantly reducing heat usage compared to the baseline assumptions used in the initial savings estimates. Furthermore, data collection occurred during the facility's wind-down period, and no additional data could be gathered once operations ceased entirely.

Despite these limitations, the project delivered meaningful reductions in energy use and greenhouse gas emissions.

Comparison and Analysis

The project achieved its primary goals of reducing energy consumption and GHG emissions, albeit at a lower scale than originally anticipated. The key improvements observed were:

- **Natural Gas Savings:** The project resulted in a reduction of 57,282 therms of natural gas per year, significantly lowering the facility's operational costs and environmental impact.

- **GHG Emissions Reduction:** The reduction of 304 $MTCO_2e$ annually represents a substantial environmental benefit, contributing to California's broader GHG reduction goals.
- **Enhanced System Efficiency:** The efficiency improvements not only reduced energy consumption but also enhanced the overall performance and reliability of the steam generation system.

Achievement of Project Goals/Objectives

The project met its objectives of reducing natural gas consumption and GHG emissions through the installation and operation of the condensing heat recovery system. However, the actual savings achieved were lower than initially projected due to the facility's closure during the post-installation M&V data collection period. Production levels were significantly reduced leading up to the closure. With less production, the facility's need for heat decreased, as the processes that relied on heat energy were scaled back. As a result, the normal heat usage that the savings estimates were originally based on was reduced, leading to lower actual savings than anticipated.

The project demonstrated the viability of such technologies in the food production sector, providing a model for similar initiatives. If the plant is acquired by another company, Thermal Energy International will be available to recommission the equipment to ensure that the intended savings can be achieved. This would involve re-optimizing the system to align with the new operational conditions and ensuring that the staff are adequately trained to maintain and operate the system efficiently. The equipment has been left in its original installed location, making it ready for potential recommissioning.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

Sharing Knowledge and Lessons Learned

This project serves as a case study in implementing energy-efficient technologies in the food production sector.

Internal Dissemination

Within DFA and PepsiCo, the knowledge gained from this project has been systematically documented and shared across various departments and teams. This internal dissemination included detailed reports, presentations, and training sessions aimed at educating staff about the benefits and implementation processes of condensing heat recovery systems.

CHAPTER 5: Conclusions/Recommendations

Conclusions

The implementation of the condensing heat recovery system at the DFA Ventura facility demonstrated achievements in energy efficiency and GHG emissions reduction. The project met its primary objectives, despite lower-than-expected savings due to the unforeseen closure of the facility, which impacted the initial savings estimates. Nevertheless, the project provided insights into the potential for similar initiatives in the food production sector.

Energy Efficiency and Environmental Impact

The project achieved a reduction in annual natural gas consumption of 57,282 therms resulting in a decrease of 304 $MTCO_2e$. These savings were achieved by capturing and reusing waste heat from the boiler exhaust gases, which improved the efficiency of the facility’s steam generation system. Using performance data from April 2023, a month less affected by the facility closure, as a baseline, annual savings could have reached up to 107,063 therms and 567 $MTCO_2e$ under normal operating conditions. This indicated that the system has strong potential to deliver greater benefits in a fully operational setting.

Technological Viability

The installation and commissioning of the condensing heat recovery system validated the technological viability of such systems in industrial settings. The project demonstrated that with proper planning, engineering, and execution, energy savings and environmental benefits could be realized. The use of advanced monitoring and control systems ensured optimal performance and reliability of the installed technology.

CHAPTER 6: Benefits to California

This project has achieved benefits for the project site, the local community, the food production industry, and the State of California as a whole. Despite the facility's closure, the implementation of the condensing heat recovery system resulted in environmental and economic gains that align with California's broader sustainability and climate goals.

Site Benefits

This project led to an improvement in energy efficiency and operational sustainability. The installation of the condensing heat recovery system reduced the facility's natural gas consumption by approximately 57,282 therms per year. This decrease in energy usage translated into significant cost savings for the facility, enhancing its economic viability and competitiveness. Additionally, the reduction of 304 $MTCO_2e$ emissions annually lessened the facility's environmental footprint, contributing to a cleaner and more sustainable operation. The enhanced efficiency and reliability of the steam generation system also improved overall process performance, supporting continuous and efficient production, albeit for a shorter period than anticipated due to the facility closure.

Local Community Benefits

Since the Ventura, California facility is situated in a low-income community, the criteria pollutant reductions have a particularly meaningful impact. By engaging local contractors and vendors during the installation and commissioning phases, the project created job opportunities and supported local businesses in a low-income area.

Industry Benefits

The project demonstrated the technical and economic feasibility of heat recovery systems, providing a replicable example for other facilities looking to improve energy efficiency and reduce GHG emissions.

Statewide Benefits

The project aligns with California's ambitious climate goals and commitment to reducing GHG emissions. The reduction of 304 $MTCO_2e$ emissions annually contributes to the State's efforts to mitigate climate change and improve air quality. If operated under typical conditions, the system's potential to reduce up to 567 $MTCO_2e$ per year would have further amplified these contributions. By showcasing the successful implementation of energy-efficient technologies, the project supports California's policy objectives and reinforces the state's leadership in environmental sustainability.

The cost savings achieved through reduced natural gas consumption enhance the competitiveness of California’s food production sector, supporting the State’s economic resilience and sustainability.

Additionally, the project’s positive environmental impact supports California’s broader environmental goals, including the protection of natural resources and the promotion of clean energy technologies. The project serves as an example of how targeted investments in energy efficiency can deliver environmental and economic benefits, encouraging further investment and innovation in sustainable technologies.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
boiler exhaust	The waste gases released from a boiler during combustion.
CEC	California Energy Commission
CEQA	California Environmental Quality Act. A statute that requires state and local agencies to identify the significant environmental impacts of their actions and to avoid or mitigate those impacts if feasible.
CIP	clean in place: a method of cleaning the interior surfaces of pipes, vessels, process equipment, filters, and associated fittings, without disassembly.
CO_2	carbon dioxide: a greenhouse gas produced by the combustion of carbon-based fuels.
condensing heat recovery System	A system that captures both latent and sensible heat from exhaust gases, typically from boilers, to preheat water or other fluids, improving overall energy efficiency.
DFA	Dairy Farmers of America: a national milk marketing cooperative in the United States.
EF-01	exhaust fan: a component of the heat recovery system that facilitates the movement of exhaust gases through the heat recovery unit.
FPIP	Food Production Investment Program: a program aimed at supporting energy-efficient technologies in the food production sector to reduce greenhouse gas emissions.
GHG	greenhouse gas: gases that trap heat in the atmosphere, contributing to global warming and climate change.
HX-01 and HX-02	heat exchangers: devices used to transfer heat between two or more fluids. In this project, they were used to preheat boiler make-up water and process water using recovered heat.
input and output checks	Tests performed during system startup to verify that all sensors and control devices are functioning correctly.
IPMVP	International Performance Measurement and Verification Protocol
latent heat	heat energy required for a substance to change phases without changing temperature
M&V Plan	Measurement and Verification Plan: a plan developed to measure and verify the performance and impact of an energy efficiency project.
$MTCO_2e$	metric tons of carbon dioxide equivalent, a unit of measurement used to calculate greenhouse gas emissions.

Term	Definition
PLC	programmable logic controller. A control panel equipped with variable frequency drives (VFDs) and sensors, used to monitor and control system operations.
primary pump (CP-01)	A pump used to circulate water through the heat recovery system.
project implementation	The process of planning, preparing, procuring equipment, installing, and commissioning a project.
sensible heat	heat energy that causes a change in temperature of a substance without a phase change
steam generation	The process of producing steam from water by heating it, typically using boilers.
VFD	variable frequency drive: a device used to control the speed and torque of electric motors by varying the frequency and voltage of the power supplied to the motor.

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: Measurement and Verification Plan

July 2025 | CEC-500-2025-036

Overview

Sub Projects

This project will have one subcomponent. It will use a single condensing boiler economizer to offset steam usage and natural gas usage at the Dairy Farmers of America (DFA) facility in Ventura. The economizer will take heat from all three (3) natural gas boilers and use it to offset steam usage by heating boiler make up water and process water.

Potential Variations Impacting M&V Efforts

The project will be heating both boiler make up water and process water. Both are dictated by facility production rates. If the facility is producing lower or higher amounts than the baseline used to design the system, there will be some fluctuations in actual energy savings. Some examples of routine events that could lead to instances of lower savings include plant wide shutdowns and equipment replacements. However, TEI does not believe there will be large enough deviations in production to impact yearly energy savings.

Flue Gas Heat Recovery

Heat Recovery Using a High Efficiency Indirect – Condensing Heat Recovery Unit

System Description

This project will use a single indirect condensing economizer to recover waste heat from DFA's three (3) boilers. This waste heat will be used to offset steam usage by heating boiler make up water (otherwise being heating by steam in the deaerator tank) and process water (currently heated by steam in various process shell and tube heat exchangers).

The reduction in steam load will have a cascading impact on the boiler steam system that will result in a reduction of natural gas being fed into the boilers.

This will be achieved by using an indirect contact condensing economizer, a booster fan, pumps, various piping circuits and an array of sensors and control valves.

This system will be completely passive and redundant in order to avoid production disturbance and offer energy savings hassle-free.

M&V Method

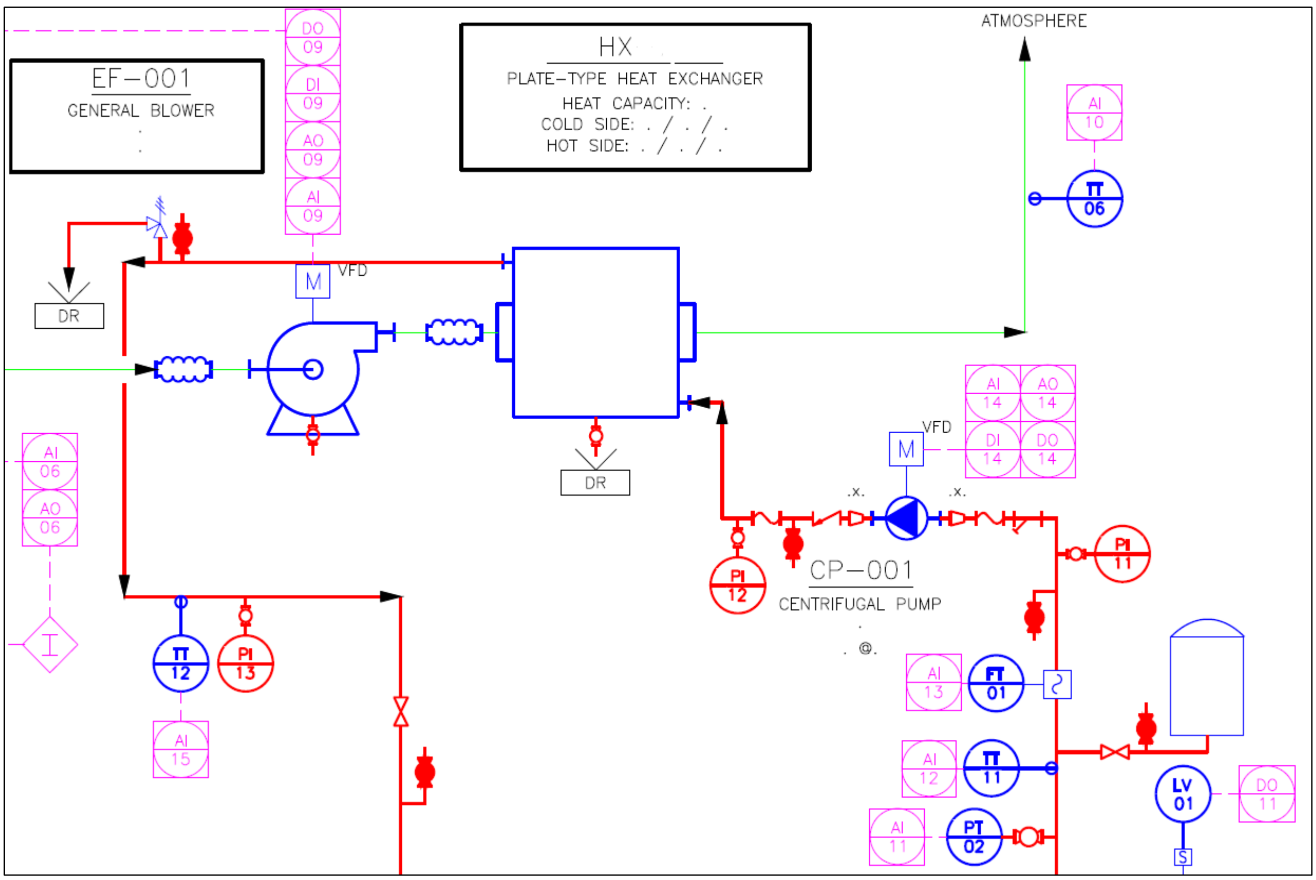
TEI proposes to quantify and verify energy savings using IPMVP Option B – Retrofit Isolation. As the system savings are relatively simple to calculate and measure, TEI believes this will be the most practical verification method. The system will be heating water and offsetting steam. The amount of heat added to the water will be proportional to the amount of steam saved. To determine the heat added to the water, TEI will measure the water temperature before the economizer (after delivering heat to the "heat sinks"), water temperature after the economizer (to be sent to the "heat sinks"), and the water flow rate. A factor will be applied to the heat added value to convert steam displaced to natural gas displaced.

Variables measured are listed below. These values will be measured by sensors on the P&ID and be able to provide readings every minute for any desired duration.

- Water Flow Rate (lb/h) by **FT-01**
- Economizer Water Inlet Temperature (°F) by **TT-11**
- Economizer Water Outlet Temperature (°F) by **TT-12**

Figure A-1 below illustrates which instrumentation will be utilized to complete these measurements.

Figure A-1: M&V Measurement Points



Source: Thermal Energy International Inc.

The amount of heat added to the water will be equal to the heat displaced in the shell and tube heat exchangers by steam. The relationship between steam heating and natural gas generation can be described by the following equations.

Starting with a heat demand by a steam heater in the plant:

$$(1) \quad Q_{rsh} = \dot{S}_h * L_h$$

Where Q_{rsh} represents heat required at the steam heater, S_h is required steam flow at steam heater for respective heat required, L_h is the latent heat released by condensing steam.

The relationship between steam required at heater for a given load and steam required at boiler in order to deliver said load is represented by Equation 2.

$$(2)\quad \dot{S}_h = \dot{S}_b * \eta_{dist}$$

Where S_b represents the flow of steam required to generate steam at heater (S_h) and η_{dist} represents the efficiency of the heat distribution system and accounts for steam losses between the boiler and end steam user.

The relationship between steam generated at the boiler and the natural gas required to generate it is as follows.

$$(3)\quad \dot{S}_h(E_s) - \dot{W}_{fw}(E_{fw}) = \dot{NG}(HHV)(\eta_b)$$

Where E_s and E_{fw} represent the enthalpy of the generated steam and the boiler feedwater, respectively. W_{fw} represents the boiler feedwater flow. NG represents the required mass flow of natural gas to generate some steam S_h at the boilers steam outlet. HHV represents the higher heating value of natural gas. η_b represents the efficiency of the boiler and is best indicated by boiler flue gas temperature. This equation assumes negligible heating is done to the blend of condensate return and make-up water by steam in the deaerator tank. This is a conservative assumption used to simplify calculations for demonstrative purposes. This also neglects boiler blow down losses varying due to lower steam generation.

As steam flow rate equals feedwater flow rate, equations 1 – 3 can be rearranged to give the following:

$$(4)\quad NG(HHV) = \frac{Q_{rsh}(E_s - E_{fw})}{L_h * \eta_{\mathrm{dis}} * \eta_{\mathrm{b}}}$$

The previous equation can be further simplified if the difference between feedwater enthalpy and steam enthalpy is approximately equal to the latent heat released ant steam heater (a conservative assumption). The equation then becomes:

$$(5)\quad NG(HHV) = \frac{Q_{rsh}}{\eta_{\mathrm{dis}} * \eta_{\mathrm{b}}}$$

The heat recovered by the proposed system will be delivering cold water (the "heat sink") that would otherwise require heating in heat exchangers that use steam from the boilers. Therefore, the heat delivered to the "heat sink" will displace heat required at heat exchanger. Therefore, the natural gas saved by heating the cold water or "heat sink" by the heat recovery system by an amount Q_{hr} can be calculated using the following equation:

$$(6)\quad NG(HHV) = \frac{Q_{hr}}{\eta_{\mathrm{dis}} * \eta_{\mathrm{b}}}$$

This is how the energy savings the system delivers will be calculated. Where Q_{hr} is calculated by the heat recovery systems sensors values (TT-11, TT-12 and FT-01) and the following equation:

$$(7)\quad Q_{hr} = FT01 * 1\frac{btu}{lb\ F} * (TT12 - TT11)$$

Where FT-01 is in lb/h, TT-11,12 are both in degrees Fahrenheit. η_{dis} is a unitless factor and depends on specifics of the heat distribution factors of the plant. A conservative value used by TEI from industry experience is 0.9. η_b will be a unitless factor and is best determined by boiler flue gas temperature and combustion air excess percentage. Industry standard literature estimates this to be 0.81 for a boiler operating at 425 F and 120% stoichiometric combustion air requirement. This factor varies slightly over the boiler's actual operating parameters.

Baseline Monitoring

The data in Table A-1 was used to calculate the energy savings TEI has provided in the FPIP funding application as well as in the kickoff meeting presentation. The same data will be monitored and collected as required to meet baseline monitoring standards.

Table A-1: Baseline Monitoring Variables Summary

Variable	Measurement Method and Duration	Notes
Boiler Natural Gas Flow	Daily Average – 1 Year	
Boiler Flue Gas Temperature and Moisture Content	3 Spot Checks over the course of 1 year	No trending available
Boiler Make-up (BMU) Water Flow Rate	Minute Averages – 1 Month	Used to verify sinks
Process Batches	Total Batches – 9 Months	Used to verify sinks

Source: Thermal Energy International Inc.

Note that the BMU water was measured using an ultrasonic clamp-on flow meter as no onsite metering of this variable was available. This data can be provided for baseline monitoring, but no further metering will be done.

Boiler Natural Gas Flow and Process batches can continue to be monitored until the system is in place. Boiler flue gas temperature and moisture content will be spot checked occasionally until the system is in place.

Post-Installation Monitoring

See heat recovery unit (condensing boiler economizer) nominal performance specifications in Figure A-2 below.

Figure A-2: Rainmaker-Silver-Dual D6 – Performance Specifications

Performance at 100%	Mass Flow Rate	Temperature In	Temperature Out	Pressure Drop
Water Side	50 GPM	75 deg F in	140.9 deg F out	1 psi
Flue Gas Side	6070 ACFM	350 deg F in	139 deg F out	0.763 inches WC

Sensible Energy Recovered: 1015287 btu/hr
Latent Energy Recovered: 634305 btu/hr
Total Energy Recovered 1649592 btu per hour

Source: Thermal Energy International Inc.

The above unit is the core of the heat recovery system and energy savings recovered here are equivalent to heat delivered to end users. To quantify the amount of energy recovered, TEI will be tracking on a 1-minute basis the values of the following elements to calculate energy savings:

- Water Flow Rate (lb/h) by **FT-01**
- Economizer Water Inlet Temperature (°F) by **TT-11**
- Economizer Water Outlet Temperature (°F) by **TT-12**

These values will be recorded on a new PLC system that will be provided by TEI as part of the heat recovery system. All sensor data will be accurate within +/-2% and exact datasheets will be provided as part of the validation report. Exact sensors will be decided prior to the equipment procurement phase once the project commences. As per the FPIP funding requirements, TEI will complete measurements of these variables over a one-year period.

Sample calculations will be provided to show how raw data is converted to energy savings and GHG reductions. Savings calculations will follow the equations presented previously in this report. GHG reduction will be calculated by applying location appropriate emission factors to the displaced amount of natural gas.

Savings calculated by TEI assume that the last year of operation is indicative of how the plant will operate with the system in the coming years. Variations in production, extra shutdowns, equipment replacements are a list of some things that can impact savings. However, from TEI's experience and site investigation, there are no anticipated changes that will cause the system to vary enough to significantly impact the system's estimated savings.

CALIFORNIA ENERGY COMMISSION

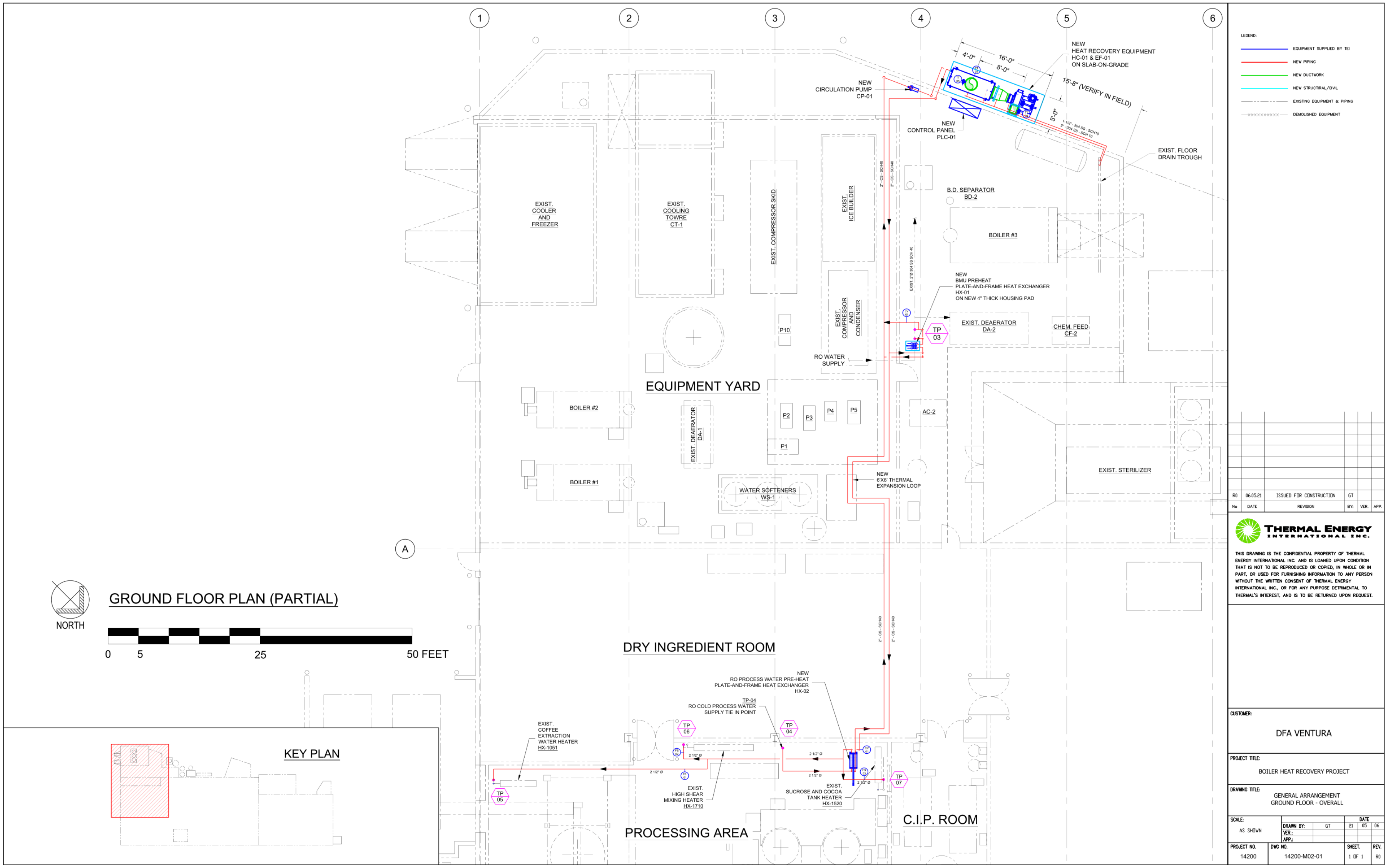
CALIFORNIA NATURAL RESOURCES AGENCY

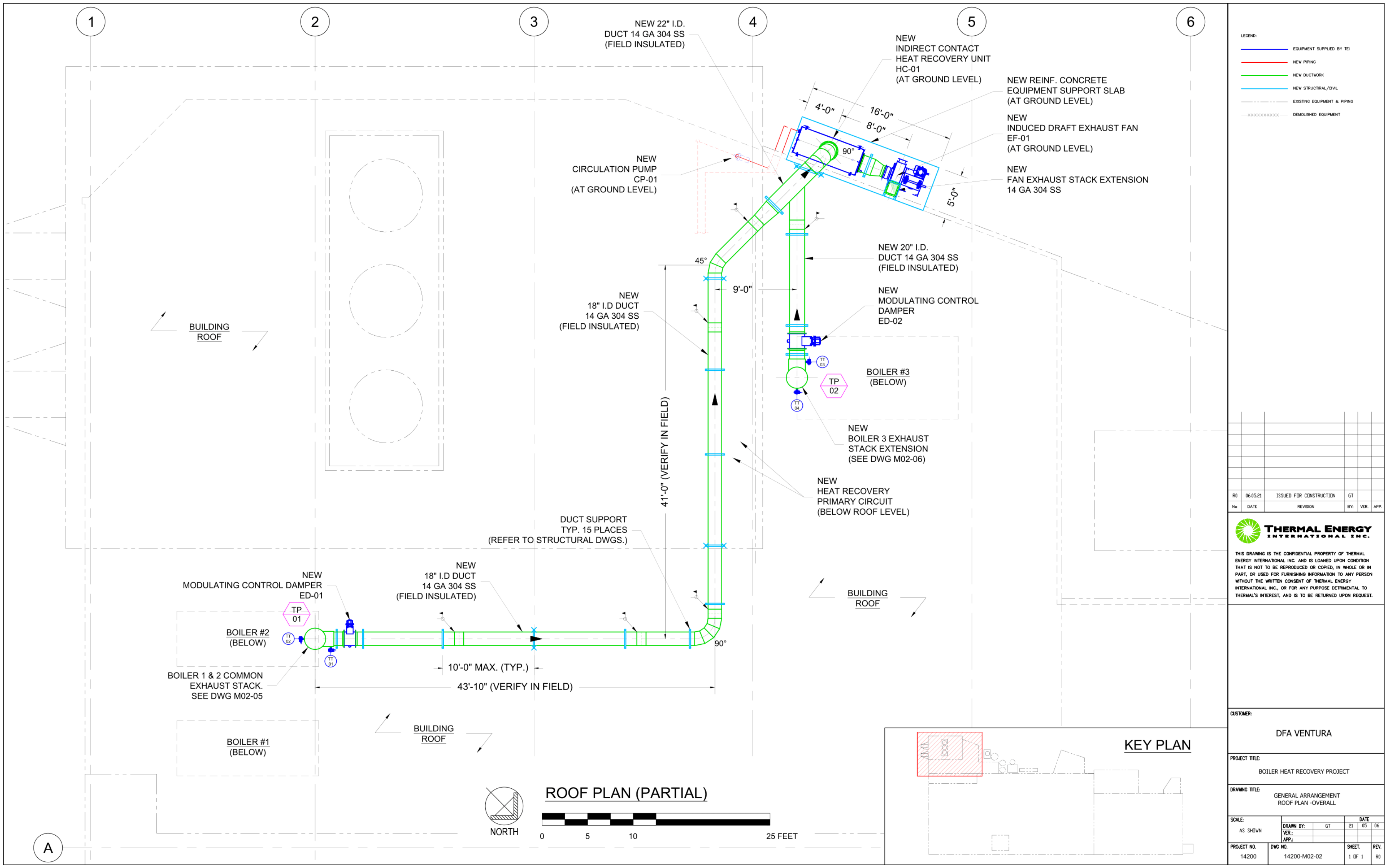
ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX B: General Arrangement Drawings

July 2025 | CEC-500-2025-036

APPENDIX B:
General Arrangement Drawings





1
2
3
4
5
6
A
NEW 22" I.D.
DUCT 14 GA 304 SS
(FIELD INSULATED)
NEW
INDIRECT CONTACT
HEAT RECOVERY UNIT
HC-01
(AT GROUND LEVEL)
NEW REINF. CONCRETE
EQUIPMENT SUPPORT SLAB
(AT GROUND LEVEL)
NEW
INDUCED DRAFT EXHAUST FAN
EF-01
(AT GROUND LEVEL)
NEW
FAN EXHAUST STACK EXTENSION
14 GA 304 SS
4'-0"
16'-0"
8'-0"
90°
5'-0"
NEW
CIRCULATION PUMP
CP-01
(AT GROUND LEVEL)
45°
9'-0"
NEW 20" I.D.
DUCT 14 GA 304 SS
(FIELD INSULATED)
NEW
18" I.D DUCT
14 GA 304 SS
(FIELD INSULATED)
NEW
MODULATING CONTROL
DAMPER
ED-02
BUILDING
ROOF
BOILER #3
(BELOW)
TP
02
41'-0" (VERIFY IN FIELD)
NEW
BOILER 3 EXHAUST
STACK EXTENSION
(SEE DWG M02-06)
NEW
HEAT RECOVERY
PRIMARY CIRCUIT
(BELOW ROOF LEVEL)
DUCT SUPPORT
TYP. 15 PLACES
(REFER TO STRUCTURAL DWGS.)
NEW
MODULATING CONTROL DAMPER
ED-01
NEW
18" I.D DUCT
14 GA 304 SS
(FIELD INSULATED)
TP
01
BOILER #2
(BELOW)
90°
BUILDING
ROOF
10'-0" MAX. (TYP.)
43'-10" (VERIFY IN FIELD)
BOILER 1 & 2 COMMON
EXHAUST STACK.
SEE DWG M02-05
BOILER #1
(BELOW)
BUILDING
ROOF
NORTH
ROOF PLAN (PARTIAL)
0
5
10
25 FEET
KEY PLAN
LEGEND:
EQUIPMENT SUPPLIED BY TEI
NEW PIPING
NEW DUCTWORK
NEW STRUCTIRAL/CIVIL
EXISTING EQUIPMENT & PIPING
DEMOLISHED EQUIPMENT
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PROJECT TITLE:
BOILER HEAT RECOVERY PROJECT
DRAWING TITLE:
GENERAL ARRANGEMENT
ROOF PLAN -OVERALL
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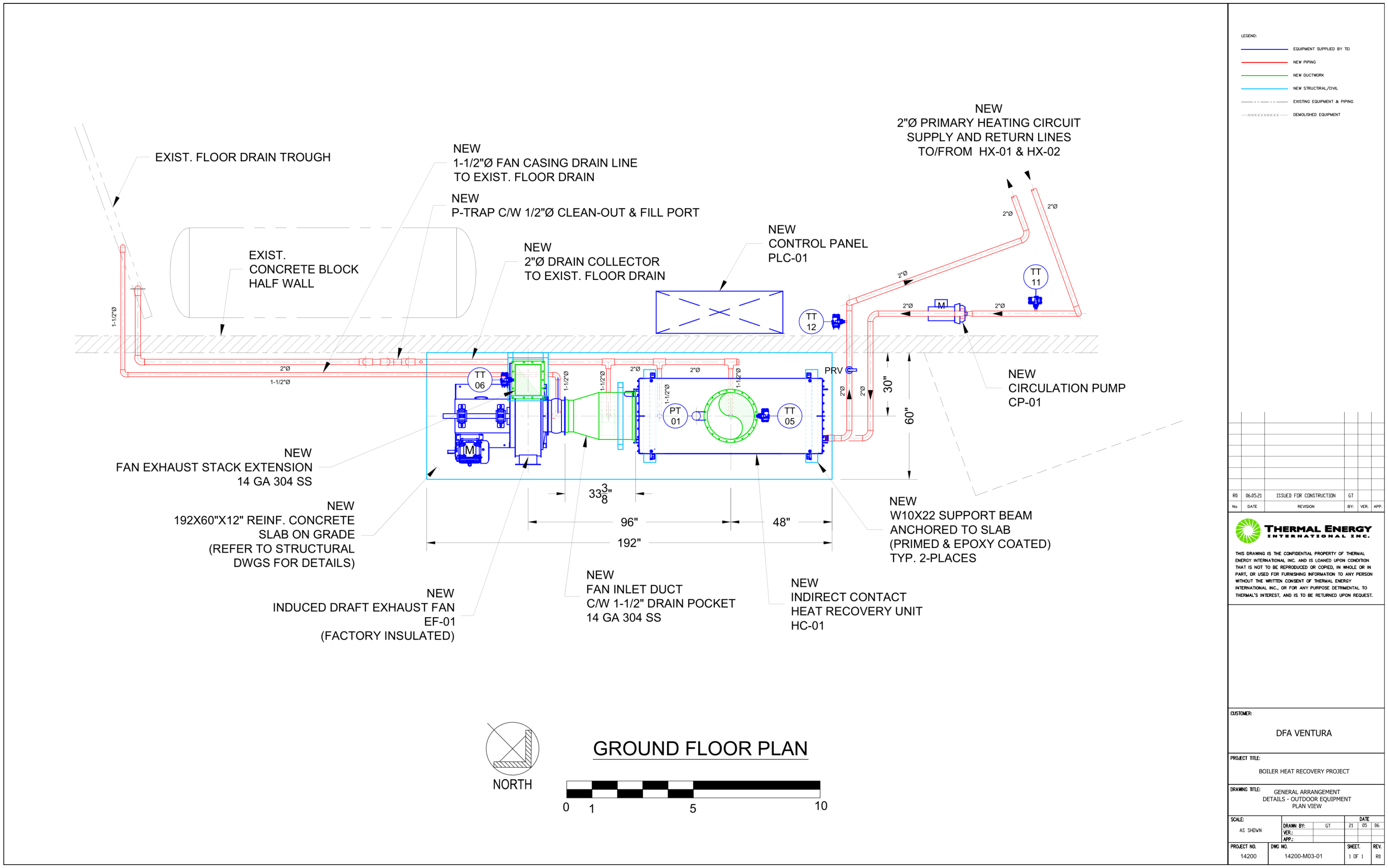
EXIST. FLOOR DRAIN TROUGH
NEW
1-1/2"Ø FAN CASING DRAIN LINE
TO EXIST. FLOOR DRAIN
NEW
P-TRAP C/W 1/2"Ø CLEAN-OUT & FILL PORT
NEW
2"Ø PRIMARY HEATING CIRCUIT
SUPPLY AND RETURN LINES
TO/FROM HX-01 & HX-02
EXIST.
CONCRETE BLOCK
HALF WALL
NEW
2"Ø DRAIN COLLECTOR
TO EXIST. FLOOR DRAIN
NEW
CONTROL PANEL
PLC-01
TT 11
TT 12
TT 06
PT 01
TT 05
PRV
M
30"
60"
NEW
CIRCULATION PUMP
CP-01
NEW
FAN EXHAUST STACK EXTENSION
14 GA 304 SS
NEW
192X60"X12" REINF. CONCRETE
SLAB ON GRADE
(REFER TO STRUCTURAL
DWGS FOR DETAILS)
$33\frac{3}{8}$"
96"
48"
192"
NEW
W10X22 SUPPORT BEAM
ANCHORED TO SLAB
(PRIMED & EPOXY COATED)
TYP. 2-PLACES
NEW
INDUCED DRAFT EXHAUST FAN
EF-01
(FACTORY INSULATED)
NEW
FAN INLET DUCT
C/W 1-1/2" DRAIN POCKET
14 GA 304 SS
NEW
INDIRECT CONTACT
HEAT RECOVERY UNIT
HC-01
NORTH
GROUND FLOOR PLAN
0
1
5
10
LEGEND:
EQUIPMENT SUPPLIED BY TEI
NEW PIPING
NEW DUCTWORK
NEW STRUCTIRAL/CIVIL
EXISTING EQUIPMENT & PIPING
DEMOLISHED EQUIPMENT
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PROJECT TITLE:
BOILER HEAT RECOVERY PROJECT
DRAWING TITLE:
GENERAL ARRANGEMENT
DETAILS - OUTDOOR EQUIPMENT
PLAN VIEW
SCALE:
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14200-M03-01
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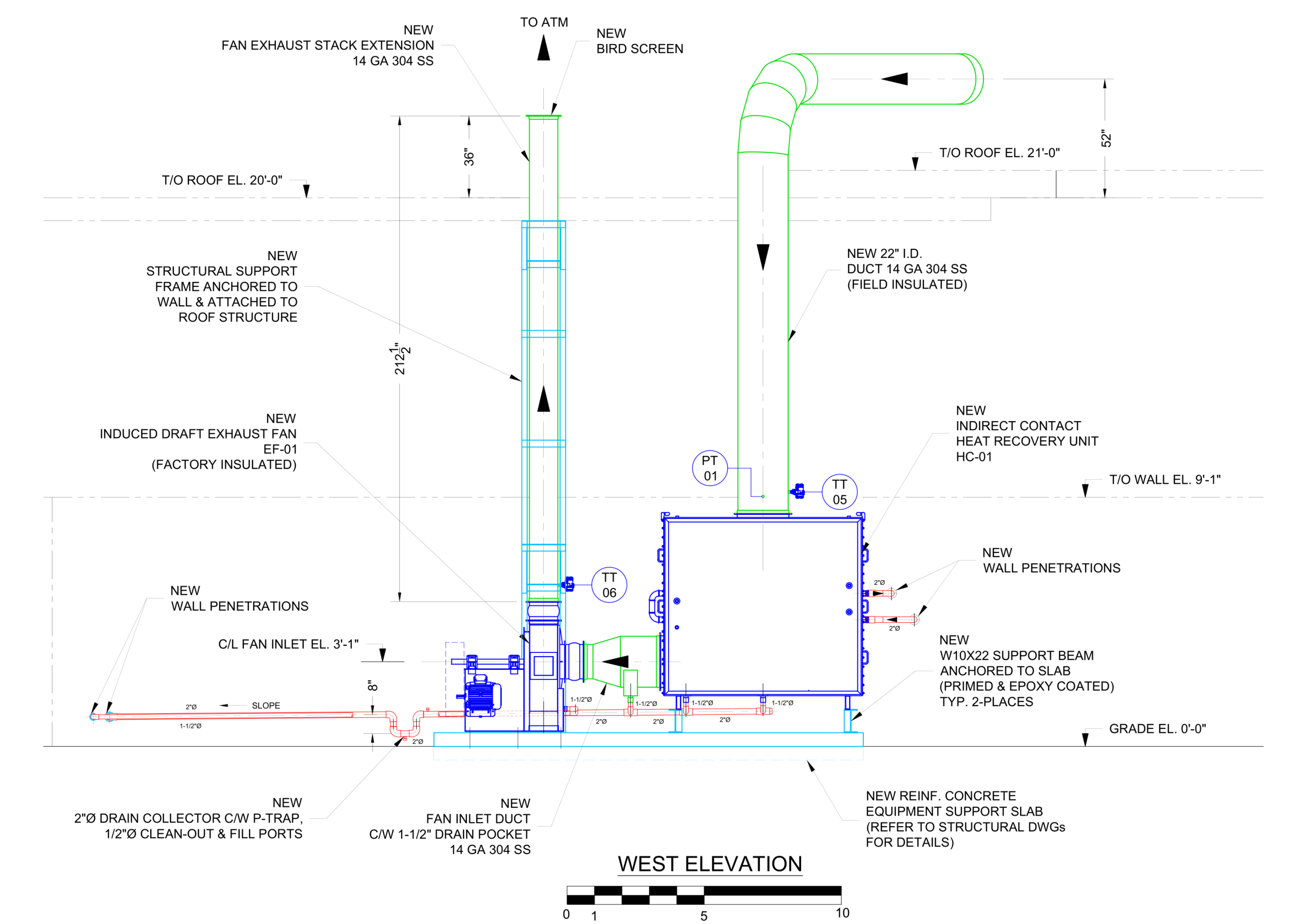

WEST ELEVATION

LEGEND:

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- NEW DUCTWORK
- NEW STRUCTIRAL/CIVIL
- EXISTING EQUIPMENT & PIPING
- DEMOLISHED EQUIPMENT

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CUSTOMER: DFA VENTURA

PROJECT TITLE: BOILER HEAT RECOVERY PROJECT

DRAWING TITLE: GENERAL ARRANGEMENT
DETAILS - OUTDOOR EQUIPMENT
WEST ELEVATION

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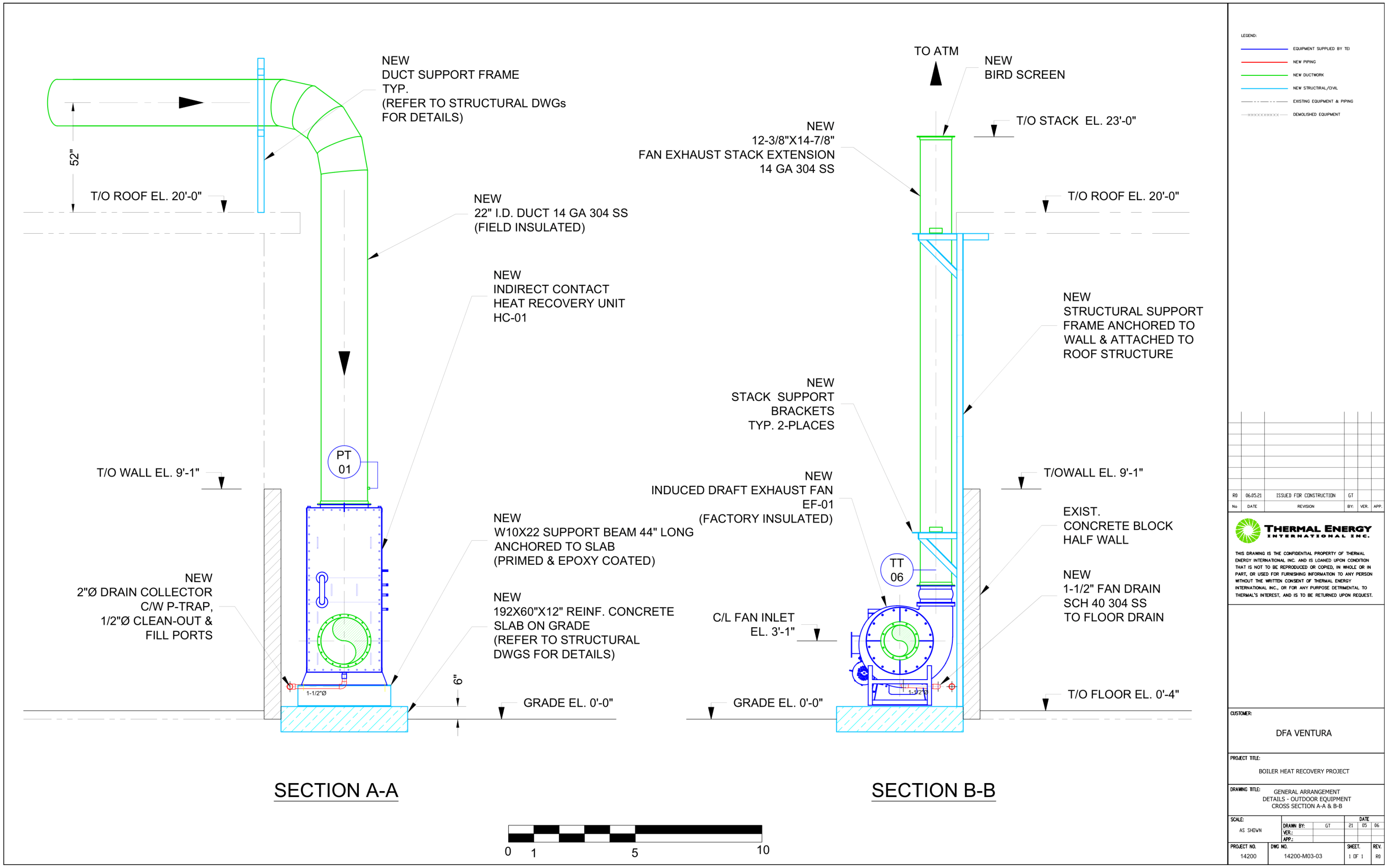

NEW
DUCT SUPPORT FRAME
TYP.
(REFER TO STRUCTURAL DWGs
FOR DETAILS)
52"
T/O ROOF EL. 20'-0"
NEW
22" I.D. DUCT 14 GA 304 SS
(FIELD INSULATED)
NEW
INDIRECT CONTACT
HEAT RECOVERY UNIT
HC-01
PT
01
T/O WALL EL. 9'-1"
NEW
W10X22 SUPPORT BEAM 44" LONG
ANCHORED TO SLAB
(PRIMED & EPOXY COATED)
NEW
2"Ø DRAIN COLLECTOR
C/W P-TRAP,
1/2"Ø CLEAN-OUT &
FILL PORTS
NEW
192X60"X12" REINF. CONCRETE
SLAB ON GRADE
(REFER TO STRUCTURAL
DWGS FOR DETAILS)
1-1/2"Ø
6"
GRADE EL. 0'-0"
SECTION A-A
TO ATM
NEW
BIRD SCREEN
T/O STACK EL. 23'-0"
NEW
12-3/8"X14-7/8"
FAN EXHAUST STACK EXTENSION
14 GA 304 SS
T/O ROOF EL. 20'-0"
NEW
STRUCTURAL SUPPORT
FRAME ANCHORED TO
WALL & ATTACHED TO
ROOF STRUCTURE
NEW
STACK SUPPORT
BRACKETS
TYP. 2-PLACES
T/OWALL EL. 9'-1"
NEW
INDUCED DRAFT EXHAUST FAN
EF-01
(FACTORY INSULATED)
EXIST.
CONCRETE BLOCK
HALF WALL
TT
06
NEW
1-1/2" FAN DRAIN
SCH 40 304 SS
TO FLOOR DRAIN
C/L FAN INLET
EL. 3'-1"
GRADE EL. 0'-0"
T/O FLOOR EL. 0'-4"
SECTION B-B
0 1 5 10
LEGEND:
EQUIPMENT SUPPLIED BY TEI
NEW PIPING
NEW DUCTWORK
NEW STRUCTIRAL/CIVIL
EXISTING EQUIPMENT & PIPING
DEMOLISHED EQUIPMENT
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PROJECT TITLE:
BOILER HEAT RECOVERY PROJECT
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GENERAL ARRANGEMENT
DETAILS - OUTDOOR EQUIPMENT
CROSS SECTION A-A & B-B
SCALE:
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DATE
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PROJECT NO.
14200
DWG NO.
14200-M03-03
SHEET.
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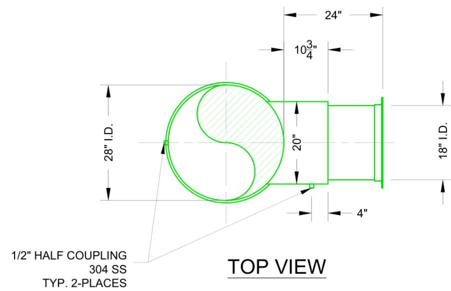
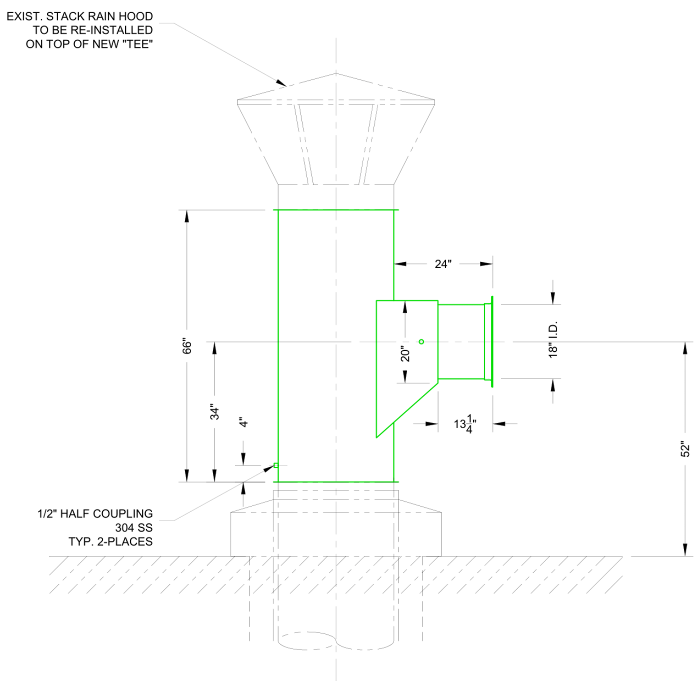
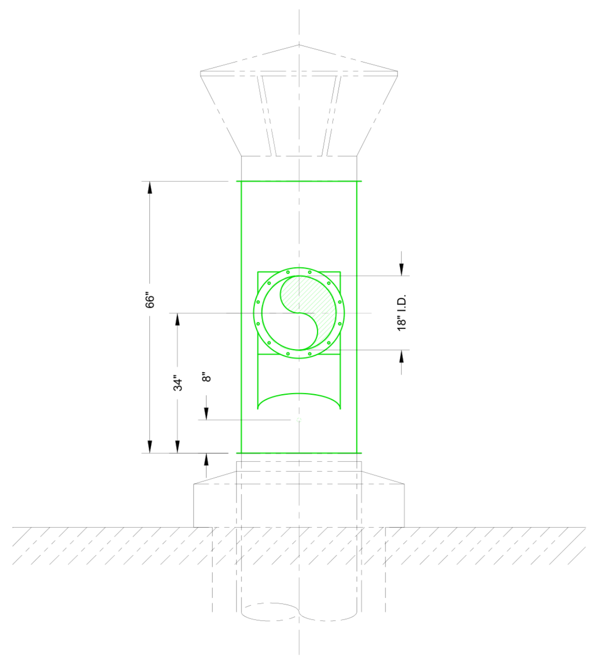
NOTE:
DUCT FABRICATOR TO FIELD VERIFY VERTICAL REFERENCES AND ELEVATION OF STACK TIE-IN POINTS. ADJUST FOR SLOPE AS REQUIRED.



TOP VIEW



SIDE VIEW



FRONT VIEW

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- NEW DUCTWORK
- NEW STRUCTIRAL/CIVIL
- EXISTING EQUIPMENT & PIPING
- DEMOLISHED EQUIPMENT

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THERMAL ENERGY INTERNATIONAL INC.

CUSTOMER:
DFA VENTURA

PROJECT TITLE:
HEAT RECOVERY PROJECT

DRAWING TITLE:
BOILER #1 & #2 STACK TIE-IN DETAILS
TP-01

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PROJECT NO.	DWG NO.	SHEET.	REV.
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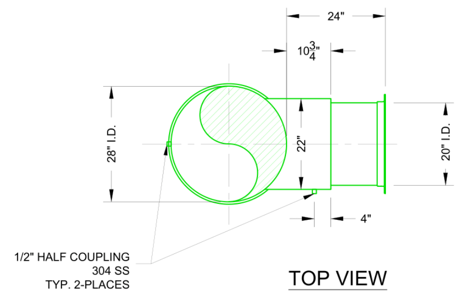

NOTE:
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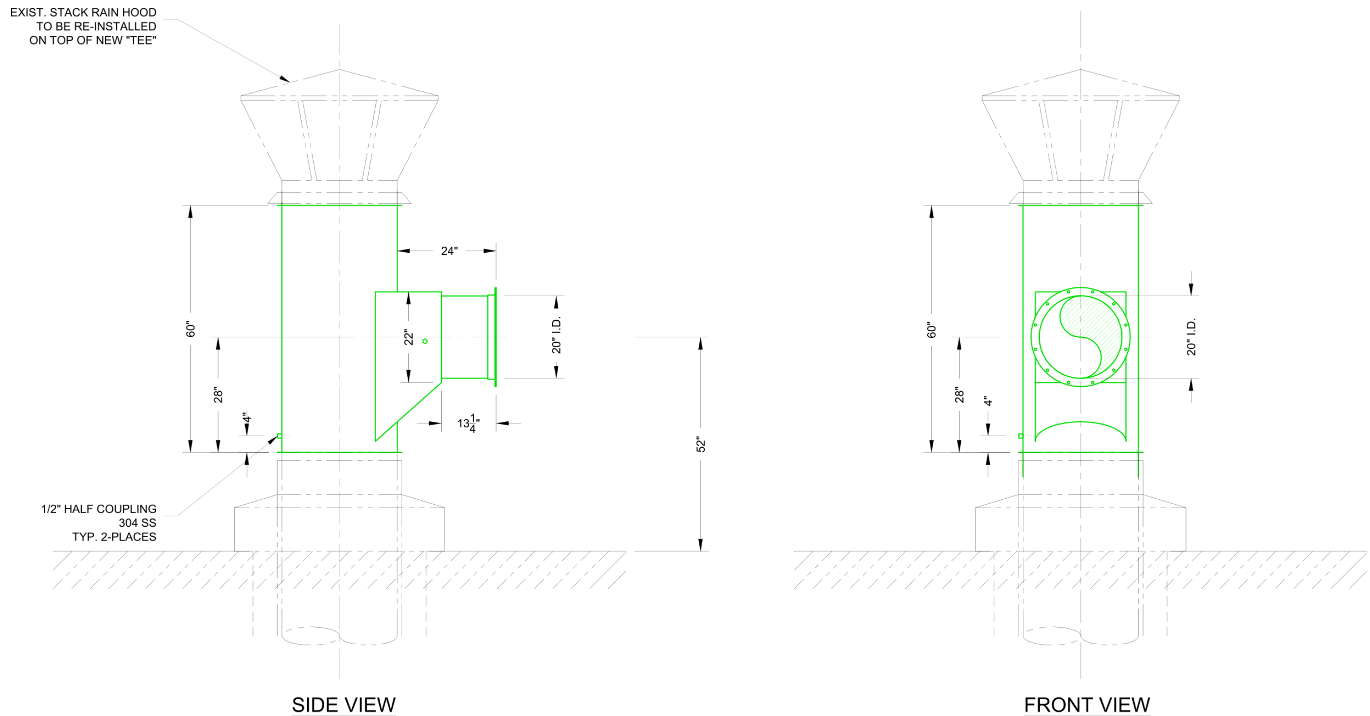

LEGEND:

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- NEW PIPING
- NEW DUCTWORK
- NEW STRUCTIRAL/CIVIL
- EXISTING EQUIPMENT & PIPING
- DEMOLISHED EQUIPMENT

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THERMAL ENERGY INTERNATIONAL INC.

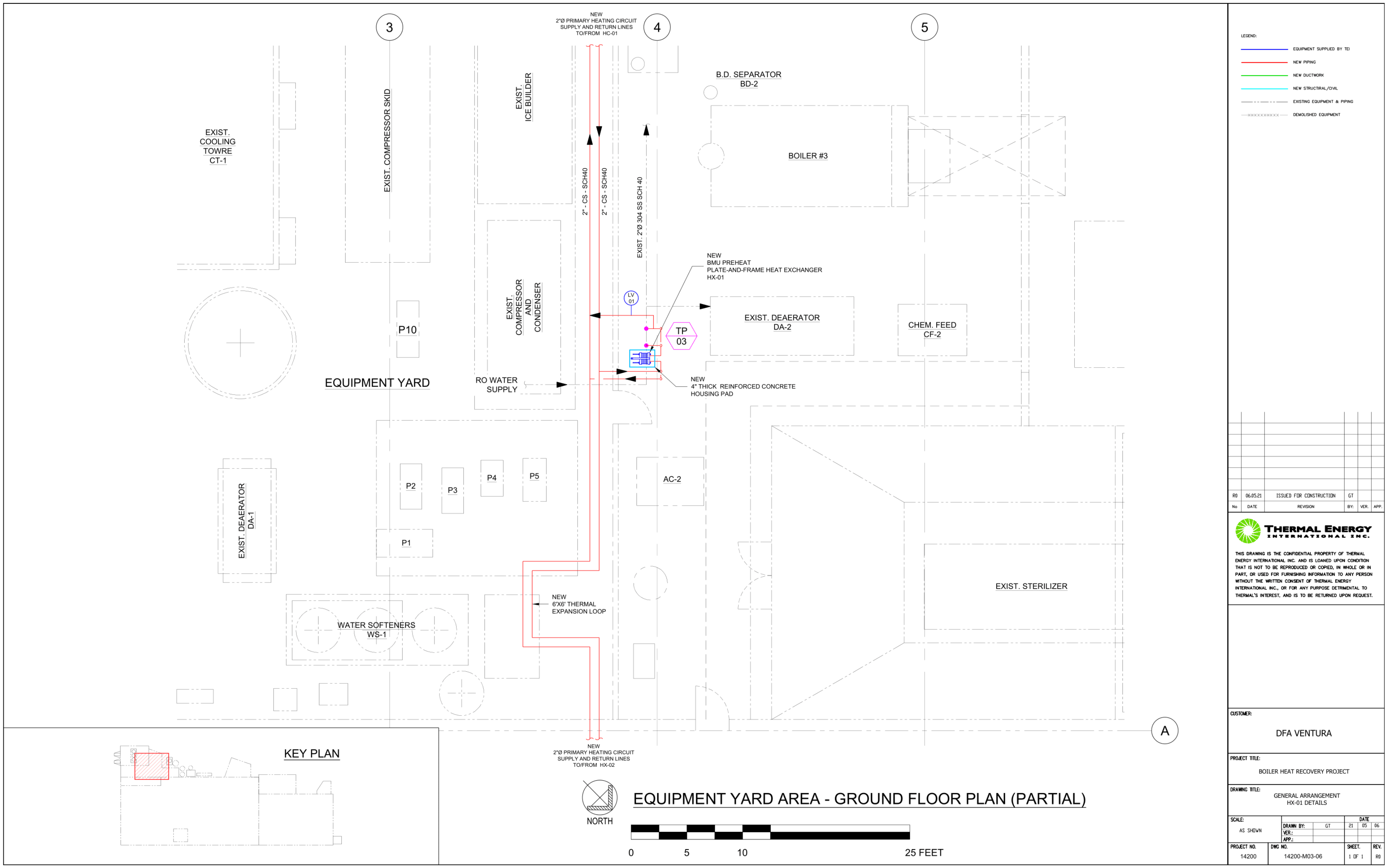
CUSTOMER:
DFA VENTURA

PROJECT TITLE:
BOILER HEAT RECOVERY PROJECT

DRAWING TITLE:
BOILER #3 STACK TIE-IN DETAILS
TP-02

SCALE:			DATE		
AS SHOWN	DRAWN BY:	GT	21	04	21
	VER.:				
	APP.:				

PROJECT NO.	DWG NO.	SHEET.	REV.
14200	14200-M03-05	1 OF 1	R0


NEW
2"Ø PRIMARY HEATING CIRCUIT
SUPPLY AND RETURN LINES
TO/FROM HC-01
3
4
5
EXIST. COOLING TOWRE CT-1
EXIST. COMPRESSOR SKID
EXIST. ICE BUILDER
2" - CS - SCH40
2" - CS - SCH40
EXIST. 2"Ø 304 SS SCH 40
B.D. SEPARATOR
BD-2
BOILER #3
NEW
BMU PREHEAT
PLATE-AND-FRAME HEAT EXCHANGER
HX-01
LV
01
EXIST. COMPRESSOR AND CONDENSER
P10
TP
03
EXIST. DEAERATOR
DA-2
CHEM. FEED
CF-2
EQUIPMENT YARD
RO WATER
SUPPLY
NEW
4" THICK REINFORCED CONCRETE
HOUSING PAD
AC-2
P2
P3
P4
P5
P1
EXIST. DEAERATOR
DA-1
NEW
6'X6' THERMAL
EXPANSION LOOP
WATER SOFTENERS
WS-1
EXIST. STERILIZER
A
NEW
2"Ø PRIMARY HEATING CIRCUIT
SUPPLY AND RETURN LINES
TO/FROM HX-02
KEY PLAN
NORTH
EQUIPMENT YARD AREA - GROUND FLOOR PLAN (PARTIAL)
0
5
10
25 FEET
LEGEND:
EQUIPMENT SUPPLIED BY TEI
NEW PIPING
NEW DUCTWORK
NEW STRUCTIRAL/CIVIL
EXISTING EQUIPMENT & PIPING
DEMOLISHED EQUIPMENT
R0
06.05.21
ISSUED FOR CONSTRUCTION
GT
No
DATE
REVISION
BY:
VER.
APP.
THERMAL ENERGY
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CUSTOMER:
DFA VENTURA
PROJECT TITLE:
BOILER HEAT RECOVERY PROJECT
DRAWING TITLE:
GENERAL ARRANGEMENT
HX-01 DETAILS
SCALE:
AS SHOWN
DRAWN BY:
GT
DATE
21
05
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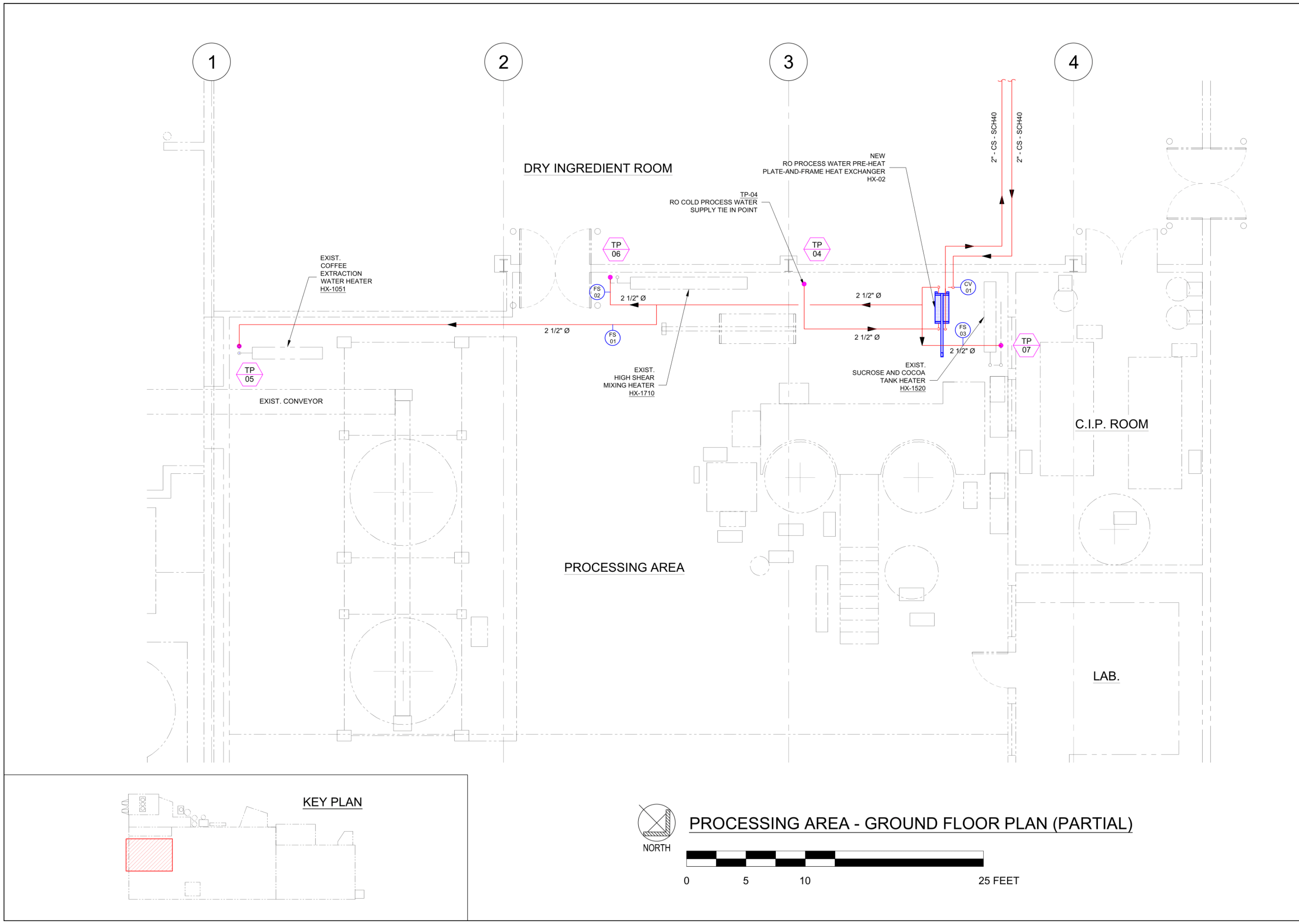
VER.:
APP.:
PROJECT NO.
14200
DWG NO.
14200-M03-06
SHEET.
1 OF 1
REV.
R0



LEGEND:

- EQUIPMENT SUPPLIED BY TEI
- NEW PIPING
- NEW DUCTWORK
- NEW STRUCTIRAL/CIVIL
- EXISTING EQUIPMENT & PIPING
- DEMOLISHED EQUIPMENT

No	DATE	REVISION	BY:	VER.	APP.
R0	06.05.21	ISSUED FOR CONSTRUCTION	GT		

THERMAL ENERGY INTERNATIONAL INC.

CUSTOMER:
DFA VENTURA

PROJECT TITLE:
BOILER HEAT RECOVERY PROJECT

DRAWING TITLE:
GENERAL ARRANGEMENT
HX-02 DETAILS

SCALE:			DATE		
AS SHOWN	DRAWN BY:	GT	21	05	06
	VER.:				
	APP.:				

PROJECT NO.	DWG NO.	SHEET.	REV.
14200	14200-M03-07	1 OF 1	R0

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ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX C: Additional Photos

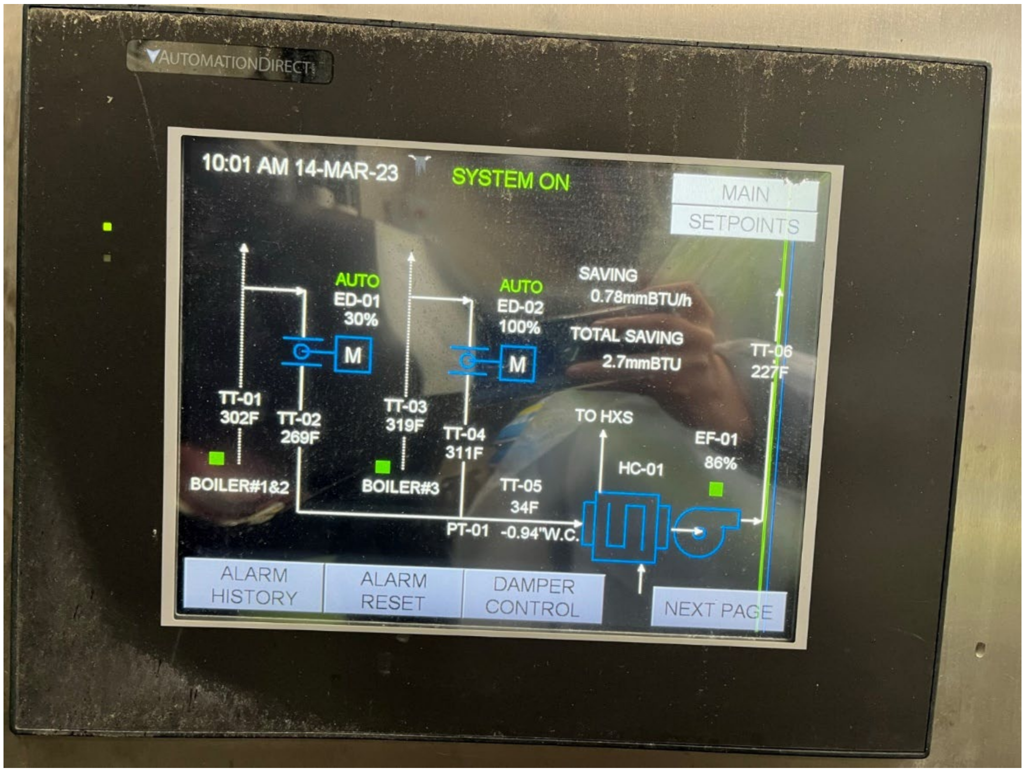
July 2025 | CEC-500-2025-036

APPENDIX C: Additional Photos

Figure C-1: Heat Exchanger Piping Tie-Ins

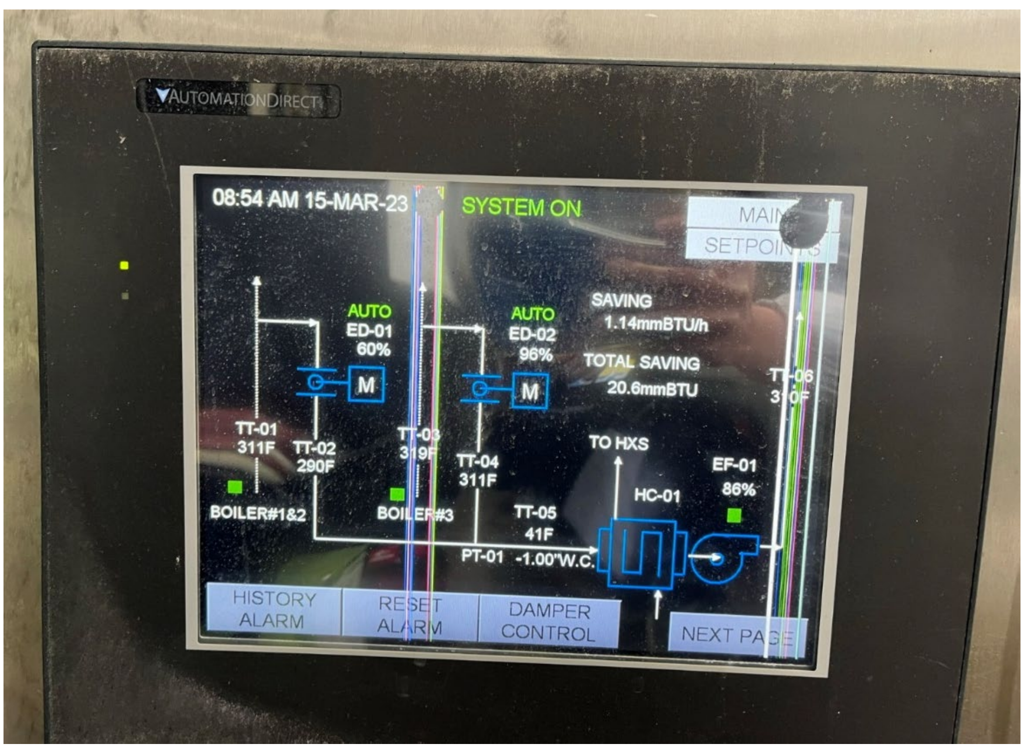
Source: Thermal Energy International Inc.

Figure C-2: PLC Screen Reading During March 14th 2023 Site Visit



Source: Thermal Energy International Inc.

Figure C-3: PLC Screen Reading During March 15th 2023 Site Visit



Source: Thermal Energy International Inc.

Figure C-4: Installed Fan and HeatSponge Economizer Unit

Source: Thermal Energy International Inc.

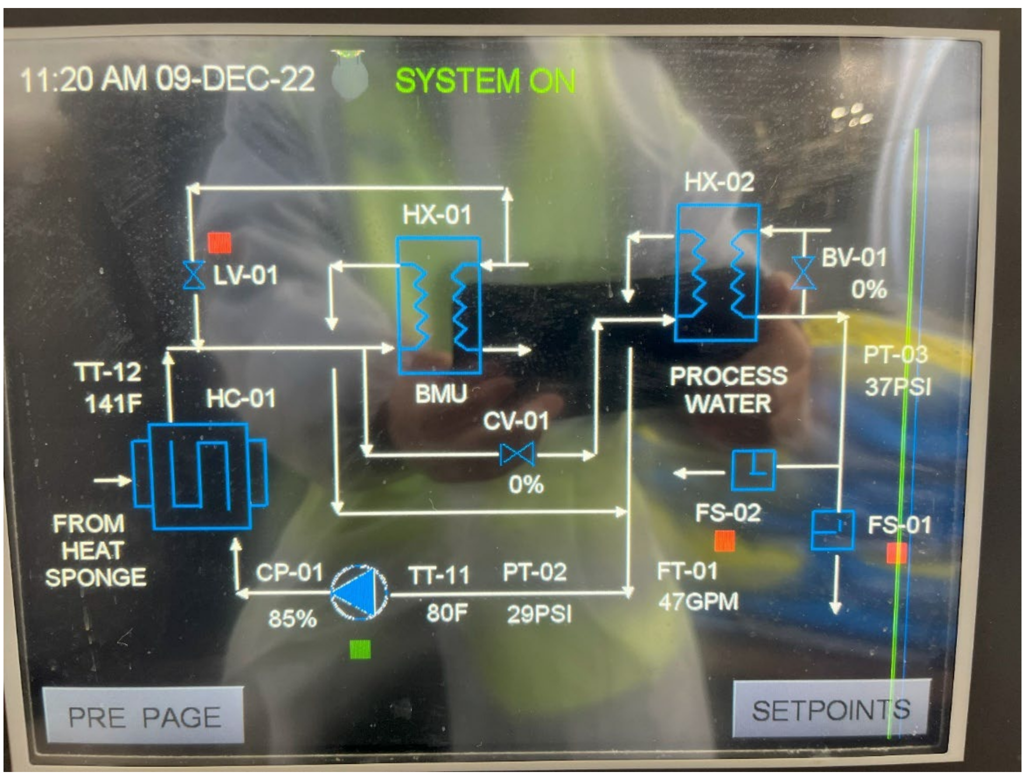
Figure C-5: Installed Heat Exchanger

Source: Thermal Energy International Inc.

Figure C-6: PLC Screen Reading During December 9th 2022 Site Visit 1/2

Source: Thermal Energy International Inc.

Figure C-7: PLC Screen Reading During December 9th 2022 Site Visit 2/2



Source: Thermal Energy International Inc.

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ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX D: Post-Installation Measurement and Verification Report

July 2025 | CEC-500-2025-036

Executive Summary

This report details the post-installation measurement and verification (M&V) results for the heat recovery system installed at the Dairy Farmers of America (DFA) facility in Ventura, California. The project, which received grant funds through the California Energy Commission's Food Production Investment Program (FPIP), aimed to reduce natural gas consumption and greenhouse gas (GHG) emissions by capturing and reusing waste heat from boiler exhaust gases.

The recovered heat is used to preheat boiler make-up water and process water, reducing the facility's natural gas usage for steam generation.

Table D-1 shows the key findings after approximately 9 months as the post-installation monitoring period:

Table D-1: Post-Installation Key Findings

Metric	Grant Application Reduction Estimates	Pre-Installation Usage	Post-Installation Reduction
Annual Natural Gas	139,962 therms	1,008,900 therms	57,282 therms
Annual GHG	743 $MTCO_2e$	5,348 $MTCO_2e$	304 $MTCO_2e$

Source: Thermal Energy International Inc.

The project achieved significant reductions in natural gas consumption and GHG emissions, though lower than initially projected. This is primarily due to the facility's closure shortly after project completion, which necessitated changes in processes and reduced normal heat usage compared to the original savings calculations.

Despite the lower-than-expected savings, the project demonstrates the viability of condensing heat recovery technology in food production facilities and provides valuable insights for future implementations.

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Flue Gas Heat Recovery: Heat Recovery Using a High Efficiency Indirect – Condensing Heat Recovery Unit

Overview

This project used a single condensing boiler economizer to offset steam usage and natural gas usage at the Dairy Farmers of America (DFA) facility in Ventura. The economizer took heat from all three natural gas boilers and used it to offset steam usage by heating boiler make up water and process water.

Third Party M&V Contractor, Thermal Energy International

Thermal Energy International (TEI) performed the measurement and verification (M&V) data analysis and reporting for this project.

Potential Variations Impacting M&V Efforts

The project heated both boiler make-up water and process water, both of which were influenced by facility production rates. Naturally, any production facility experiences fluctuations due to routine factors such as equipment troubleshooting or other external influences. When the facility's production levels varied from the baseline used to design the system, fluctuations in actual energy savings occurred. These variations are a normal part of operations and do not indicate an issue with the system’s performance. Examples of routine events that may temporarily result in lower savings include plant-wide shutdowns and equipment replacements

The project achieved notable reductions in natural gas consumption and greenhouse gas (GHG) emissions, though less than projected due to the facility's progressive closure during decommissioning. As production gradually diminished, normal heat usage declined, leading to reduced gas consumption and, consequently, less gas saved by the economizer. While the project initially expected to achieve energy savings of 139,962 therms per year and a GHG reduction of 743 $MTCO_2e$, only 57,282 therms per year and 304 $MTCO_2e$ were ultimately saved due to the facility closing. Despite this, the project highlights the potential of condensing heat recovery technology in food production and offers valuable insights for future applications.

System Description

A single two-stage condensing economizer was implemented in this project to recover waste heat from the exhaust of DFA’s three boilers. The system operates in two phases:

- **First Stage:** Pre-heats boiler feedwater using residual heat from the exhaust gases.
- **Second (Condensing) Stage:** Further cools the exhaust below its dew point temperature, extracting latent heat by condensing water vapor from the combustion products. This stage pre-heats cold boiler make-up water.

The economizer’s water circuits are arranged perpendicular to the exhaust gas flow, enabling indirect heat exchange. By cooling the exhaust below its dew point, water vapor in the flue gas condenses, releasing latent heat of vaporization—recovering roughly 10 percent of the natural gas’s higher heating value that would otherwise be lost.

The recovered heat offsets steam demand in two ways:

- **Boiler make-up water** is pre-heated, reducing the steam required to heat it in the deaerator tank.
- **Process water** is warmed, decreasing reliance on steam-powered shell-and-tube heat exchangers.

This reduction in steam load directly lowered the natural gas consumption of the boilers, improving overall energy efficiency.

This was achieved by using an indirect contact condensing economizer, a booster fan, pumps, various piping circuits and an array of sensors and control valves. The system piping and instrumentation diagram (P&ID) can be found in M&V Report Appendix A.

The system was completely passive and redundant in order to avoid production disturbance and offer energy savings hassle free.

M&V Method

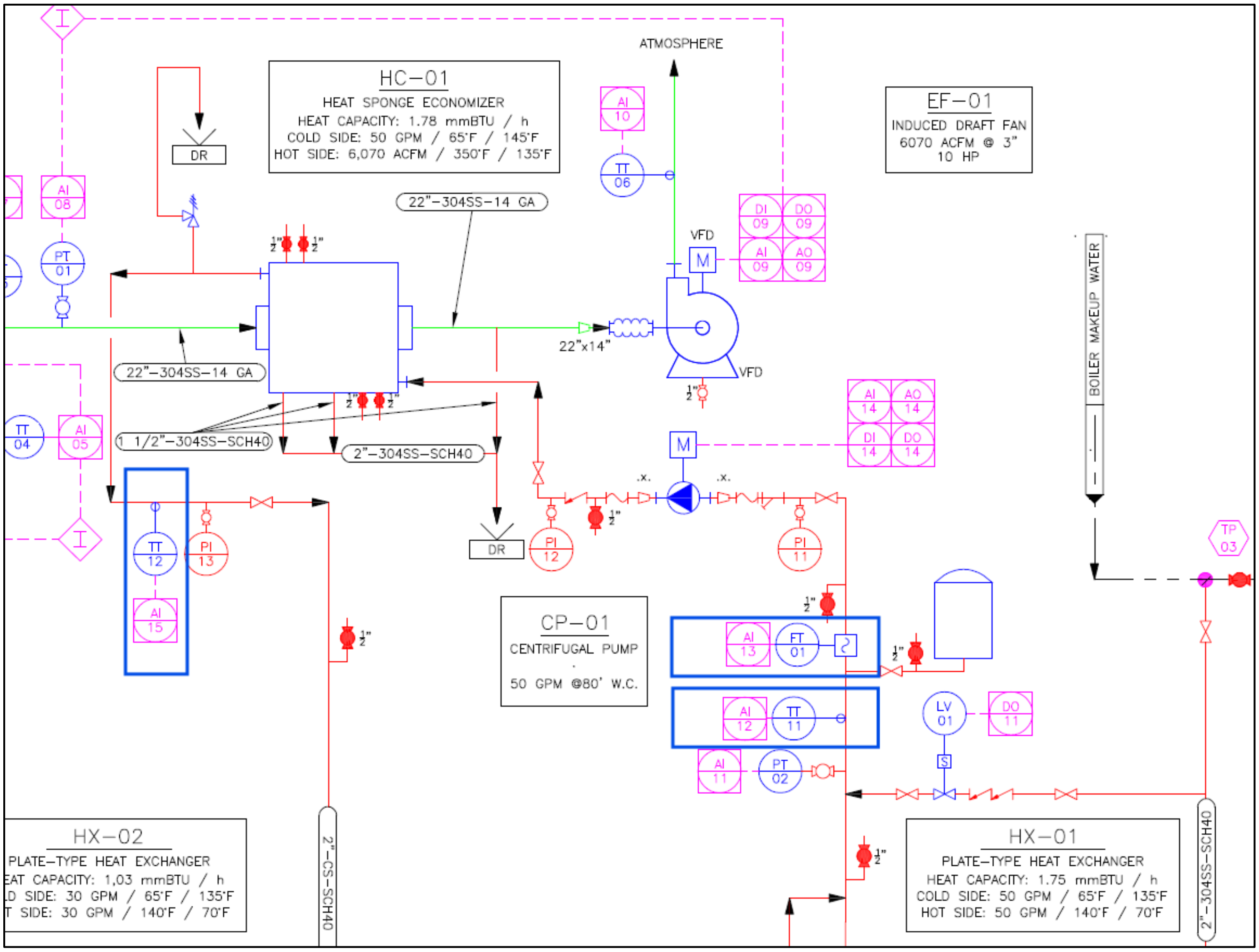
TEI quantified and verified energy savings using the International Performance M&V Protocol (IPMVP) Option B – Retrofit Isolation. As the system savings were relatively simple to calculate and measure, this was the most practical verification method. The system heated water to offset steam. The amount of heat added to the water was proportional to the amount of steam saved. To determine the heat added to the water, measurements of the water temperature before the economizer (after delivering heat to the “heat sinks”), water temperature after the economizer (to be sent to the “heat sinks”), and the water flow rate were taken. A factor was applied to the heat added value to convert steam displaced to natural gas displaced.

Variables measured are listed below. These values were measured by sensors on the P&ID in M&V Report Appendix A and were able to provide readings on a 10-second basis for any desired duration.

- Water Flow Rate (lb/h) by **FT-01**
- Economizer Water Inlet Temperature (°F) by **TT-11**
- Economizer Water Outlet Temperature (°F) by **TT-12**

Figure D-1 below illustrates which instrumentation was utilized to complete these measurements. The full P&ID can be found in M&V Report Appendix A.

Figure D-1: M&V Measurement Points



Source: Thermal Energy International Inc.

The amount of heat added to the water was equal to the heat displaced in the shell and tube heat exchangers by steam. The relationship between steam heating and natural gas generation can be described by the equations in Table D-2.

Table D-2: Key Variables for Heat Recovery and Carbon Reduction Calculations

VARIABLE	DESCRIPTION	UNITS
Q_{rsh}	Heat required at the steam heater	Therms/hr
$\dot{S}_h$	Steam flow required at the steam heater	lb/h
L_h	Latent heat released by condensing steam	Therms/lb
$\dot{S}_b$	Steam flow required at the boiler	lb/h
η_{dist}	Efficiency of heat distribution system	Unitless
E_s	Enthalpy of generated steam	Btu/lb or kJ/kg

VARIABLE	DESCRIPTION	UNITS
E_{fw}	Enthalpy of boiler feedwater	Therms/lb
$\dot{W}_{fw}$	Boiler feedwater flow	GPM
$\dot{NG}$	Natural gas flow rate	Therms/hr
HHV	Higher heating value of natural gas	Therms/lb
η_b	Boiler efficiency	Unitless
Q_{hr}	Heat recovered by the proposed system	Therms/hr
GHG	Greenhouse gas emissions	$MTCO_2e$/hr
NG	CO_2e per therm of natural gas	$MTCO_2e$/therm
$FT01$	Flow rate of water in the heat recovery system	GPM
$TT11$	Economizer Water Inlet Temperature	°F
$TT12$	Economizer Water Outlet Temperature	°F

Source: Thermal Energy International Inc.

Starting with a heat demand by a steam heater in the plant:

$$(1)\quad Q_{rsh} = \dot{S_h} * L_h$$

Where Q_{rsh} represents heat required at the steam heater, S_h is required steam flow at steam heater for respective heat required, L_h is the latent heat released by condensing steam.

The relationship between steam required at heater for a given load and steam required at boiler in order to deliver said load is represented by Equation 2.

$$(2)\quad \dot{S_h} = \dot{S_b} * \eta_{dist}$$

Where S_b represents the flow of steam required to generate steam at heater (S_h) and η_{dist} represents the efficiency of the heat distribution system and accounts for steam losses between the boiler and end steam user.

The relationship between steam generated at the boiler and the natural gas required to generate it is as follows.

$$(3)\quad \dot{S}_h(E_s) - \dot{W}_{fw}(E_{fw}) = \dot{NG}(HHV)(\eta_b)$$

Where E_s and E_{fw} represent the enthalpy of the generated steam and the boiler feedwater, respectively. W_{fw} represents the boiler feedwater flow. NG represents the required mass flow of natural gas to generate some steam S_h at the boilers steam outlet. HHV represents the higher heating value of natural gas. η_b represents the efficiency of the boiler and is best indicated by boiler flue gas temperature. This equation assumes negligible heating is done to the blend of condensate return and make-up water by steam in the deaerator tank. This is a conservative a

As steam flow rate equals feedwater flow rate, equations 1 – 3 can be rearranged to give the following:

$$(4) \quad NG(HHV) = \frac{Q_{rsh}\left(E_s - E_{fw}\right)}{L_h * \eta_{\mathrm{dis}} * \eta_{\mathrm{b}}}$$

The previous equation can be further simplified if the difference between feedwater enthalpy and steam enthalpy is approximately equal to the latent heat released ant steam heater (a conservative assumption). The equation then becomes:

$$(5) \quad NG(HHV) = \frac{Q_{rsh}}{\eta_{\mathrm{dis}} * \eta_{\mathrm{b}}}$$

The heat recovered by the proposed system was delivered to cold water (the "heat sink") that would otherwise require heating in heat exchangers that use steam from the boilers. Therefore, the heat delivered to the "heat sink" was displace heat required at heat exchanger. Therefore, the natural gas saved by heating the cold water or "heat sink" by the heat recovery system by an amount Qhr can be calculated using the following equation:

$$(6) \quad NG(HHV) = \frac{Q_{hr}}{\eta_{\mathrm{dis}} * \eta_{\mathrm{b}}}$$

GHG reduction due to natural gas savings can be calculated using the following equation:

$$(7) \quad GHG(MtCO_2e) = NG * \eta_{\mathrm{ng}}$$

This is how the energy savings the system delivered were calculated. Where Q^{hr} is calculated by the heat recovery systems sensors values (TT-11, TT-12 and FT-01) and the following equation:

$$(8) \quad Q_{hr} = FT01 * 1\frac{btu}{lb\ F} * (TT12 - TT11)$$

Where FT-01 is in lb/h, TT-11,12 are both in degrees Fahrenheit. ηdis is a unitless factor and depends on specifics of the heat distribution factors of the plant. A conservative value used by TEI from industry experience is 0.90. η_b will be a unitless factor and is best determined by boiler flue gas temperature and combustion air excess percentage. Industry standard literature estimates this to be 0.80 for a boiler operating at 425 F and 120% stoichiometric combustion air requirement. This factor varies slightly over the boilers' actual operating parameters. η_{ng} is a factor that represents the CO_2e per therm of natural gas. A conservative value used by TEI from industry experience is 0.0053 $MtCO_2e$/therm.

Baseline Monitoring

The data in Table D-3 was used to calculate the energy savings estimates TEI provided in the FPIP grant project application. The same data was monitored and collected as required to meet baseline monitoring standards.

Table D-3: Baseline Monitoring Variables Summary

Variable	Measurement Method and Duration	Notes
Boiler Natural Gas Flow	Daily Average – 1 Year	
Boiler Flue Gas Temperature and Moisture Content	3 Spot Checks over the course of 1 year	No trending available
Boiler Make-up (BMU) Water Flow Rate	Minute Averages – 1 Month	Used to verify sinks
Process Batches	Total Batches – 9 Months	Used to verify sinks

Source: Thermal Energy International Inc.

Note 1: BMU water was measured using an ultrasonic clamp-on flow meter as no onsite metering of this variable was available.

Note 2: Boiler Natural Gas Flow and Process batches continued to be monitored until the system was in place. Boiler flue gas temperature and moisture content were spot checked occasionally until the system was in place.

Post-Installation Monitoring

See heat recovery unit (condensing boiler economizer) nominal performance specifications in Figure D-2. For more detailed specifications, refer to Appendix B.

Figure D-2: Rainmaker-Silver-Dual D6 - Performance Specifications

Performance at 100%	Mass Flow Rate	Temperature In	Temperature Out	Pressure Drop
Water Side	50 GPM	75 deg F in	140.9 deg F out	1 psi
Flue Gas Side	6070 ACFM	350 deg F in	139 deg F out	0.763 inches WC

Sensible Energy Recovered: 1015287 btu/hr
Latent Energy Recovered: 634305 btu/hr
Total Energy Recovered 1649592 btu per hour

Source: Thermal Energy International Inc.

The above unit is the core of the heat recovery system and energy savings recovered here are equivalent to heat delivered to end users. To quantify the amount of energy recovered, TEI was tracking, on a 10-second basis, the values of the following elements to calculate energy savings:

- Water Flow Rate (GPM) by **FT-01**
- Economizer Water Inlet Temperature (°F) by **TT-11**
- Economizer Water Outlet Temperature (°F) by **TT-12**

These values were recorded on a new Programmable Logic Controller (PLC) system that was provided by TEI as part of the heat recovery system. All sensor data were accurate within +/- 2%. Due to an unforeseen closure of the DFA Ventura facility shortly after project completion, only 251 days (roughly 9 months) of data was monitored and analyzed to calculate energy savings. This data was annualized to portray the yearly energy savings of the project.

With equations 6 to 8, the following are sample calculations to show how raw data was converted to energy savings and GHG reductions. Table D-4 shows the first few data points from the system for March 27th, 2023:

Table D-4: Extract of Data Measured on March 27th, 2023

Date	TT-01	TT-02	TT-03	TT-04	TT-05	TT-06	TT-11	TT-12	ED-01 FB	ED-02 FB	PT-01	PT-02	EF-01 SPEED FB	BV-01 FB	CV-01 FB	FT-01	PT-03
2023-03-27 0:00	311	289	319	53	148	93	89	92	38	40	-1.02885	46.7488	46	0	5	46.91106	102.8165
2023-03-27 0:00	311	290	319	53	147	93	89	92	38	40	-1.02885	46.73678	46	0	5	46.78185	103.0649
2023-03-27 0:00	311	291	319	53	146	93	89	92	40	40	-1.02428	46.72476	46	0	5	46.91406	102.9007
2023-03-27 0:00	311	292	319	53	146	93	89	91	40	40	-1.02091	46.73077	46	0	5	46.89003	103.1891
2023-03-27 0:00	311	293	319	53	145	93	89	91	42	40	-1.01611	46.71875	46	0	5	46.88702	102.8526
2023-03-27 0:00	311	294	319	53	145	93	88	91	42	40	-1.01394	46.72476	46	0	5	46.89603	102.8926
2023-03-27 0:01	311	295	319	53	144	93	87	92	44	40	-1.00361	46.70673	46	0	5	46.86599	103.089
2023-03-27 0:01	311	297	319	53	144	93	86	92	44	40	-1.00697	46.70072	46	0	5	46.94712	102.7244
2023-03-27 0:01	311	299	319	53	144	93	86	92	46	40	-0.99303	46.70072	46	0	5	46.96214	102.4159
2023-03-27 0:01	311	302	319	53	144	93	85	93	46	40	-1.01659	46.69471	47	0	5	46.91707	102.2757
2023-03-27 0:01	311	304	319	53	144	93	85	93	48	40	-1.01106	46.6887	47	0	5	46.91106	102.7324
2023-03-27 0:01	311	307	319	53	144	93	85	93	48	40	-1.01346	46.69471	47	0	5	46.83894	102.9247
2023-03-27 0:02	311	309	319	53	145	93	85	94	50	40	-0.99687	46.69471	47	0	5	46.86899	102.5601
2023-03-27 0:02	311	311	319	53	145	93	85	94	50	40	-1.00072	46.69471	47	0	5	47.01923	102.3077
2023-03-27 0:02	311	311	319	53	146	93	85	94	52	40	-0.98005	46.69471	47	0	5	46.91106	102.8926
2023-03-27 0:02	311	311	319	53	147	93	85	94	52	40	-0.98173	46.70673	47	0	5	46.83894	102.4599
2023-03-27 0:02	311	311	319	53	147	93	86	94	54	40	-0.97764	46.72476	48	0	5	46.95613	102.6122

Source: Thermal Energy International Inc.

From these measurements, the values for sensors TT-11, TT-12 and FT-01 are known. Taking the first row of data for that day, TT-11 reads 89 F, TT-12 reads 92 F and FT-01 reads 46.91106 GPM. With equation 8, the heat recovered from the system at that data point is:

Step 1 (Equation 8):

$$Q_{hr} = FT01 * 1\frac{btu}{lb\ F} * (TT12 - TT11)$$

Step 2 (Inserting variables):

$$Q_{hr} = 46.91106\ (\text{GPM}) * 1(\frac{btu}{lb\ F}) * (92\ (F) - 89\ (F))$$

Step 3 (Converting flow from GPM to lb/hr):

$$Q_{hr} = 46.91106\left(\frac{\text{gal}}{min}\right) * 8.34\ \frac{\text{lb}}{gal}\ \text{x}\ 60\ \frac{\text{min}}{hr} * 1(\frac{btu}{lb\ F}) * (92\ (F) - 89\ (F))$$

Step 4 (Simplifying):

$$Q_{hr} = 46.91106\left(\frac{\cancel{\text{gal}}}{\cancel{min}}\right) * 8.34\ \frac{\cancel{\text{lb}}}{\cancel{gal}}\ \text{x}\ 60\ \frac{\cancel{\text{min}}}{hr} * 1(\frac{btu}{\cancel{lb\ F}}) * (92\ (\cancel{F}) - 89\ (\cancel{F}))$$

Step 5 (Converting and simplifying from btu to therms):

$$Q_{hr} = 46.91106 * 8.34\ \text{x}\ 60\ \frac{\cancel{\text{btu}}}{hr} * \frac{1\text{therm}}{10^5\cancel{btu}}(3)$$

Step 6 (Solving for Q_{hr}):

$$Q_{hr} = 46.91106 * 8.34\ \text{x}\ 60\ \frac{\text{therm}}{10^5 hr} * (3)$$

$$Q_{hr} = 0.7\ \text{therms/hr}$$

From here, the heat savings can be inserted in equation 6 to find the natural gas savings:

Step 1 (Equation 6):

$$NG(HHV) = \frac{Q_{hr}}{\eta_{\text{dis}} * \eta_{\text{b}}}$$

Step 2 [Inserting variables (with η_{dis} being estimated at 90% and η_b being estimated at 80%)]:

$$NG(HHV) = \frac{0.7\ \text{therms/hr}}{0.9 * 0.8}$$

Step 3 [Solving for $NG(HHV)$]:

$$NG(HHV) = 0.97\ \text{therms/hr}$$

From the value of NG, the GHG reduction can be calculated with equation 7 with the following steps:

Step 1 (Equation 7):

$$(\qquad {}_2e\ ) = \qquad * \eta_{\text{ng}}$$

Step 2 [Inserting variables (with η_{dg} being equal to 0.0053 $MtCO_2e$/therm)]:

$$GHG(MtCO_2e) = 0.97\ \frac{\text{therms}}{\text{hr}} * 0.0053\ \frac{MtCO_2e}{therms}$$

Step 3 (Simplifying):

$$GHG(MtCO_2e) = 0.97\ \frac{\cancel{\text{therms}}}{\text{hr}} * 0.0053\ \frac{MtCO_2e}{\cancel{therms}}$$

Step 4 (Solving for GHG):

$$GHG(MtCO_2e) = 0.0051\ \frac{MtCO_2e}{\text{hr}}$$

These calculations were done with all data points and were summed up for each month. Table D-54 represents the monthly gas savings and CO_2 reduction.

Table D-5: Monthly Heat Recovery and Carbon Reduction

Month	Heat Recovered (therms)	CO_2 Reduction (metric tons)
Mar-23	3349.89	17.75
Apr-23	6135.36	32.52
May-23	5390.49	28.57
Jun-23	4854.74	25.73
Jul-23	3647.19	19.33
Aug-23	4193.13	22.22
Sep-23	4549.00	24.11
Oct-23	4830.15	25.60
Nov-23	2441.37	12.94
Total	**39,391.31**	**208.77**

Source: Thermal Energy International Inc.

With this, the monthly values were then annualized by multiplying each monthly value by 365 days per year/251 days to get a yearly savings comparison, since due to the facility closure only 251 days of data was available for analysis. After applying this annualization factor, the data shows the annual natural gas usage was 57,282 therms and annual GHG emissions reductions were 304 $MTCO_2e$.

Table D-6 summarizes the annual gas usage as well as the annual GHG emissions before and after the installation of the heat recovery system:

Table D-6: Key Findings

Metric	Grant Application Reduction Estimates	Pre-Installation Usage	Post-Installation Reduction
Annual Natural Gas	139,962 therms	1,008,900 therms	57,282 therms
Annual GHG	743 $MTCO_2e$	5,348 $MTCO_2e$	304 $MTCO_2e$

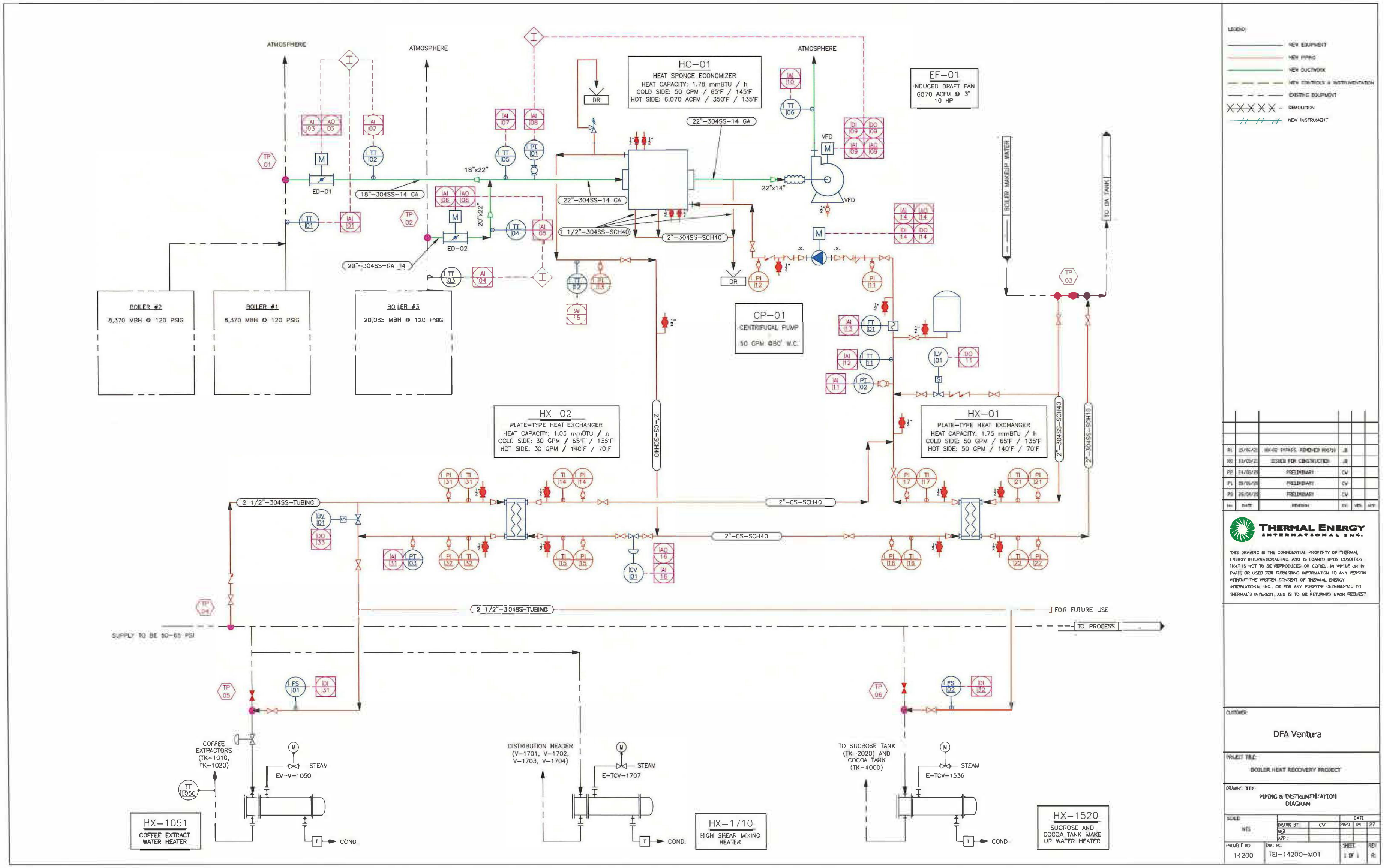
Source: Thermal Energy International Inc.

Conclusion

The implementation of the high-efficiency indirect condensing heat recovery unit at the Dairy Farmers of America Ventura facility has demonstrated significant potential for energy conservation and GHG reduction. By capturing waste heat from the exhaust gases of three natural gas boilers, the system effectively pre-heats both boiler make-up water and process water, thereby reducing the demand for steam and lowering overall natural gas consumption.

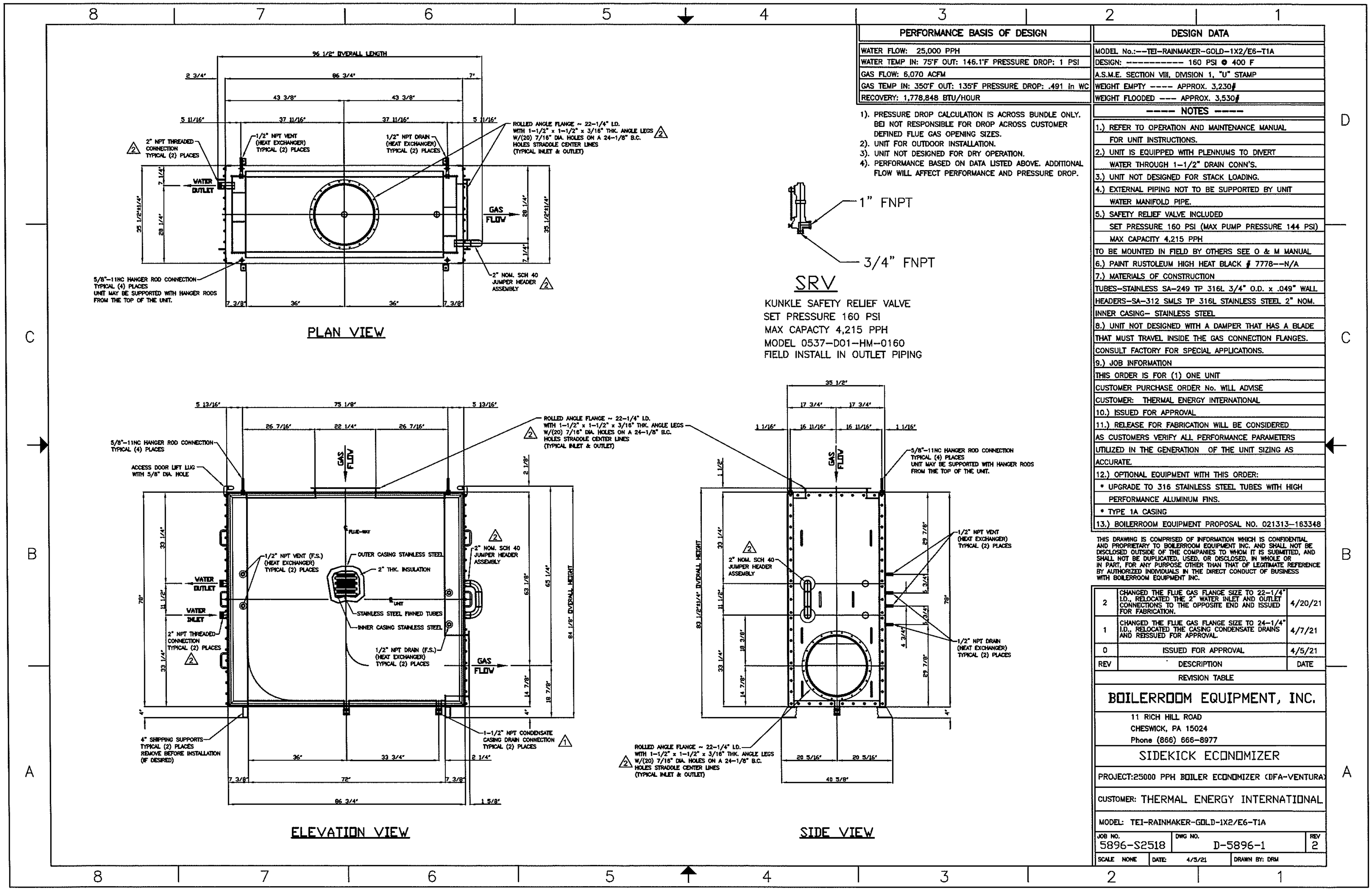
Despite the limited operational period, due to the facility's closure shortly after installation, the M&V efforts, based on the IPMVP Option B methodology, provide compelling evidence of the system's efficacy. Annualized data indicates a reduction of approximately 57,282 therms in natural gas usage and a concomitant decrease of 304 $MTCO_2e$ emissions. These figures not only validate the design and operational strategies employed but also highlight the environmental benefits of adopting such technologies in industrial settings.

M&V Report Appendix A: P&ID of System Installed



Source: Thermal Energy International Inc.

M&V Report Appendix B: Economizer Performance Information



Source: Thermal Energy International Inc.

CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX E: Daily Heat Recovery Data – 30 Day Sample

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APPENDIX E:
Daily Heat Recovery Data – 30 Day Sample

DATE	HEAT RECOVERED (MMBTU)
2023-04-01	22.78791178
2023-04-02	5.534431005
2023-04-03	1.850413496
2023-04-04	0.000111539
2023-04-05	5.766830423
2023-04-06	19.68620599
2023-04-07	17.17540329
2023-04-08	16.70742064
2023-04-09	6.259589077
2023-04-10	13.92910786
2023-04-11	17.88518844
2023-04-12	15.61981176
2023-04-13	19.18226758
2023-04-14	20.65825332
2023-04-15	18.93725185
2023-04-16	9.107902804
2023-04-17	8.595571294
2023-04-18	13.38251362
2023-04-19	11.88598807
2023-04-20	20.12438947
2023-04-21	19.13258101
2023-04-22	21.04143329
2023-04-23	7.184127319
2023-04-24	19.02253118
2023-04-25	21.62064837
2023-04-26	19.53319086
2023-04-27	20.54543073
2023-04-28	19.33287685
2023-04-29	20.30182936
2023-04-30	8.954963804

Source: Thermal Energy International Inc.