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ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Foster Farms Food Processing Efficiency Project Final Report

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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.

Foster Farms Food Processing Efficiency Project Final Report is the final report for the Foster Farms Food Processing Efficiency project (FPI-18-003) conducted by Foster Farms with measurement and verification assistance from Cascade Energy. 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

This project installed a series of energy efficient upgrades, including boiler economizers, improved boiler controls, and hot water recovery loops at five of Foster Farm's poultry production facilities. The project resulted in 458,050 Therms/year in reduced natural gas energy use and 2,665 metric tons of carbon dioxide equivalent of greenhouse gas (GHG) emissions reductions at each facility.

Foster Farms is an American poultry company. It was privately owned from 1939 until 2022, when Atlas Holdings purchased the company from the Foster family. The company is based in Livingston, California, and maintains several California locations as well as a number of locations in Alabama, Colorado, Louisiana, and Washington. The company specializes in a variety of chicken and turkey products advertised as fresh and naturally locally grown in addition to cooked and prepared food.

The Foster Farms engineering team collaborated with industry leading service vendors including Energy Resource Company, Nexus Engineering, Solecon, and others to complete design and implementation of project activities. This included: 1) installation of boiler economizers that capture wasted heat from boiler stacks and transfer that heat to the boiler feed water tank, raising the boiler feed water temperature without the need for additional fuel usage, lowering GHG emissions and energy costs; 2) upgrading the boiler controls to provide more efficient boiler operations to achieve the same or higher boiler steam throughput at the same or lower energy use, resulting in lower GHG emissions and fuel costs; and 3) installation of a hot water recovery system to produce hot water on demand, reducing the amount of energy wasted and GHG emissions produced compared with the old system that utilized only steam produced by a boiler.

Keywords: poultry production facility energy upgrades, boiler economizers, boiler controls upgrade, hot water recovery loops

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Executive Summary

Foster Poultry Farms, also known as Foster Farms, is an American company that specializes in chicken and turkey products. Established in 1939, Foster Farms strives to promote sustainability through energy conservation.

The purpose of the project was to deploy advanced and innovative technologies to reduce energy consumption, greenhouse gas (GHG) emissions, and criteria air pollutants from food production activities at five California-based Foster Farm production facilities located in Turlock, Fresno (South Cherry Ave and West Belgravia Ave.), Porterville, and Livingston (the main facility).

There were five upgrades proposed as part of the project, although only three were installed. The first upgrade was the installation of condensing boiler economizers on seven boilers across five facilities. These economizers capture waste heat from the boiler exhaust and use it to heat the water going into the boiler. This reduces energy consumption and GHG emissions.

The second upgrade was the installation of boiler control and oxygen trim systems on four boilers at the Livingston facility. These systems make the burners self-adjusting, which reduces fuel costs and emissions. The oxygen trim system measures the amount of excess oxygen in the boiler exhaust and adjusts the incoming combustion air accordingly, which helps improve efficiency as excess combustion air is wasteful. The system also includes a Variable Frequency/Speed Drive (VFD) on each boiler's combustion fan to control air flow more efficiently.

The third and final upgrade was installation of a hot water waste heat recovery system at the Livingston facility. Previously, hot condensate water was directed to a drain in the rendering plant. Since installation, heat is recovered from this water and used to boost the temperature of the water entering the steam heat exchangers. This reduces the amount of steam energy needed for sanitation and washdown processes.

The two upgrades that were not implemented included replacing the deaerator tank and repiping the stack on Boiler 6 at the Livingston facility and several upgrades on the refrigeration system at the Livingston facility. Replacement of the deaerator tank and repiping the stack on Boiler 6 was not completed because logistical and structural challenges made the subproject impractical and more expensive than originally expected.

The upgrades to the refrigeration system at the Livingston facility included controls improvements along with adding VFDs to several of the refrigeration compressors. VFDs only provide energy savings when the compressors are operating at less than full load, and during design investigation Foster Farms determined that the compressors all operate at nearly full load. Therefore, the electrical energy savings would have been small, whereas the project cost was high, so the refrigeration upgrades were not implemented.

Project Approach

Project Team

Foster Farms managed the project internally. Energy Resource Company was hired to install all implemented subprojects: boiler economizers, boiler controls and oxygen trim, and hot water recovery. Access Industrial Automation updated the controls for each subproject. Cascade Energy, an energy efficiency consultant, completed the pre- and post-installation measurement and verification (M&V) analysis and reporting to compare the energy efficiency and GHG emissions of the steam-producing natural gas-fired boilers and the hot water systems. Nexus Engineering and Solecon were contractors who contributed to assessing the original equipment, project planning, and some of the equipment installation.

Summary of Measurement and Verification

A baseline was developed for each of the three subprojects. The baseline boiler efficiencies were assessed and compared to post-installation efficiencies to determine the impact on natural gas consumption and GHG reductions.

Subproject 1 installed boiler economizers on seven boilers across five facilities. Three months of data was collected to calculate the baseline natural gas usage of the boilers. After the economizers were installed, twelve months of boiler data was collected and analyzed to calculate the post-installation natural gas usage.

Subproject 2 implemented oxygen trim and combustion air fan speed control on four boilers at the Livingston facility. The pre-installation M&V utilized the same data collected from the Livingston boilers for Subproject 1 to establish the baseline natural gas and electricity usage. The post-installation M&V used twelve months of boiler and combustion fan data to determine the updated natural gas and electricity usage.

Subproject 3 installed a heat recovery system to utilize heat from hot condensate water that was previously wasted. For pre-installation M&V, hot water savings estimates were calculated based on system operations and estimated waste heat exchanger operations. The load on the steam system was converted to natural gas usage by compiling boiler data to calculate overall plant efficiency. The post-installation M&V collected twelve months of data on the new waste heat exchanger pumps to calculate flow, which was used in conjunction with the inlet and outlet temperatures of the heat exchangers to calculate heat load contribution. The upgraded boiler efficiencies from Subprojects 1 and 2 were used to update the overall plant efficiency to convert the heat load savings to natural gas savings.

Subprojects 4 and 5 were not implemented, therefore no M&V work was done.

Results

The savings proposed in the project grant application are compared to the post-installation M&V results for each subproject in Table 1.

Table 1: Proposed Savings Estimates vs Post-Installation M&V Savings

Subproject	Proposed Natural Gas (therms/yr)	Proposed Electric (kWh/yr)	Proposed Total GHG Emissions Savings ($MTCO_2e$)	Post-M&V Natural Gas (therms/yr)	Post-M&V Electric (kWh/yr)	Post-M&V Total GHG Emissions Savings ($MTCO_2e$)
Boiler Economizers	289,504	6,271	1,538.9	231,172	0	1,227.5
Boiler Controls and Oxygen Trim	151,801	6,997	807.7	4,431	276,734	86.6
Hot Water Recovery	222,447	0	9,820.3	222,447	-144,540	1,351.4
Deaerator Tank and Repiping	216,974	0	2,436.3	*	*	*
Livingston Refrigeration System Upgrades	0	10,689,898	1,152.1	*	*	*
Totals	**880,726**	**10,703,166**	**15,755**	**458,050**	**132,194**	**2,665**

* Not measured because the subproject was not installed
Source: Cascade Energy

Savings estimates were recalculated prior to installation using pre-installation M&V data, which are compared to the post-installation M&V savings for each subproject in Table 2. Two of the subprojects were not implemented, which contributed to the decreased total savings in some categories in Table 2 compared to Table 1.

Table 2: Pre-Installation M&V Savings Estimates vs Post-Installation M&V Savings

Subproject	Pre-M&V Estimated Natural Gas Savings (therms/yr)	Pre-M&V Estimated Electric Savings (kWh/yr)	Pre-M&V Estimated Total GHG Emissions Savings ($MTCO_2e$)	Post-M&V Natural Gas (therms/yr)	Post-M&V Electric (kWh/yr)	Post-M&V Total GHG Emissions Savings ($MTCO_2e$)
Boiler Economizers	155,823	0	1,416.1	231,172	0	1,227.5
Boiler Controls and Oxygen Trim	187,798	544,031	1,028.6	4,431	276,734	86.6

Subproject	Pre-M&V Estimated Natural Gas Savings (therms/yr)	Pre-M&V Estimated Electric Savings (kWh/yr)	Pre-M&V Estimated Total GHG Emissions Savings ($MTCO_2e$)	Post-M&V Natural Gas (therms/yr)	Post-M&V Electric (kWh/yr)	Post-M&V Total GHG Emissions Savings ($MTCO_2e$)
Hot Water Recovery	100,123	-117,530	489.2	222,447	-144,540	1,351.4
Deaerator Tank and Repiping	*	*	*	*	*	*
Livingston Refrigeration System Upgrades	*	*	*	*	*	*
Totals	**443,739**	**426,501**	**2,934**	**458,050**	**132,194**	**2,665**

* Not measured because the subproject was not installed
Source: Cascade Energy

The final results are substantially lower than the proposed savings. The reason for this is unknown because documentation could not be found on the proposed savings calculations. The final savings are much closer to the pre-installation M&V savings estimates, which were based on actual collected data and system information. The final savings were lower than the pre-installation M&V estimates because the boiler economizers and boiler controls with oxygen trim did not operate as efficiently as expected. The system likely requires additional commissioning, which would involve a technician testing and adjusting the economizers and controls to achieve a more optimal boiler performance. Foster Farms plans to work with the boiler contractor to investigate the issues.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

The Foster Farms Food Processing Efficiency Project installed multiple drop-in ready emissions reducing technologies. These technologies were extensively researched and installed at industrial facilities throughout the U.S. and the world for many years prior to this project and their benefit to energy reduction is already well characterized. Foster Farms implemented the technologies using industry standard components. Foster Farms will allow any future non-competitor end user who would like to implement similar projects to visit the site and review the installations including sharing all details and learning key points.

CHAPTER 1: Introduction/Project Purpose

Background

Foster Poultry Farms, also known as Foster Farms, is an American company established in 1939 that specializes in chicken and turkey products. The company creates retail products including raw whole rotisserie, raw parts such as drums and thighs, ground turkey, and cooked products such as wings, tenders, hot dogs, and corn dogs.

Five chicken and turkey processing facilities were involved in this project. The facilities are located in Livingston, Turlock, Fresno (West Belgravia Ave), Fresno (South Cherry Ave), and Porterville and all operate Monday through Friday from 4:00 am to 10:00 pm with a sanitation shift from 10:00 pm to 4:00 am. Depending on production demand, the facilities also occasionally operate on Saturdays and Sundays.

Project Overview

The purpose of the project was to install energy efficient upgrades, including boiler economizers at five facilities, boiler controls and oxygen trim on four boilers at the Livingston facility, and a hot water heat recovery system at the Livingston facility. Two additional upgrades that were originally proposed, but did not get installed included replacing the Livingston deaerator tank and repiping the stack; and a comprehensive refrigeration upgrade at the Livingston facility.

Boiler Economizers

Boiler economizers were installed in all five plants. The economizers reduce energy consumption and greenhouse gas (GHG) emissions by capturing waste heat from the gases produced by the boilers. The captured heat is then used to warm up the water that is fed into the boiler. Raising the temperature of the water before it enters the boiler reduces the energy needed to heat it further so the boilers can operate at a lower firing rate while still producing the same amount of heat, saving natural gas and electricity.

Boiler Controls and Oxygen Trim

To reduce fuel costs and GHG emissions, dynamic boiler and oxygen trim controls were installed on four boilers at the Livingston facility. The existing controls did not allow for adjustments in the speed of the electric motor or oxygen trim, so the fans on the boiler always ran at a fixed speed regardless of the boiler’s needs. The motor starter was replaced with a Variable Frequency/Speed Drive (VFD), which allows for the motor to operate at a predetermined speed based on the desired fuel and air levels.

Oxygen trim increases efficiency by using a sensor to measure excess oxygen in the boiler exhaust and then trimming incoming combustion air by comparing the measured oxygen to a predetermined value (a curve point determined by initial tuning). This enables the burner to run at optimal ratios irrespective of changes in ambient air temperature and/or density, thereby reducing fuel consumption.

Hot Water Recovery System

Three waste heat exchangers were installed at the Livingston facility in the process heating system to capture waste heat from the boiler condensate and then use that heat to preheat water for sanitation and washdown. By using recovered waste heat to make and store hot water, the amount of fuel required to heat the water to the necessary temperatures is reduced, leading to lower overall energy demands and GHG emissions.

Boiler Deaerator Tank and Stack Repiping

This upgrade was outlined in the project proposal but was not installed. This subproject planned to install a new deaerator tank for Livingston Boiler 6 and adjust piping to optimize the system. These measures were expected to have reduced energy consumption and GHG emissions by 2 percent by recapturing and using wasted hot condensate water from Boilers 4 and 5 to preheat the water at the Boiler 6 deaerator tank, reducing the overall boiler heating requirement. This would have also eliminated the plume of steam continuously being released through the stack outside Boilers 4 and 5.

However, the physical distance between Boilers 4 and 5 and Boiler 6 presented considerable logistical challenges. A pipe bridge and supports would have had to span across multiple roofs, which was not practical due to structural limitations of the existing buildings. Additionally, a road that runs between the two buildings would have further complicated the installation process. It was determined that there was no beneficial use for the steam being released through the stack outside Boilers 4 and 5 if it could not be piped to Boiler 6. As such, this subproject was determined not to be a good fit for the facility and was removed from the project.

Livingston Refrigeration System Upgrades

This upgrade was planned in the project proposal but was not installed. The ammonia refrigeration optimization would have enhanced the controls of all five refrigeration plants at the Livingston Complex by running floating head pressure controls on the condenser and staging the compressors more efficiently. VFDs would have also been installed on several of the refrigeration compressors. Floating head pressure controls self-modulate based on ambient weather rather than relying on a fixed setpoint, allowing for more balanced energy usage between the condensers and compressors. Effective compressor staging would have only allowed for one compressor to trim at a time with the rest base loaded or off. VFDs allow the compressors to modulate to meet the load more efficiently than the standard slide valve capacity control on screw compressors. Before work began on this subproject, it was determined that the compressors were operating highly loaded, so the VFD electrical energy savings would have been low while the cost of the subproject was very high. Therefore, these upgrades were removed from the project.

CHAPTER 2: Project Approach

Boiler Economizers

Seven boilers were retrofitted with condensing stack economizers. The Livingston facility and the Porterville facilities installed two economizers each while Turlock and the two Fresno facilities installed one economizer each. The economizers capture waste heat from boiler stack gases which is then transferred to preheat the boiler feed water. Preheating the boiler feed water reduces the firing rate for the boiler to achieve the required output temperature, lowering energy input and therefore lowering natural gas and electricity usage and reducing GHG emissions.

To prepare the sites, the Foster Farms project manager and contractors reviewed the existing equipment and facility areas where the project would be installed. Sections of roof above the boilers at each location needed to be temporarily removed to allow access for a crane to lift out existing economizers and to place the new economizers.

Boiler Controls and Oxygen Trim

Dynamic boiler and oxygen trim controls were added to four boilers at the Livingston facility. Additionally, a VFD was installed on each boiler combustion fan to improve air flow control. One boiler at a time was changed over from legacy controls to the new controls. Testing was done to ensure the controls were operating effectively and then production resumed before moving on to update the controls of the next boiler.

The addition of dynamic boiler controls and oxygen trim reduced fuel costs and emissions by making the burner self-tuning. The existing controls did not permit variable frequency of the electric motor on the combustion fan or oxygen trim. The fans on the boiler constantly ran at a speed of 60 HZ irrespective of boiler demands. The motor starter was replaced with a VFD which controls the motor to a pre-set speed for fuel and air curve points automatically. Oxygen trim increases efficiency by measuring excess oxygen with a sensor in the boiler exhaust, and then trimming incoming combustion air by comparing the measured oxygen to a predetermined value (a curve point determined by initial tuning). This enables the burner to run at optimal ratios irrespective of changes in ambient air temperature and/or density, thereby reducing fuel consumption. Both the VFD and oxygen trim were drop-in ready additions to the system.

In addition to electrical savings, the system also reduced the amount of natural gas used because controlling airflow with the oxygen trim is much more precise than with an air damper alone, allowing for a more consistent combustion setting.

Hot Water Recovery System

Three heat exchangers were installed at the Livingston facility. Waste heat is recovered from the boiler condensate and used to preheat water for sanitation and washdown. An area was selected near the existing hot water system for installation. All equipment was placed, installed, and tested to ensure it was operating correctly. After testing was completed, the facility switched over to the new hot water recovery system over a weekend.

Project Team

- Albert Mulhim, Project Manager, Foster Farms
- Aimn Al Haider, Project Engineer III, Foster Farms
- Jose Ramos, Controls Engineer, Access Industrial Automation
- Amanda Buklow, Billing/Engineering Specialist, Energy Resources Corporation
- James Conder, Boiler Technician, Energy Resources Corporation
- Jason Ruhl, Sr. Project Engineer, Cascade Energy
- Miri Goldade, Sr. Project Engineer, Cascade Energy

Access Industrial Automation contributed to the control systems upgrades and exporting measurement and verification (M&V) data.

Energy Resources Corporation provided support during the boiler upgrades.

Cascade Energy performed the pre- and post-installation M&V data analysis and reporting.

Projected Benefits

A total GHG reduction of 15,755 $MTCO_2e$ was estimated in the project application, as summarized in Table 3. These proposed savings were very roughly estimated and are therefore very high compared to the post-installation results. There was likely a calculation error on the hot water recovery project proposed savings as those estimates are unrealistically high.

Table 3: Proposed Benefits Summary

Subproject	Proposed Natural Gas (therms/yr)	Proposed Electric (kWh/yr)	Proposed Total GHG Emissions Savings ($MTCO_2e$)
Boiler Economizers	289,504	6,271	1,538.9
Boiler Controls and Oxygen Trim	93,469	726	807.7
Hot Water Recovery	222,447	0	9,820.3
Deaerator Tank and Repiping	216,974	0	2,436.3
Livingston Refrigeration System Upgrades	0	10,689,898	1,152.1
Totals	**822,394**	**10,696,895**	**15,755**

Source: Cascade Energy

Project Changes and Challenges

The project was installed as planned, except the timeline was slightly delayed due to the COVID-19 pandemic. Supply chain disruptions, store closures, and limited access to necessary goods were all factors caused by the pandemic that compounded the logistical challenges of the project. There were no challenges encountered during installation.

There were commissioning issues on the hot water recovery subproject that caused delay to the post-installation M&V data collection. Manual valves were unintentionally closed during maintenance, which prevented the hot water heat exchangers from functioning. This was corrected in October 2022 and then the year of post-installation M&V data collection restarted.

The boiler economizers, boiler controls, and oxygen trim did not perform as efficiently as expected and may require additional commissioning.

Measurement and Verification Plan

The M&V was completed by collecting boiler and hot water recovery system operating information and trend data for three months to develop the baseline energy usage and then was collected for twelve months after installation to calculate the energy savings. See Appendix A for more detail.

Boiler Economizers

Baseline boiler efficiency was calculated using stack temperature (See Figure 1) and percent oxygen in the flue gas as measured by each facility over a three-month span. Upgrade boiler efficiency was determined using the same method as the baseline, although data was collected over twelve months.

Boiler efficiencies were measured by determining the amount of heat carried away by dry flue gases and moisture loss. The ASME PTC-4 – Indirect Method: Stack Loss Method is used for efficiency calculations and requires readings of stack oxygen ($O_2\%$) and stack temperature (T_{Stack}).

$$Eq.1{:}\, S_{flow} \;=\; Rated\ Boiler\ Steam\ Rate\ \left(\frac{lbs}{hr}\right) = Boiler\ HP\ x\ 34.5\ \left(\frac{\frac{lbs}{hr}}{HP}\right)$$

$$Eq.2{:}\, \eta = \ Boiler\ Efficiency\ (\%) = 100\% - \ L_{DG} - \ L_{WG} - 1\%_{Other\ Losses}$$

Where:

$$\begin{aligned} Eq.2a{:}\, L_{DG} \;&=\; Dry\ Losses\ (\%) \\ &= 0.001044\ x\ \left[14.7365\left(\frac{O_2\%}{21\% - \ O_2\%}\right) + 15.371\right]\ x\ (T_{Stack} - 70) \end{aligned}$$

$$Eq.2b{:}\, L_{DG} \;=\; Wet\ Losses\ (\%) = 9.482 + (0.004351\ x\ T_{Stack})$$

$$T_{Stack} = Stack\ Temperature\ (°F);\ O_2\% = percent\ Oxygen\ in\ the\ stack;$$

$$Eq.3{:}\, Q = \ Boiler\ Energy\ \left(\frac{Therms}{hr}\right) = \frac{S_{flow}\ \left(\frac{lbs}{hr}\right)\ x\ 1{,}100\,\frac{BTU}{lb}\,x\ 100{,}000\,\frac{Therms}{BTU}}{\eta}$$

$$Eq.4{:}\, Boiler\ Usage\ \left(\frac{Therms}{yr}\right) = Boiler\ Energy\ \left(\frac{Therms}{hr}\right) x\ Run\ hours\ x\ Firing\ Rate\ Adjustment\ Factor$$

Where:

- Baseline run hours were updated with the post-installation M&V monitored run hours.
- The Firing Rate Adjustment Factor was calculated by taking the ratio of the billed monthly natural gas usage for each facility to the calculated full load boiler usage based on actual operations. The billed natural gas usage for each facility includes primarily the boiler usage and a small amount of office HVAC usage which was conservatively assumed to be 5 percent. Note that for Livingston, the boiler gas usage is sub-metered, so sub-metered monthly gas usage was compared to the calculated full load boiler usage based on actual operations.

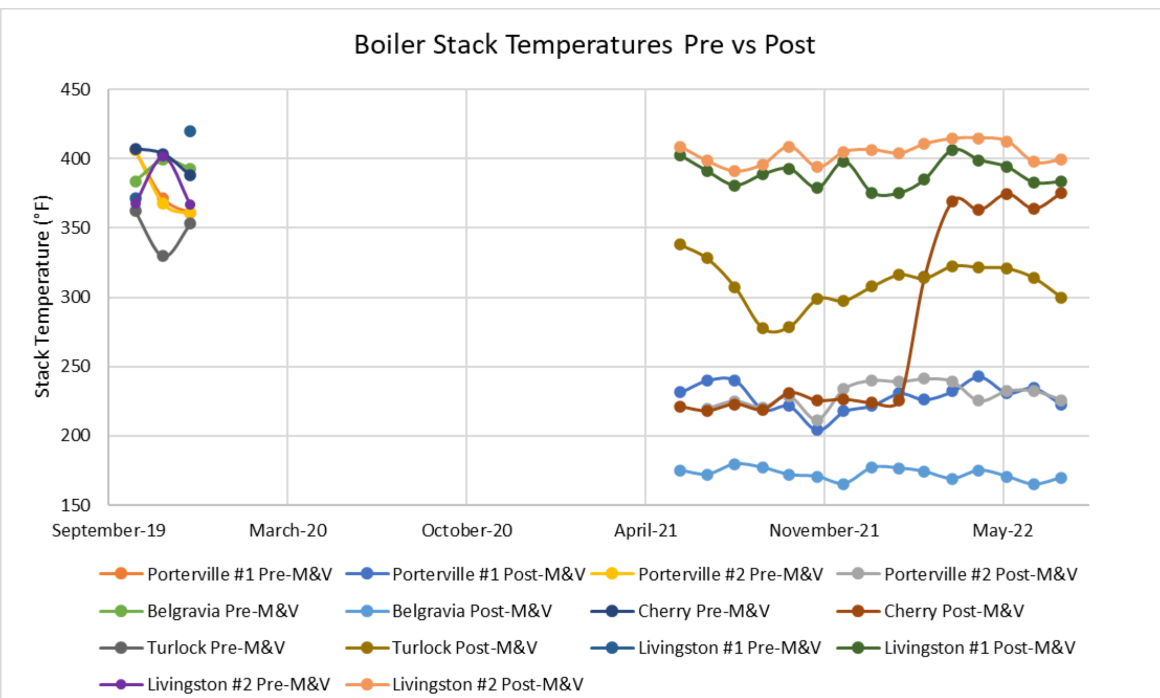
Assumptions:

- The steam has 1,100 British Thermal Unit (BTU) of energy per 1 lb.
- The twelve months of post-installation M&V boiler runtime is representative of a typical year.
- Weather does not impact boiler operation.

Twelve months of post-installation M&V data was collected to determine the boiler runtimes, boiler efficiencies, and boiler capacity. The following boiler data monitoring was collected using Foster Farm's Supervisory Control and Data Acquisition (SCADA) system in 15-minute intervals from August 1, 2021, to July 31, 2022, for all boilers:

- Boiler stack temperature
- Boiler run hours

Figure 1: Stack Temperature Data



Source: Cascade Energy

The baseline and upgrade boiler efficiencies are shown in Table 4.

Table 4: Baseline vs Upgrade Boiler Efficiency

Boiler Location	Boiler Number	Average Baseline Boiler Efficiency (%)	Average Upgrade Boiler Efficiency (%)
Porterville #1	#1	80.3 %	84.6 %
Porterville #2	#2	79.6 %	84.4 %
Fresno Belgravia	#1	81.2 %	86.9 %
Fresno Cherry	#1	80.7 %	84.1 %
Turlock	#1	80.7 %	83.4 %
Livingston #1	#1	79.4 %	80.3 %
Livingston #2	#2	79.7 %	80.1 %

Source: Cascade Energy

A boiler firing rate adjustment factor was calculated using monthly facility gas usage compared to rated boiler input gas usage (see Table 5).

Table 5: Calculated Boiler Firing Rate Adjustment Factors

Facility	Boiler Firing Rate Adjustment Factor
Porterville	98.0%
Fresno Belgravia	83.4%
Fresno Cherry	80.1%
Turlock	100.0%
Livingston	*

* Livingston boiler gas usage is sub-metered, so did not need an adjustment factor. See Firing Rate Adjustment Factor explanation above for detail.
Source: Cascade Energy

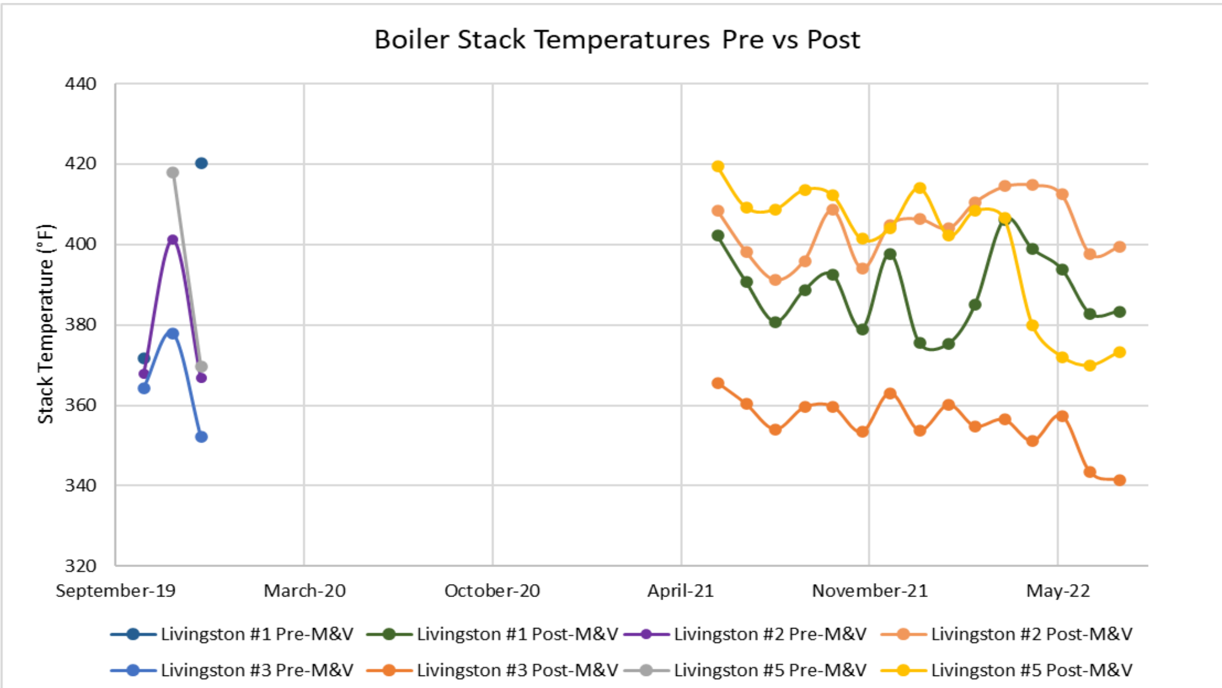
Boiler Controls and Oxygen Trim

Baseline boiler efficiency was calculated using stack temperature (See Figure 2) and percent oxygen in the flue gas as measured by each facility. The same equations from the Boiler Economizer subproject were used for this analysis. Upgrade boiler efficiency was determined using the same method, with data collected over twelve months. Note that Boilers 1 and 2 also had economizers installed, so all natural gas savings from improving the efficiency of the boiler were accounted for in the Boiler Economizer subproject and additional savings would only come from the fan VFDs. Boilers 3 and 5 natural gas and fan savings were attributed to this subproject. Note that the efficiency on Boiler 5 slightly decreased with the upgrade, resulting in increased natural gas usage.

Twelve months of post-installation M&V data was collected to determine the boiler runtimes, boiler efficiencies, boiler capacity, and boiler fan power. The following boiler data monitoring was collected using Foster Farm's SCADA system in 15-minute intervals from August 1, 2021, to July 31, 2022, for all boilers:

- Boiler stack temperature
- Boiler run hours
- Boiler combustion fan speed
- Boiler combustion fan power

Figure 2: Stack Temperature Data



Source: Cascade Energy

The following data was collected in monthly intervals from August 2021, through July 2022:

- Stack oxygen percent
    - Collected by Foster Farm's boiler service company, McNulty Mechanical, for monthly emissions measurement compliance with District Rule 4306.
    - Oxygen levels were measured at five firing rates and the average was used for calculations.

The upgrade boiler efficiencies were calculated using the same methods as the baseline analysis with twelve months of post-installation M&V data. The baseline and post-installation M&V boiler efficiencies are shown in Table 6.

Table 6: Livingston Baseline vs Upgrade Boiler Efficiency

Boiler Location	Average Baseline Boiler Efficiency (%)	Average Upgrade Boiler Efficiency (%)
Livingston #1	79.4 %	80.3 %
Livingston #2	79.7 %	80.1 %

Boiler Location	Average Baseline Boiler Efficiency (%)	Average Upgrade Boiler Efficiency (%)
Livingston #3	80.7%	81.4%
Livingston #5	80.3%	80.1%

Source: Cascade Energy

Hot Water Recovery System

Baseline boiler efficiency was calculated using measured stack temperature and percent oxygen in the flue gas. During post-installation M&V, the heat transferred to the sanitation and washdown water was determined using twelve months of facility trend data. Savings were calculated assuming this recovered load resulted in a direct load reduction on the steam boiler system. The following equation was used to calculate the heat load reduction from the installed waste heat exchanger.

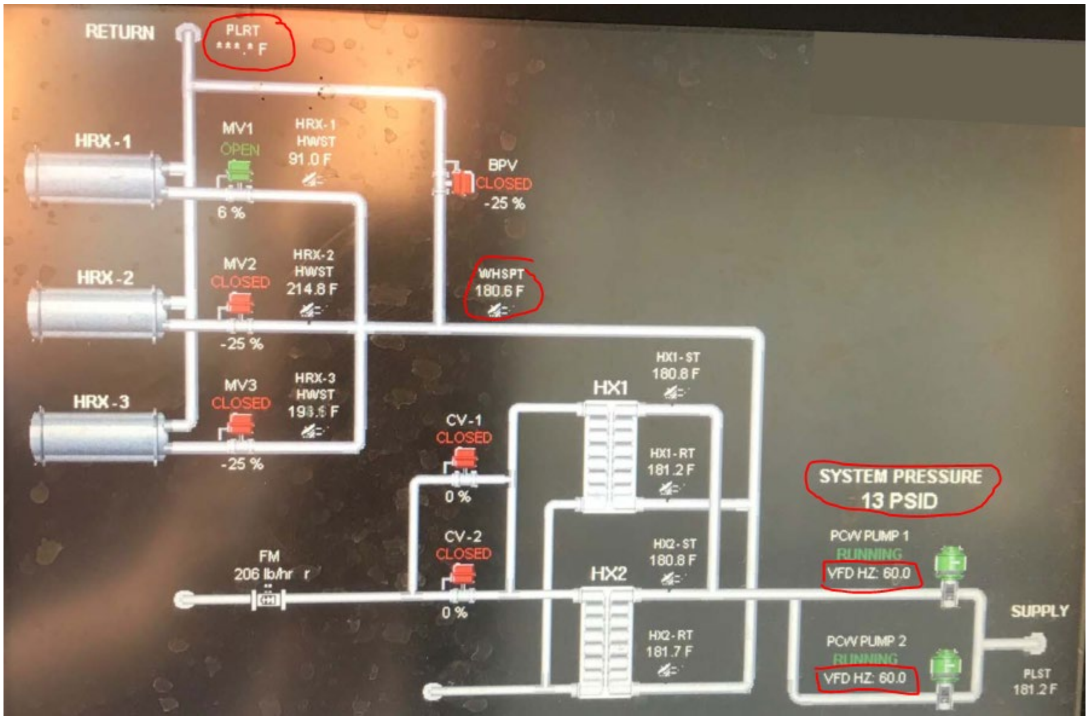
$$Heat\ Recovered\ (Therms) = Water\ Flow\ \left(\frac{lb}{hr}\right)\ x\ \ C_P\left(\frac{Btu}{lb\ x\ °F}\right)\ x\ (Water\ Temp_{Inlet}(°F) - Water\ Temp_{Outlet}(°F)\ )$$

Post-installation trend data was collected in 15-minute intervals from October 2022 to October 2023 for the following variables:

- Inlet water temperature to the new heat exchangers
- Outlet water temperature to the new heat exchangers
- Water pump speed
- Water pump differential pressure

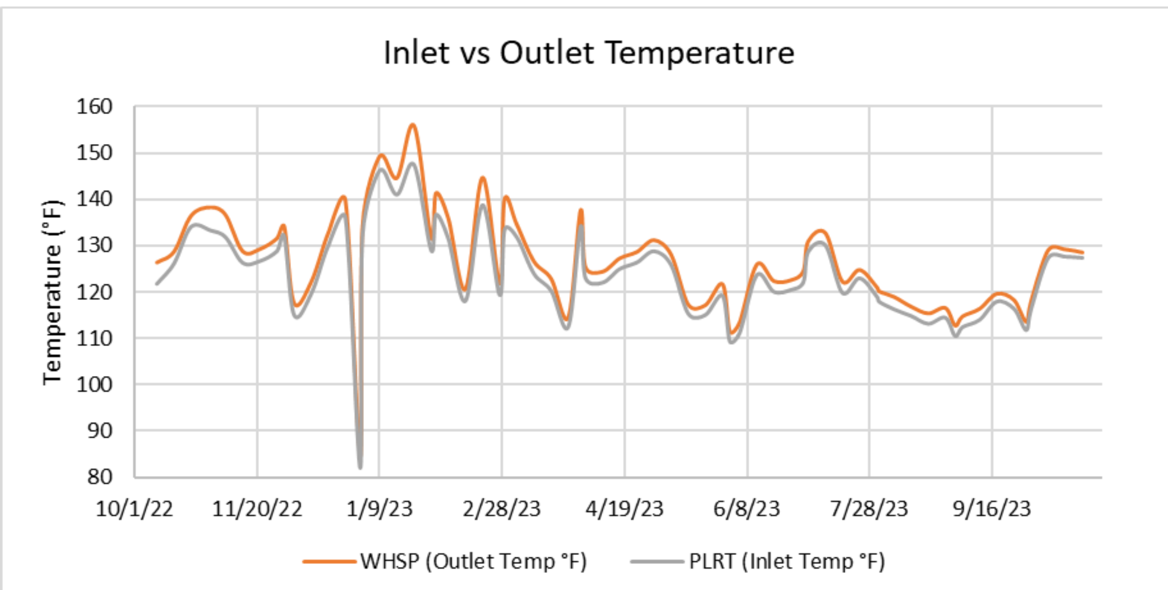
These variables are circled in red in Figure 3, a photo of the system control screen. Figure 4 shows the inlet and outlet temperature trend data collected over the twelve months. The average difference between the inlet and outlet temperatures was 2.8°F (–16.2°C). The calculated heat was then converted to natural gas usage by dividing by the overall boiler plant efficiency.

Figure 3: Process Water Control Screen Trended Variables



Source: Cascade Energy

Figure 4: Heat Exchanger Inlet and Outlet Temperatures



Source: Cascade Energy

CHAPTER 3: Project Results

Boiler Economizers

Table 7 summarizes the therms for the baseline, upgrade, and the final savings of the boiler economizer subproject. The baseline therms are boiler usage before the economizers were installed. The three months of baseline usage calculated during the pre-installation M&V was annualized during the post-installation M&V with updated boiler runtime and loading data so it could be compared to the twelve months of post-installation M&V. The pre-installation M&V data collection did not include any runtime data on the boilers because the facilities did not collect it at that time. Runtime data was included in the post-installation M&V data collection plan instead. Therefore, the full year of runtime data collected during the post-installation M&V period was used to calculate the baseline usage with the assumption that facility operations were equivalent during the pre- and post-installation time periods.

Table 7: Therms Savings Summary

Boiler	Baseline Therms/yr	Post-Install Therms/yr	Savings Therms/yr
Porterville #1	419,545	398,127	21,418
Porterville #2	1,430,124	1,348,875	81,248
Fresno Belgravia #1	983,240	919,220	64,020
Fresno Cherry #1	769,266	737,675	31,591
Turlock #1	518,731	501,609	17,122
Livingston #1	1,085,319	1,073,192	12,127
Livingston #2	825,194	821,549	3,645
Total	**6,031,419**	**5,800,247**	**231,172**

Source: Cascade Energy

Table 8 summarizes the GHG emissions savings. The post-installation M&V savings are higher than expected for Porterville and Fresno (Belgravia) because condensing economizers were installed when standard feedwater economizers were expected. A standard economizer will reduce stack temperature by about 80°F (27°C) and improve efficiency by about 2 percent, whereas a condensing economizer can reduce stack temperatures much further. Fresno (Cherry) was also upgraded with a condensing economizer, although the stack temperature spiked about halfway through the post-installation M&V period for unknown reasons. The post-installation M&V savings were lower for Turlock and Livingston because the boiler efficiency did not improve as much as predicted. The reason for this is unknown and Foster Farms plans to work with their boiler contractor to investigate the operational issues.

Table 8: Boiler Economizers
(Baseline and Upgrade GHG Emissions and Overall GHG Savings)

Boiler Economizers	Baseline GHGs ($MTCO_2e/yr$)	Post-Installation GHGs ($MTCO_2e/yr$)	GHG Savings ($MTCO_2e/yr$)
Porterville #1	2,227.79	2,114.05	113.73
Porterville #2	7,593.96	7,162.53	431.43
Fresno Belgravia #1	5,221.01	4,881.06	339.95
Fresno Cherry #1	4,084.80	3,917.05	167.75
Turlock #1	2,754.46	2,663.54	90.92
Livingston #1	5,763.04	5,698.65	64.39
Livingston #2	4,381.78	4,362.43	19.36
Total	**32,026.84**	**30,799.31**	**1,227.52**

Source: Cascade Energy

Boiler Controls and Oxygen Trim

Table 9 summarizes the therms for the baseline, upgrade, and the final savings of the boiler control and oxygen trim subproject. The baseline therms are boiler usage before the boiler controls and oxygen trim were installed. The baseline usage calculated during the three-month pre-installation M&V period was annualized during the post-installation M&V with updated boiler runtime and loading data so it could be compared to the twelve months of post-installation M&V.

Table 9: Boiler Controls and Oxygen Trim
(Therms Savings Summary)

Boiler	Baseline Therms/yr	Post-Install Therms/yr	Savings Therms/yr
Livingston #1*	1,085,319	*	*
Livingston #2*	825,94	*	*
Livingston #3	845,834	838,138	7,696
Livingston #5	1,089,236	1,092,501	-3,265
Total	**3,845,583**	**1,930,640**	**4,431**

*Boiler efficiency savings are accounted for in the economizer subproject calculations, therefore are not included in this table.
Source: Cascade Energy

Table 10 summarizes the kilowatt-hours (kWh) for the baseline, upgrade, and the final savings.

Table 10: Electric Savings Summary

Boiler	Baseline kWh/yr	Post-Install kWh/yr	Savings kWh/yr
Livingston #1	159,418	84,803	74,615
Livingston #2	165,089	100,958	64,131
Livingston #3	150,381	87,256	63,125
Livingston #5	168,333	93,470	74,63
Total	**643,221**	**366,486**	**276,734**

Source: Cascade Energy

Table 11 summarizes the GHG emissions savings from gas and electric savings combined.

Table 11: Boiler Controls and Oxygen Trim (Baseline and Upgrade GHG Emissions and Overall GHG Savings)

Boiler	Baseline GHGs ($MTCO_2e/yr$)	Post-Install GHGs ($MTCO_2e/yr$)	GHG Savings ($MTCO_2e/yr$)
Livingston #1	36.33	19.33	17.01
Livingston #2	37.62	23.01	14.62
Livingston #3	4,525.65	4,470.40	55.25
Livingston #5	5,822.21	5,822.48	-0.27
Total	**10,421.82**	**10,335.22**	**86.60**

Source: Cascade Energy

The post-installation M&V savings for Boilers 1 and 2 are lower than expected because the boiler efficiency increase was accounted for in Sub-Project 1 with the installed economizers and only the electrical fan savings are accounted for here. The savings are lower than expected for Boilers 3 and 5 because the boiler efficiency did not improve as much as predicted. The reason for this is unknown and Foster Farms plans to work with their boiler contractor to investigate these issues.

Hot Water Recovery System

Table 12 summarizes the calculated energy savings and Table 13 summarizes the GHG emissions reductions of the hot water recovery subproject.

Table 12: Hot Water Heat Recovery Energy Savings Summary

Upgrade Overall Boiler Plant Efficiency (%)	82.20%
Sanitation Water Flow (GPM)	1,517
Water Inlet Temp (°F)	123.6
Water Outlet Temp (°F)	126.3

Upgrade Overall Boiler Plant Efficiency (%)	82.20%
Energy Recovered (Therms/hr)	20.9
Boiler Natural Gas Avoided (Therms/hr)	25.4
Boiler Natural Gas Avoided (Therms/yr)	222,447
Pump Power (kW)	16.5
Pump Energy Consumed (kWh)	144,540
Elec GHG Generation ($MTCO_2e$/yr)	-32.9
Boiler GHG Reduction ($MTCO_2e$/yr)	1,181
Total GHG Savings ($MTCO_2e$/yr)	**1,148.25**

Source: Cascade Energy

Table 13: Hot Water Heat Recovery System GHG Emissions Reductions

Hot Water Recovery	Baseline GHGs ($MTCO_2e$/yr)	Post-Install GHGs ($MTCO_2e$/yr)	GHG Savings ($MTCO_2e$/yr)
Hot Water Recovery System	1,181.2	32.9	1,148.3

Source: Cascade Energy

It was initially expected that the new heat recovery system would be able to offset the entire heat load on the process water system. The design ended up not being able to provide quite enough heat, so some steam was still needed. However, the subproject was still able to achieve an annual reduction of 1,148.3 $MTCO_2e$.

Boiler Deaerator and Repiping the Stack

This subproject was not pursued; therefore, no savings were achieved.

Livingston Refrigeration System Upgrades

This subproject was not pursued; therefore, no savings were achieved.

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

Before the project was implemented, Foster Farms shared a companywide newsletter to provide awareness, highlighting energy savings and emissions reductions of the project. Foster Farms also highlighted the project in a public announcement. Another food producer read the article and reached out to Foster Farms to learn more about the CEC grant and the kinds of projects being installed. Foster Farms readily provided details, potentially helping to influence them to pursue GHG emissions reduction projects.

CHAPTER 5: Conclusions/Recommendations

Conclusions

Three subprojects were completed including adding economizers to seven boilers across five facilities, upgrading the boiler controls on the Livingston facility boilers, and adding a hot water heat recovery system at Livingston. These subprojects were installed as originally proposed. The project resulted in a total GHG emissions reduction of 2,665 $MTCO_2e$. This project was a success for Foster Farms by reducing gas usage by 458,050 Therms/yr and electric usage by 132,194 kWh/yr. In addition to electrical and natural gas usage reduction, these projects lowered the startup time for hot water readiness at the beginning of shifts, resulting in lower total energy usage.

During the planning stages of this project, Foster Farms saw the potential benefits of the boiler economizer subproject and worked with their other facilities to investigate and implement economizers on the boilers where it made sense in parallel with this project. Foster Farms also plans to investigate if any of their other facilities would benefit from the boiler controls and oxygen trim.

CHAPTER 6: Benefits to California

Impacts of GHG Emission Reduction

By implementing energy efficiency measures, Foster Farms reduces its reliance on fossil fuels, which decreases their overall GHG emissions. This contributes to a healthier environment and mitigates the negative effects of pollution on the local communities. The lower fuel usage also results in financial savings for Foster Farms.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
Economizer	A boiler feedwater economizer is a heat exchanger installed on a boiler stack (where hot exhaust gases from combusted natural gas are released to the atmosphere) to provide heat to the incoming feedwater to the boiler. This reduces the natural gas needed to heat the water.
Food Production Investment Program (FPIP)	A California Energy Commission program which provides grants to help California food processors accelerate the adoption of advanced energy and decarbonization technologies to support electrical grid reliability, energy efficiency, and reduce GHG emissions.
Greenhouse gas (GHG)	Gases that trap heat and contribute to the warming of Earth's atmosphere. These primarily include carbon dioxide, methane, nitrous oxide, and fluorinated gases.
HVAC	Heating, ventilation and air conditioning
Kilowatt-hours per year (kWh/yr)	A kilowatt-hour is a measure of electrical energy equivalent to a power consumption of 1,000 watts for 1 hour. kWh/yr is a unit of measurement that describes the amount of kilowatt-hours in a twelve month period.
Measurement & Verification (M&V)	A detailed engineering assessment which measures the pre- and post-installation metrics of a project (such as energy usage, GHG emissions, etc) in order to verify the results of the project.
Metric Tons of Carbon Dioxide equivalent ($MTCO_2e$)	A unit of measurement where a metric ton is 1,000 kilograms and carbon dioxide equivalent (CO_2e) represents an amount of greenhouse gases whose atmospheric impact has been standardized to that of one unit mass of carbon dioxide based on the global warming potential of the gas or gases. This report used the conversion factor of 0.00531 $MTCO_2e$ per Therm and 0.000228 $MTCO_2e$ per kWh.
Oxygen (O_2)	Oxygen gas, discussed in this report in regard to the amount of oxygen in the air delivered to the boilers for combustion of natural gas.
SCADA	Supervisory Control and Data Acquisition, an industrial control system which collects data from sensors and other devices to monitor and control facility processes in real time.
Therms per year (therms/yr)	A therm is a unit of heat equal to 100,000 British Thermal Units. Therms/year is a unit of measurement that describes the amount of therms in a twelve month period.
Variable Frequency/ Speed Drive (VFD)	Variable speed drives allow the speed of motors to be adjusted, allowing for efficient part loading of equipment to meet variable system loads.

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APPENDIX A: Measurement and Verification Plan

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APPENDIX A: Measurement and Verification Plan

*Some changes were made to the M&V plan due to data availability varying in the post-installation M&V compared to the pre-installation M&V.

Subproject 1: Boiler Economizers

Foster Farms plans to install seven feedwater economizers across five facilities. A feedwater economizer reduces steam boiler fuel requirements by transferring heat from the flue gas to incoming feedwater through a heat exchanger in the exhaust stack.

The M&V Plan will follow an Option A: Retrofit Isolation with Key Parameter Measurement approach. The baseline and post-installation efficiencies of each boiler will be determined. Additionally, annualized steam flow based on the boilers rated output and annual runtimes will be used to calculate steam flow. The calculated steam flow from the post installation period will be used to normalize the impacts and account for any variation in production between the monitoring periods.

Baseline Monitoring

The baseline boiler efficiencies will be determined using ASME PTC-4 – Indirect Method: Stack Loss Method.[1] Readings are taken monthly by Foster Farms boiler service company, McNulty Mechanical, for their monthly Low NOx burner emissions measurement compliance with District Rule 4306. The monthly tests span various firing rates, and the average values from these stack test reports (along with stack temperature, which will be added to the tests) will be used to calculate the boiler efficiency.

$$Eq.2: \eta = \ Boiler\ Efficiency\ (\%) = 100\% - \ L_{DG} - \ L_{WG} - 1\%_{Other\ Losses}$$

Where:

$$Eq.2a: L_{DG} \ = \ Dry\ Losses\ (\%) = 0.001044\ x\ \left[14.7365\left(\frac{O_2\%}{21\% - \ O_2\%}\right) + 15.371\right]\ x\ (T_{Stack} - 70)$$

$$Eq.2b: L_{DG} \ = \ Wet\ Losses\ (\%) = 9.482 + (0.004351\ x\ T_{Stack})$$

- Stack O_2 – Testo 335
- Stack Temperature – Testo 335

Post Install Monitoring

The post-install boiler efficiencies will also be determined using ASME PTC-4 (See Eq.2). Additionally, along with the boiler capacity (this was not directly trended, see note below on Boiler Runtime bullet) the boiler runtime will be captured by the Supervisory Control and Data

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[1] The American Society of Mechanical Engineers. 2014. *Fired Steam Generators*. Publication Number: *ASME PTC-4-2013*. URL: https://ww3.arb.ca.gov/cc/capandtrade/allowanceallocation/boiler_efficiency_calc.pdf

Acquisition (SCADA) boiler control system which will log the boiler runtimes. There are no electrical impacts; only the natural gas impacts are evaluated.

- Stack O2 – Testo 335
- Stack Temperature – Testo 335
  - This was collected from Foster Farm's SCADA system instead of from the monthly emissions reports.
- Boiler Runtime – SCADA/Boiler BMS
  - While boiler runtime data was collected, boiler capacity was not. Livingston has natural gas sub-meters on each boiler which were used to calculate usage. For all other sites, monthly billed gas usage was utilized. See the previous sections in this report for more details.

Sub-project 2: Boiler Controls and Oxygen Trim

O2 Trim senses the oxygen in the exhaust of the boiler. The oxygen levels change based on fluctuations in ambient air temperature and air density which in turn causes the combustion to vary. The O_2 trim control will correct for the changes and make adjustments to keep the air fuel ratio at the best efficiency point and reduce the amount of fuel needed to fire the boiler.

The M&V Plan will follow an Option A: Retrofit Isolation with Key Parameter Measurement approach. The baseline and post-installation efficiencies of each boiler will be determined. Additionally, annualized steam flow based on the boilers rated output and annual runtimes will be used to calculate steam flow. The calculated steam flow from the post installation period will be used to normalize the impacts and account for any variation in production between the monitoring periods.

An additional aspect of the controls project will be the installation of a VFD to control the speed of the combustion air fan. The energy saving impacts will be calculated using affinity laws and monitoring the VFD frequency output and fan power in the post installation period.

Baseline Monitoring

The baseline boiler efficiencies will be determined using ASME PTC-4 (See Eq. 2). Readings are taken monthly by Foster Farms boiler service company, McNulty Mechanical, for their monthly Low NOx burner emissions measurement compliance with District Rule 4306.

- Stack O_2 – Testo 335
- Stack Temperature – Testo 335

Post Install Monitoring

The post-install boiler efficiencies will also be determined using ASME PTC-4 (See Eq.2). Additionally, the boiler runtime, VFD frequency, and fan power will be captured by the Supervisory Control and Data Acquisition (SCADA) boiler control system which will parameters.

To normalize the baseline fan power requirements the affinity laws along with power and frequency measurements during the post installation period will be used.

$$Eq\ 4{:}\ Power\ (kW_{Base}) = Power\ (kW_{Post})\ x\ \left(\frac{Hz_{Base}}{Hz_{Post}}\right)^3\ x\ \left(\frac{Diameter_{Base}}{Diamater_{Post}}\right)^2\ x\ \left(\frac{Density_{Base}}{Density_{Post}}\right)$$

The fan wheel diameter and air densities are the same for both baseline and post-install periods which simplifies the equation.

$$Eq\ 4a{:}\ Power\ (kW_{Base}) = Power\ (kW_{Post})\ x\ \left(\frac{60\ Hz}{Hz_{Post}}\right)^3$$

- Stack O_2 – Testo 335
- Stack Temperature – Testo 335
  - This was collected from Foster Farm's SCADA system instead of from the monthly emissions reports.
- Boiler Runtime – SCADA
  - While boiler runtime was collected, boiler capacity was not. Livingston has natural gas sub-meters on each boiler which were used to calculate usage.
- Fan Power – SCADA
- VFD Frequency – SCADA

Sub-project 3: Hot Water Recovery System

Foster Farms uses hot water around the facility for required sanitation and washdown of equipment. The hot water was previously generated using plant steam to heat water. The proposal is to recover heat from condensate in the rendering plant that would otherwise go to the drain; the recovered heat will offset the amount required from the main boiler plant.

The M&V Plan will follow an Option A: Retrofit Isolation with Key Parameter Measurement approach. The hot water recovery system project does not receive steam from a single boiler, but from a common header that supplies the entire facility so an overall plant efficiency will be established based on a weighted average of all the boilers in the system.

Additionally, annualized steam flow based on the boilers rated output and annual runtimes will be used to calculate steam flow. Steam flow to this system was not monitored, and therefore was not utilized for the post-M&V analysis. The analysis is only accounting for the added heat to the system with the upgrade system and the baseline, so there is no need to normalize.

Baseline Monitoring

The baseline boiler efficiencies will be determined using ASME PTC-4 (See Eq. 2). Readings are taken monthly by Foster Farms boiler service company, McNulty Mechanical, for their monthly Low NOx burner emissions measurement compliance with District Rule 4306.

- Stack O_2 – Testo 335
- Stack Temperature – Testo 335

Post Install Monitoring

The post-install hot water recovery system M&V will consist of monitoring the energy transferred from the hot wastewater from the rendering plant, and the pumps in the system will be used to determine the hours of operation. Pump power was not directly monitored and was instead calculated from pump speed and differential pressure.

$$Eq\ 5: Heat\ Recovered\ (Therms) = Water\ Flow\ \left(\frac{lb}{hr}\right)\ x\ \ C_P\left(\frac{Btu}{lb\ x\ °F}\right)\ x\ (Water\ Temp_{Inlet}(°F) - Water\ Temp_{Outlet}(°F)\ )$$

- Pump Speed – SCADA
- Pump Differential Pressure – SCADA
- Pump Runtime – Calculated
    - Pump speed data was used to determine this. The pumps run nearly constantly.
- Pump Power – Calculated instead of from trend data
    - The system was not trending this, so it was calculated from pump speed and differential pressure data, along with manufacturer pump curves.
- Water Flow – Calculated instead of from trend data
    - The system was not trending this, so it was calculated from pump speed and differential pressure data, along with manufacturer pump curves.
- Water Inlet Temp – SCADA
    - Collected weekly averages, which were then rolled up into monthly averages for the 12-month post M&V period.
- Water Outlet Temp – SCADA
    - Collected weekly averages, which were then rolled up into monthly averages for the 12-month post M&V period.

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APPENDIX B: Additional Photos

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APPENDIX B:
Additional Photos

Boiler Controls

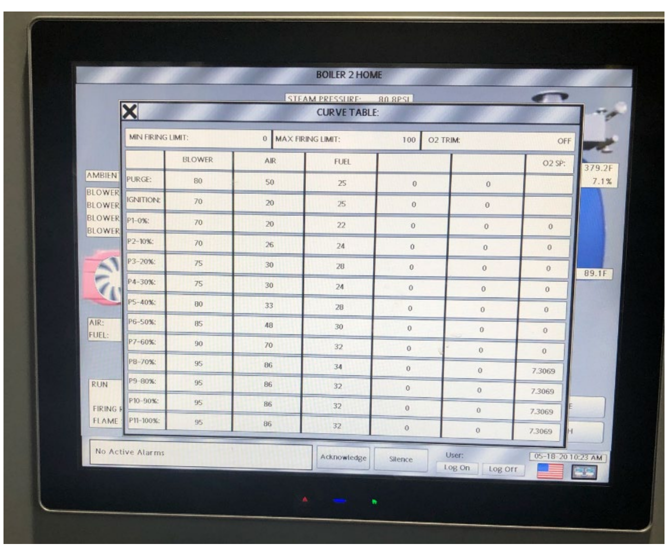
Figure B-1: Livingston Boiler #1 Controls

Source: Foster Farms

Figure B-2: Livingston Boiler #2 Controls

Source: Foster Farms

Figure B-3: Livingston Boiler #3 Controls (1)



Source: Foster Farms

Figure B-4: Livingston Boiler #3 Controls (2)

Source: Foster Farms

Figure B-5: Livingston Boiler #5 Controls

Source: Foster Farms

Figure B-6: Panel B CRT 22A

Source: Foster Farms

Hot Water Recovery

Figure B-7: Pumps

Source: Foster Farms

Figure B-8: Pump and Tank

Source: Foster Farms

Figure B-9: Electrical Panel

Source: Foster Farms

Figure B-10: Control Equipment and Tank

Source: Foster Farms

Boiler Economizers

New Economizers

Figure B-11: Turlock FTP1 New Economizer1

Source: Foster Farms

Figure B-12: Turlock FTP1 New Economizer2

Source: Foster Farms

Figure B-13: Fresno Belgravia Boiler New Economizer

Source: Foster Farms

Figure B-14: Fresno Cherry New Boiler Economizer

Source: Foster Farms

Figure B-15: Livingston Boilers #1 & #2 New Economizers

Source: Foster Farms

Figure B-16: Porterville Hurst New Boiler Economizer1

Source: Foster Farms

Figure B-17: Porterville Hurst New Boiler Economizer2

Source: Foster Farms

Figure B-18: Porterville Unilux New Boiler Economizer1

Source: Foster Farms

Figure B-19: Porterville Unilux New Boiler Economizer2

Source: Foster Farms

Old Economizers

Figure B-20: Livingston Old Economizers

Source: Foster Farms

Figure B-21: Livingston Old Piping

Source: Foster Farms