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FINAL PROJECT REPORT

Industrial Steam Boiler Heat Recovery for High-Efficiency Water Heating

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PREFACE

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

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

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

Industrial Steam Boiler Heat Recovery for High-Efficiency Water Heating is the final report for the Industrial Steam Boiler Heat Recovery for High-Efficiency Water Heating project (Contract Number PIR-15-009) conducted by the Gas Technology Institute. The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development Program.

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

ABSTRACT

Gas Technology Institute completed demonstration of the Boilerroom Equipment Inc. Heatsponge-Rainmaker technology integrated with an industrial steam boiler for generation of hot process water rather than its usual hydronic heating application. The configured system proved to be advantageous to the host-site and verified the potential performance, energy savings, and the emissions reduction benefits of the technology. This technology can provide reliable operation with simple controls for a wide-ranging product for energy recovery of waste heat from natural gas combustion equipment such as industrial and commercial boilers.

The modular design approach used in the Heatsponge-Rainmaker allows tailoring the equipment for each application without the added cost for custom product engineering and fabrication. The Boilerroom Equipment Inc. Heatsponge-Rainmaker offers an option that, depending on the application offers an increase in boiler efficiency typically in the four to eight percent range with a proportional reduction in carbon dioxide and nitric oxide emissions. The expected savings and payback period will vary based upon specific equipment configuration, installation requirements, and operating conditions. Based on the results of this project, the technology applied in an industrial water heating application performs as expected and is well suited to integration into process heating, and the technology is ready for further deployment at industrial facilities in an integrated process heating application.

Keywords: California Energy Commission, waste heat recovery, heat recovery products, water heating, industrial steam boiler, emissions reduction, energy savings

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EXECUTIVE SUMMARY

California's climate and environmental goals include reducing greenhouse gas emissions by 40 percent below 1990 levels by 2030 (California Global Warming Solutions Act, Assembly Bill 32, Nunez, Chapter 488, Statutes of 2006) and achieving carbon net neutrality by 2045 (former Governor Edmund G. Brown's Executive Order B-55-18). One way to help reach these goals is to reduce greenhouse gas emissions from natural gas sources by using natural gas more efficiently. Burning natural gas emits carbon dioxide, a primary greenhouse gas, and the methane in natural gas is a pollutant many times more potent than carbon dioxide when it leaks into the atmosphere.

California's estimated 3,800 industrial steam boilers consume more than 82,000 mmBtu (million British thermal units) of natural gas each year to produce steam and heat. Industries that use boilers include manufacturing, electrical, paper and pulp, agriculture, metalworking, ceramics, refining, and food and beverage. Increasing the efficient operation of these boilers could reduce natural gas use, provide energy savings to California customers, and reduce emissions of carbon dioxide and other pollutants that contribute to climate change and poor air quality.

Steam boilers commonly use heat exchangers to recover energy from the exhaust by preheating the water that is fed to the boiler. These "economizers" can improve steam boiler efficiency by as much as five percent, but substantial energy is still lost. The inability of standard economizers to achieve higher efficiency is due in part to the relatively low rate of water flow through economizers designed for such applications. The fuel efficiency of steam boiler applications could be improved if the water flow delivered to the heat recovery unit is increased and the incoming temperature is decreased.

In addition to steam, many industrial steam customers require hot water for their process needs. The focus of this project was evaluating and demonstrating heat recovery for industrial facilities that require steam and additional hot water for process applications.

Project Purpose

This project sought to demonstrate the Heatsponge-Rainmaker technology coupled to an industrial steam boiler and verify the performance, energy savings, and emissions reduction benefits of the technology. The very limited deployment of this technology so far for steam boiler and other nonstandard applications has demonstrated energy savings and reduced emissions according to some end-users and the manufacturer. Independent verification of performance, energy savings and emissions benefits are needed to help potential end users better understand the benefits of the technology.

The fuel efficiency for steam boiler applications could be greatly improved by increasing the water flow to the heat recovery economizer and lowering the exhaust temperature. Many industrial steam customers also require hot water for process needs. For such applications, the separate process water stream can be used to recover energy from the boiler exhaust. While this presents a tremendous opportunity for improving efficiency and reducing natural gas consumption in industrial markets, there are several barriers:

- Standard steam boiler heat recovery economizers are not typically sized for the higher water flow rates required for such applications.
- Typical steam boiler economizer installations have a water flow rate proportional to the size of the boiler; the water flow rate for these new applications is independent of boiler size, and hence independent of the flow rate of boiler exhaust.
- Given the lack of proportionality between exhaust flow rates and water flow rates, achieving a robust and optimized design for the heat recovery unit is a challenge.
- Standard economizer units are not typically designed to enable operation under condensing conditions, as is required to maximize heat recovery boiler exhaust.

Project Process

This project demonstrated that the Heatsponge-Rainmaker technology can overcome these barriers by allowing for low-cost customization of the heat recovery equipment that is adaptable to a broad range of waste heat recovery applications and water flow rates. The key indicator of the success of this project was demonstrating the benefits of the heat recovery technology: increased fuel efficiency, reduced greenhouse gas emissions, and lower operating costs with a favorable economic payback. The research verified the performance of this application through independent third-party measurement and verification of the ability of the system to achieve the stated performance objectives while operating under real-world conditions at the user's facility. The findings of this demonstration project provided valuable information for industrial users in California to promote increased adoption of this technology and heat recovery technologies in general.

Gas Technology Institute (GTI), in cooperation with Boilerroom Equipment, Inc., Frontier Energy (formerly the Davis Energy Group), and Tetra Tech, Inc. demonstrated the emerging Heatsponge-Rainmaker technology for industrial steam boiler applications. Boilerroom Equipment Inc. is a United States manufacturer working to deploy its Heatsponge-Rainmaker technology throughout the California industrial steam boiler market to ultimately reduce industrial and large commercial user costs and energy consumption.

GTI worked with its project partners to design a heat recovery system for the Mission Linen Supply Inc. facility in Oxnard, California. The research team coordinated with the host site to design, install, commission, and monitor the heat recovery system to evaluate performance compared to the project objectives using an independent measurement and verification contractor.

Project Results

The researchers aggregated operating performance data and information on overall system performance collected from engineering personnel at the host site. Tetra Tech provided independent measurement and verification and analyzed overall system performance and impact on facility energy use. The research team used the data to prepare a detailed breakdown of the hot water heating system operation before and after the installation of the Heatsponge-Rainmaker technology.

The energy recovery from using the technology represents a savings of 6.2 percent of annual projected natural gas energy used by the host facility boiler (resulting from an increase in boiler operational efficiency from 82 percent to 88.6 percent). The researchers project that the increase in boiler efficiency will annually save 6,889 therms of natural gas and reduce carbon dioxide emissions by 55.2 metric tons at the current production rate of the facility.

The estimated payback value based on installed cost was equal to the estimated installed equipment cost and operating life at the current single shift operation, production rate, and cost of natural gas. This calculation does not include the additional economic benefit of increased available steam and hot water capacity experienced at the facility.

Increased production at the facility would increase the operating time of the system and substantially decrease the payback value. Based on operating data for a three-shift operation, the simple payback value would drop to 8.2 years, which is still roughly twice the four-year payback goal of this project. The data does indicate it is possible to achieve a four-year payback in an installation site with an increase in operating hours and lower water inlet temperatures using this technology application.

The project demonstrated that the Heatsponge-Rainmaker technology can provide reliable operation with simple controls and a wide-ranging product for heat recovery of waste heat from natural gas combustion equipment such as industrial and commercial boilers. The modular design used in the technology allows users to tailor the equipment for each application without added cost for custom product engineering and construction.

Based on the researchers' experience with the technology, important considerations when evaluating potential applications include:

- Whether the commercial or industrial steam boiler or industrial combustion application needs a large volume of water heating.
- Whether water can be supplied to the economizer with inlet temperatures at or below 110°F.
- The amount of avoided equipment cost related to the increased heating capacity due heating load shifted to the heat recovery system proposed.

- The heating requirements of water used in proposed system to determine cost and possible savings for comparison to project equipment and installation costs.
- The availability or ability to obtain baseline boiler operating data including efficiency, flue temperatures, and annual fuel usage.

Benefits to California

This project demonstrated an energy efficient technology that can reduce the demand for natural gas at commercial and industrial sites, and consequently overall demand for natural gas in California. Industrial and commercial facilities will benefit from better energy efficiency, positive environmental impacts, lower natural gas costs, and increased profits. Further use of the Heatsponge-Rainmaker technology will provide broader environmental, cost, and operating performance benefits to California ratepayers.

California has about 5,400 industrial and commercial boilers that combined consume more than 277,307 mmBtu per hour of natural gas, according to a 2005 report prepared by Energy and Environmental Analysis Inc. This project focused on demonstrating waste heat recovery for industrial facilities that require steam and additional hot water for processing. Industries throughout California that could benefit from this technology include food processing, chemicals production, refining, minerals extraction, agriculture, and laundry services. Using a conservative estimate that 10 percent of the California commercial and industrial boiler market includes facilities that also require hot water for processing, the heat recovery approach demonstrated in this project could apply to facilities with more than 27,731 mmBtu per hour boiler capacity. The technology could, therefore, provide annual natural gas savings of more than 1.747,000 mmBtu based on a 10 percent market penetration and natural gas savings of 6.2 percent demonstrated during this project. This corresponds to $11.4 million annual energy savings for California customers (assuming natural gas costs of $6.5 per mmBtu) plus annual reduced pollutant emissions of 102,199 tons of carbon dioxide and 20,106 pounds of oxides of nitrogen.

The Heatsponge-Rainmaker economizer technology employs well-proven heat exchange design principals that can be easily understood by facility operations and maintenance personnel. The robust design is free of the moving parts and additional energy inputs that are required for direct contact heat exchangers that are sometimes employed for similar applications. This design results in low maintenance requirements and long product lifetimes, estimated at more than 20 years.

Market Opportunity and Adoption

This technology presents a promising opportunity for improving efficiency and reducing natural gas consumption in industrial markets. It’s unique approach of using predesigned modules and exclusive software to determine size and flow requirements allows for a semi-custom design to be readily prepared for a range of market applications. In California, the technology could be used in food processing, chemicals production, refining, minerals extraction, agriculture, and laundry services.

GTI has focused its efforts on assisting Boilerroom Equipment, Inc., the technology provider and partner for this project, to develop and demonstrate a highly-efficient economizer in a real-world applications. The results of this project will be made available to the utility collaboratives GTI works with, specifically the Utilization Technology Development and Emerging Technology Program collaborative.

CHAPTER 1: Project Purpose

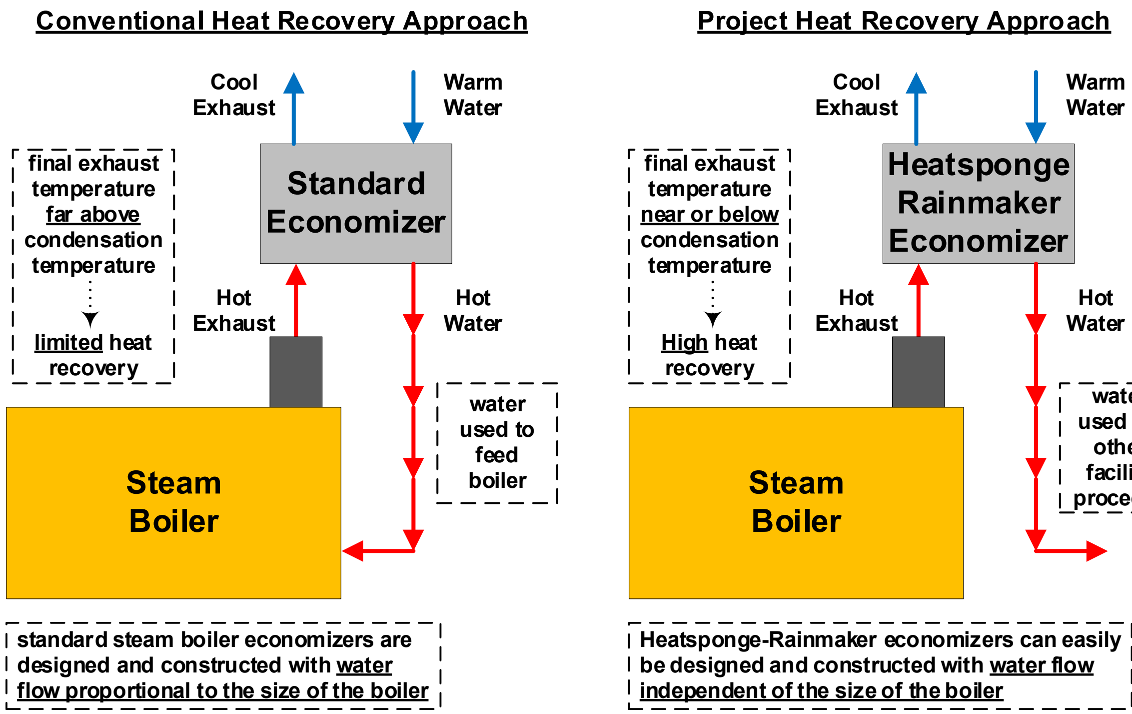
Background

Using heat exchangers to recover energy from the exhaust of steam boilers by preheating feed water to the boiler is a common practice. Marketed by manufacturers as "economizers," heat exchangers typically provide gains in efficiency of up to 5 percent in the performance of steam boilers, with nominal efficiency gains typically in the range of 1-3 percent. Even with these modest gains in efficiency, there is still significant energy lost through the high temperature exhaust for such applications, as this approach typically fails to allow for operation at or near condensing conditions. In industrial steam boilers, fuel is combusted and the hot exhaust gases produced pass through the vessel heat exchanger tubes where much of their heat is transferred to water, thus raising the water's temperature and producing steam. One of the hot gases produced in the combustion process is water vapor. Operation of an economizer in a condensing mode extracts the additional heat from the waste gases by condensing this water vapor, thus recovering its latent heat of vaporization. The inability of standard boiler economizers to achieve higher efficiency is due, in part, to the relatively low water flow rates through the economizer for such applications. The water flow rates through the economizer are limited to the boiler feed water requirements of the boiler and typically too low to allow condensing of the exhaust water vapor and recovery of the latent heat it contains.

The fuel efficiency for steam boiler applications would improve by increasing the water flow delivered to the heat recovery economizer to allow recovery of the latent heat available in the boiler exhaust stream by condensing operation of the economizer. Significant portions of industrial steam boiler installation sites also require hot water for other process applications. This water-heating requirement can be used to recover waste energy from the steam boiler exhaust, enabling efficiency gains of more than 20 percent. While this approach presents a tremendous opportunity for improving efficiency and reducing natural gas consumption in industrial markets, there are several barriers for adoption in these applications.

Standard industrial steam boiler economizer units are not designed for the higher water flow rates required for such applications and sized so the water flow rate is proportional to the size of the boiler to accommodate limited water flow of the make-up water to the boiler. In addition, standard steam boiler economizers are not typically designed or fabricated of the necessary material to allow operation under condensing conditions. The differences in heat recovery approaches and the operational requirements of the heat recovery economizer is presented in Figure 1.

Figure 1: Heat Recovery Approach Comparison



Source: Gas Technology Institute

Currently, an industrial customer needs a custom site-specific economizer to use the waste heat from a steam boiler for use other than heating boiler make up water or other limited flow applications. Few such installations exist because of the high costs associated with custom engineering, design, fabrication, and installation. Further, while these custom applications may allow for higher efficiency, they do not necessarily lead to optimized performance. Thus, high cost and suboptimal performance have restricted the broad adoption of high efficiency heat recovery systems for steam boiler installations to service facilities with additional hot process water demands.

Heatsponge-Rainmaker Technology Description

The emerging Heatsponge-Rainmaker economizer technology form Boilerroom Equipment, Inc. has the potential to overcome barriers to adoption and allow for significant gains in efficiency in industrial steam markets. The Heatsponge-Rainmaker technology was originally designed for, and is currently being deployed within, hydronic (hot water) boiler markets to preheat the incoming feed water to the boiler. Hydronic boilers operate with water flow rates that are 30 to 100 times greater than that of steam boilers. Because customer requirements for hydronic boiler conditions can vary considerably in regards to water flow and temperature, the Heatsponge-Rainmaker technology has been designed around the goal of achieving low-cost, "mass customization." A typical Heatsponge-Rainmaker economizer assembly is shown in Figure 2.

Figure 2: Heatsponge-Rainmaker Economizer

Source: Boilerroom Equipment Inc.

The Heatsponge-Rainmaker economizer is assembled from modular assemblies that are produced in large volumes to achieve low manufacturing costs. Each Heatsponge-Rainmaker unit is customized based on customer needs with an exclusive software package that automates the design and configuration of the system as based on site-specific criteria. The result is a heat exchanger product that is optimized per customer load demands and installation requirements.

The "mass customization" approach for the Heatsponge-Rainmaker technology offers an innovative solution by allowing for low-cost customization of the heat exchanger design. The Heatsponge-Rainmaker technology is adaptable to a broad range of customer applications with wide variability in boiler exhaust and process water flow rates. Further, the exclusive software used for the design and sizing of the Heatsponge-Rainmaker technology allows for optimized product designs with minimal engineering cost. These unique and innovative aspects lay a solid foundation for overcoming the substantial design and cost barriers that currently limit the adoption of steam boiler exhaust heat recovery for process water heating.

In hydronic boiler applications, the temperatures of the water inlet and outlet and the exhaust are lower than those of steam boilers. As a result, the Heatsponge-Rainmaker technology is designed to enable operation at or near condensing conditions. The resulting condensate is slightly acidic so corrosion resistant materials are required when contacted by the condensate produced. This is a key feature of the technology, because heat recovery units are appropriately designed to handle the removal of condensate and mitigate associated corrosion issues for operation at condensing conditions.

While the Heatsponge-Rainmaker technology is well-positioned to overcome the technical barriers for the implementation of heat recovery systems in steam boiler applications to heat separate process water streams, this application is not yet well proven. To date the technology has been deployed for a very limited number of such applications, there has not yet been a robust, independent characterization of the performance and cost benefits of the technology. This project objective is perform such a characterization, with independent documentation and dissemination of the energy efficiency, energy cost reductions, performance and installation requirements.

Goals and Objectives

The commercial heat recovery products and technologies currently available to recover the boiler exhaust waste heat at present have been custom engineered and fabricated for each application site or process. This makes the economic payback period unattractive to the majority of industrial customers who could potentially benefit from recovering this waste heat for other uses in their production process. The Heatsponge-Rainmaker technology has the potential to overcome these barriers to market adoption, with its cost effective, high-performance design.

This project aimed to demonstrate the Heatsponge-Rainmaker technology in an industrial steam generation application for generation of hot process water rather than its usual hydronic heating application that is advantageous to the host-site and to verify the performance, energy savings, and the emissions benefits of the technology in a new steam boiler application. In the very limited deployment of this technology for steam boiler applications thus far, energy savings and reduced emissions have been realized according to the customer and manufacturer. However, an independent verification of performance, energy savings and emissions benefits are needed to help potential customers, distributors and installers better understand the technology’s benefits.

CHAPTER 2: Project Description

Approach

Using the Heatsponge-Rainmaker product outside of its conventional application (hydronic boilers) represents a departure from the norm. Customers using steam boilers may be skeptical of the purported performance, efficiency, and cost benefits of the Heatsponge-Rainmaker technology given the technical barriers for adoption of heat recovery systems for process water heating as discussed in this report. Further, for customers who are deploying heat recovery systems for such applications, direct-contact economizers are typically employed, such that deploying the Heatsponge-Rainmaker for this use further represents a challenge to the current status quo. The attractiveness of the technology is its modular design and software application tool that allows for straightforward scaling and application of the technology. The demonstration validated this aspect of the technology, and the independent third-party evaluation will help in advancing the technology for use in steam boiler applications.

The research team identified three potential sites that fit the target application for demonstration of the heat recovery system. After evaluating these possible demonstration sites for interest and how each could benefit from the technology, researchers selected the Mission Linen Supply Inc. facility in Oxnard, California. Mission Linen Supply is commercial laundry with multiple facilities throughout California, so a successful project could help foster further deployment at multiple sites.

The project team included the Gas Technology Institute (GTI) as the technical, engineering, and administrative lead; Tetra Tech as the measurement and verification contractor; and Frontier Energy to coordinate configuration and installation of the Heatsponge-Rainmaker economizer procurement and performance monitoring system equipment. Boilerroom Equipment, the manufacturer of the Heatsponge-Rainmaker technology, assisted with the design of the unit and support for commercialization activities. Mission Linen Supply provided information to the project team to facilitate system design and handled permitting and installation of the system at the demonstration site.

The approach used in this demonstration project was to design the heat recovery system integrated into the current facility process water heating system; specify, procure, and install the Heatsponge-Rainmaker economizer; and evaluate the heat recovery system performance. The project team prepared a detailed engineering design package to facilitate installation of the system at the host facility, including the performance monitoring instrumentation.

Demonstration Host Site

Mission Linen Supply is a family-owned, privately held company providing products and services to hospitality, medical, and industrial businesses. With headquarters in Santa Barbara, California, the company has 44 locations and more than 2,500 employees in California, Arizona, Texas, Oregon, and New Mexico.

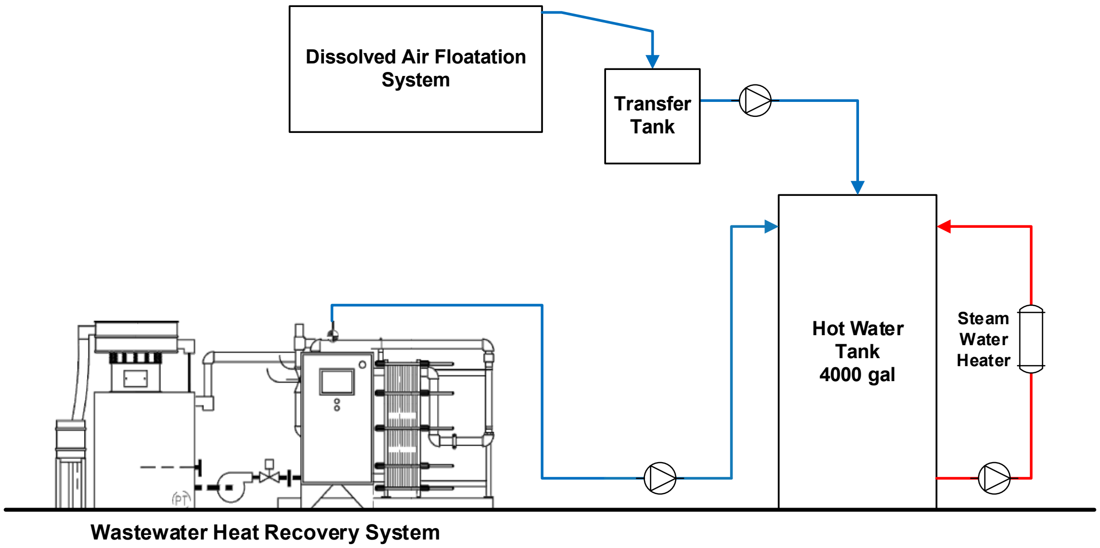
Figure 3: Mission Linen Supply Facility in Oxnard, California

Source*:* Bing.com/maps

System Design

The research team designed the system to use the waste heat from the steam boiler flue gas to augment or entirely replace the heat duty needed for process water heating at the facility. The fundamental approach was to design the system to allow the Heatsponge-Rainmaker economizer to operate at or near full condensing-mode conditions for maximum heat recovery, using the waste heat available and increasing the fuel efficiency of the boiler through reduction in the steam load. The original hot process water heating system of the facility was configured to preheat incoming process water through a wastewater heat recovery system supplying a 4000 gallon hot water holding tank. A steam circulation heater was used to boost and maintain the water temperature of the hot water tank to the required process temperature of the facility hot water supply (Figure 4).

Figure 4: Process Hot Water System



Source: Gas Technology Institute

The facility hot process water system would be modified for this project by routing the pre-heated water supply from the wastewater heat recovery system to a 1000-gallon buffer tank, which circulates the pre-heated process water through the Heatsponge-Rainmaker economizer and supplies the original hot water holding tank. This design approach allows the Heatsponge-Rainmaker to use the water supplied to the facility to recovery waste heat in the flue gas from the boiler regardless of current process water demand. During high hot process water demand, the water being supplied by the waste water heat recovery system is well below the temperature needed to allow the economizer to operate in condensing-mode and at low water demand the economizer will naturally reduce the heat recovered from the flue gas as the temperature of the water in the buffer tank rises.

The Oxnard laundry facility's steam is generated by a 1965 Dixon firetube boiler nominally rated at 250 BHP, as shown in Figure 5. This boiler provides for the various steam utilities and heating duty throughout the plant including heating of the needed hot water for operation of the laundry. The original hot water heating system of the facility was configured to preheat incoming process water through a wastewater heat recovery system supplying an insulated 4000-gallon hot water holding tank. A photograph of the wastewater heat recovery system is presented in Figure 6. A steam circulation heater piped in a closed loop attached to hot water tank is used to boost and maintain the water temperature of the hot water tank to the required process temperature of the facility hot water supply.

Figure 5: Project Site Dixon Boiler

Source: Gas Technology Institute

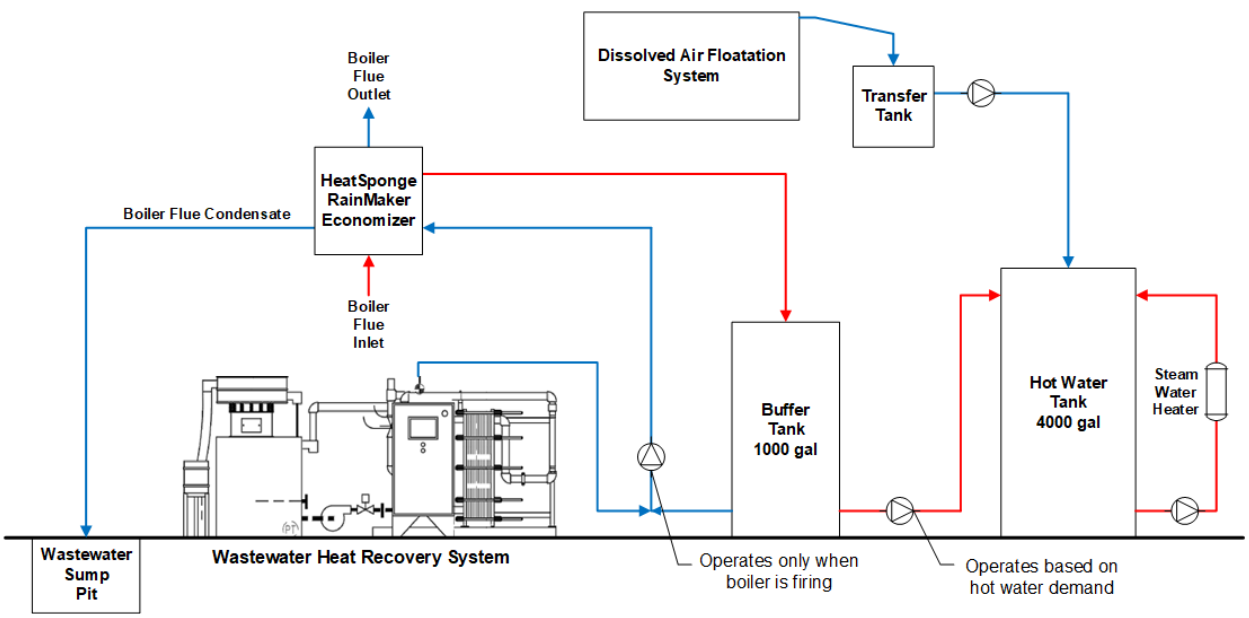
Figure 6: Wastewater Heat Recovery System

Source: Gas Technology Institute

The team reviewed the hot water heating system on-site and developed a plan for how to incorporate the recovered heat from the exhaust flue gas of the boiler into the hot water system. The design would have to ensure that recovered heat would not just displace the heat load serviced by the wastewater heat recovery system, but also provide a reduction in the steam used by the steam heater boosting and maintaining the temperature of the hot water tank. The design approach was to use the waste heat from the steam boiler flue gas to augment or entirely replace the heat duty needed by the steam circulation heater for water heating of the hot water holding tank. In addition, as presented earlier in this report, the fundamental key to maximize the heat recovered was to design the system to allow the Heatsponge-Rainmaker economizer to operate at, or near, full condensing-mode conditions. This approach would allow the economizer to operate at with the maximum heat recovery using the waste heat efficiently thereby increasing the fuel efficiency of the boiler through reduction in the steam load.

The design chosen by the team was to modify the existing facilities hot water system by routing the pre-heated water supply from the wastewater heat recovery system to a new insulated 1000-gallon buffer tank, which circulates the pre-heated process water through the Heatsponge-Rainmaker economizer during boiler firing operation (Figure 7).

Figure 7: System Design Diagram



Source: Gas Technology Institute

The new buffer tank supplies the hot water to the original plant hot water holding tank based upon facility hot water demand. The water supplied from the wastewater heat recovery system typically provides pre-heated water at about 100°F. Since this temperature is well below the condensation temperature of the boiler flue exhaust, it is ideal for operation of the Heatsponge-Rainmaker economizer in a condensing mode. The inclusion of the buffer tank in the design allows the Heatsponge-Rainmaker to recovery the waste heat in the flue gas from the boiler regardless of current hot process water demand. During high hot process water demand, the pre-heated water being supplied by the wastewater heat recovery system is well below the temperature needed to allow the economizer to operate in condensing-mode and at low water demand the economizer will naturally reduce the heat recovered from the flue gas as the temperature of the water in the buffer tank rises.

Heatsponge-Rainmaker Selection

The team consulted with the manufacturer to specify an appropriate model configuration that matches our desired performance for this project with their proprietary software that is openly available on-line to any potential customers. Their software tool generated model selection, performance estimates, and retail pricing based upon user inputs. The project site currently using an older boiler targeted for replacement in the next several years due to its age and the need for additional capacity in the future. Because of this, the economizer sizing is based upon the estimated performance of a new replacement current generation of a 300 horsepower firetube boiler. The online tool was used to match the desired return water temperature and water temperature rise based on performance curves published by the boiler manufacturers. The actual water temperature that will be entering the economizer will vary based upon the production activity in the facility and the available heat recovered from the wastewater heat recovery system. The lowest estimated water temperature and the typical highest flow rate was used during the selection process. Table 1 summarizes the design and rated performance for the model selected for this project.

Table 1: Economizer Design–Design Data and Performance Basis

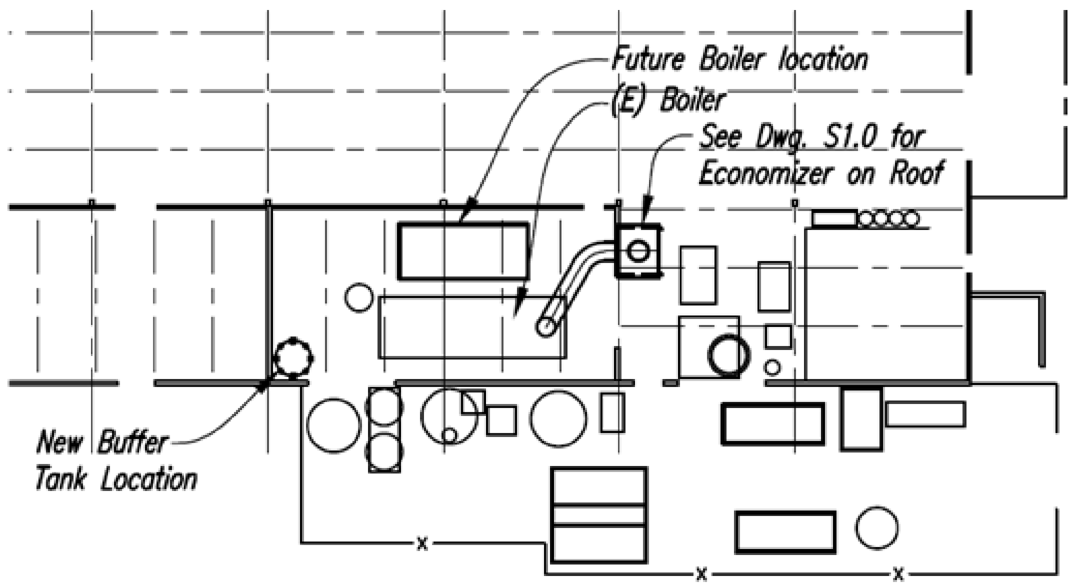
Model	HS-RAINMAKER-TRI/D6-[T3D/BPD]
Design	150 pounds/square inch @ 400°F
Weight Empty	6,200 pounds
Weight Flooded	6,600 pounds
Recovery	1,048,370 British thermal units/hour
Water Flow	45 gallons per minute
Water Temperature In	100°F
Water Temperature Out	146°F
Water Pressure Drop	0 pounds/square inch
Gas Flow	9,288 pound per hour
Gas Temp In	425°F
Gas Temp Out	111°F
Gas Pressure Drop	0.136 inches of water column

Source: Gas Technology Institute

Equipment Layout Plan

The new equipment was located in the boiler room and adjacent equipment locations (Figure 8). The 4,000 gallon insulated hot water tank was located outside in a fenced equipment pad area located adjacent to the facility boiler room. The new 1,000-gallon insulated buffer tank was located in the corner of the boiler room next to an overhead access door.

Figure 8: Equipment Layout Plan



Source: Gas Technology Institute

The Heatsponge-Rainmaker economizer was located on the facility roof just outside of the boiler room to allow removal of the roof of the boiler room for new boiler installation in the future at the facility.

System Installation

Installation of the new equipment was located according to the equipment layout plan shown in Figure 9. The approach to installation was to install the system components and piping up to the final facility tie in connections to eliminate any loss of production at the facility. Securing and piping the new insulation 1,000-gallon hot water buffer tank and pumps was completed first while the fabrication of structure steel to support the roof mounting of the Heatsponge-Rainmaker economizer was completed. Piping was roughed in according to the equipment layout plan to allow equipment connection during the equipment installation phase of the project.

Figure 9: Buffer Tank and Pumps

Source: Gas Technology Institute

Upon completion of the fabrication and installation of the structural steel for mounting, the economizer was lifted using a construction crane and placed at the desired roof location. Figure 10 shows the economizer with the roughed in piping and service valves.

Figure 10: Economizer Roof Mounting

Source: Gas Technology Institute

The design performance of the economizer is very low at 0.136 inches of water column (inWC) at a gas flow of 9,288 pound per hour (PPH). Since the facility boiler is a forced draft design, additional testing was conducted to confirm there were no burner performance issues with operation of the economizer with the present boiler configuration.

The system began operation the week of October 22, 2018 and completed commissioning and final equipment verification and control checks. The system operation was stable with no problems experienced during the initial operation. Based upon positive operational experience the installation on the piping system and the new hot water buffer tank was completed. Figure 11 shows the completed installation of the Heatsponge-Rainmaker economizer at the Mission Linen facility. The installation includes system bypass valves and internal flue damper for use during any maintenance required without affecting hot water delivered to the facility.

Figure 11: Installation of Economizer

Source: Gas Technology Institute

The primary parameter to maximize waste heat recovery waste heat on a natural gas fired combustion system is a system design that can supply inlet coolant to the economizer at temperatures less than 130°F. This lower temperature allows recovery of both sensible and latent heat content from waste flue gases economically, greatly increasing heat recovery and reuse. The latent heat represents approximately 9 percent of the fuel energy content in natural gas combustion systems. Heat recovery operation at, or near, condensing conditions condenses the water vapor produced during the combustion process. This is a key feature of the technology, as it appropriately designed to handle the removal of condensate and recovery of both the sensible and latent waste heat from the flue gas.

The internal configuration of the Heatsponge-Rainmaker economizer allows for effective management for collection and drainage of condensate resulting from operation. This allows for protection of the upstream ducting and equipment from corrosion due to the condensate and if desired, treatment and re-use of the condensate water.

CHAPTER 3: Demonstration of Performance

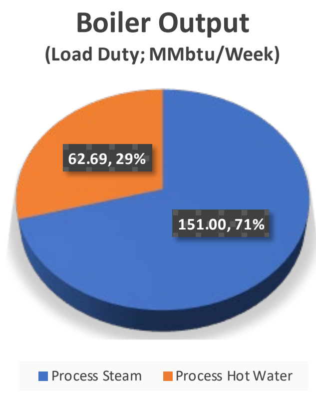
One of the primary objectives of this project was evaluation of the performance of the heat recovery system over the monitoring period of the project at the demonstration host facility. During this monitoring period, performance data was generated and logged in addition to feedback from the end user on the overall system performance. Tetra Tech was the independent, third-party measurement and verification subcontractor selected for this project and was responsible for developing the measurement and verification plan, gathering and analyzing system performance data, and reporting results. In support of these efforts, Frontier Energy was responsible for designing, installing, commissioning and maintaining the performance monitoring system, including data acquisition equipment and field instrumentation at the demonstration site.

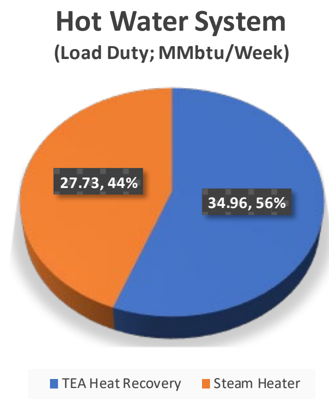
Operational Summary

The steam at the Mission Linen Supply laundry facility is generated by a 1965 Dixon firetube boiler nominally rated at 250 BHP. This boiler provides for the various steam utilities and heating duty throughout the plant including heating of the needed hot process water for operation of the laundry. During initial commissioning of the new equipment added as part of this project emission testing was completed by Tetra Tech to establish a baseline of boiler operation with and without the economizer in the flue flow path. During this testing, the estimated baseline testing indicated the boiler was operating at 82 percent efficiency.

The original hot water heating system of the facility was configured to preheat incoming process water through a wastewater heat recovery system supplying an insulated 4000-gallon hot water holding tank. A steam circulation heater piped in a closed loop attached to hot water tank was used to boost and maintain the water temperature of the hot water tank to the required process temperature of the facility hot water supply. On a typical production week at the facility approximately 92,000 gallons of fresh water is heated from the incoming utility water supply to the desired delivery temperature of 150°F. Prior to installation of the Heatsponge-Rainmaker economizer the water was heated by first passing through wastewater heat recovery system preheating the water from ambient temperature up to about 100°F depending upon the amount and temperature of the wastewater leaving the facility. A steam powered circulation heater is then used to raise the temperature to the desired process supply temperature. Figure 12shows the load duty of the boiler and hot water system prior to installation of the Heatsponge-Rainmaker for a typical production week at the facility.

Figure 12: Pre-Installation Load Duty





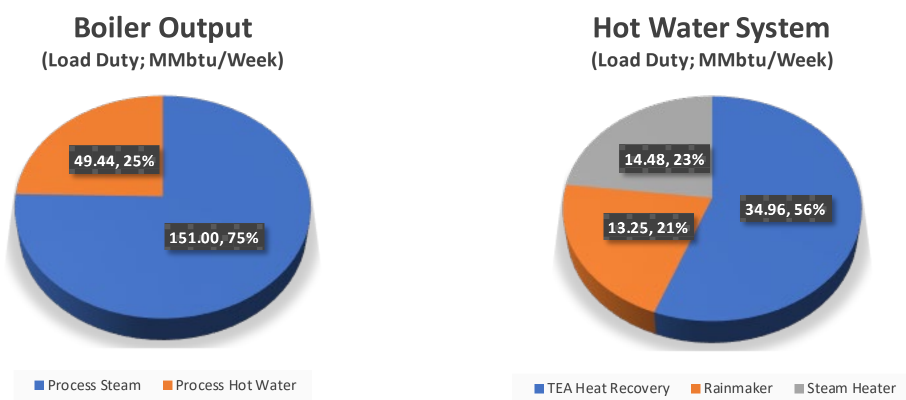
Source: Gas Technology Institute

Commissioning of the Heatsponge-Rainmaker occurred on November 18, 2018 and the system has been operating continuously since then as a component of the facility hot water heating system. The system has operated without any issues requiring intervention by plant personnel. The system was bypassed only once for a limited time for replacement of failed instrumentation related to the monitoring system performance. Several weeks after completing commissioning a review of the operational data indicated a failure of the two ultrasonic water flowmeters used for measurement of water flow through the Rainmaker economizer and delivered to the process hot water storage tank. Attempts by Frontier Energy to correct the issue were unsuccessful. Installation and commissioning of robust and proven electromagnetic based flow meters replaced the ultrasonic based flowmeters.

The Heatsponge-Rainmaker economizer in the modified process hot water system routes preheated water supply from the wastewater heat recovery system to the new insulated 1,000-gallon buffer tank, which circulates the pre-heated process water through the economizer during boiler operation. The new buffer tank supplies the hot water to the original plant hot water holding tank based upon facility hot water demand. The water supplied from the wastewater heat recovery system typically provides pre-heated water anywhere between ambient supply temperatures to at about 100°F depending on the amount of heat recovered from the wastewater heat recovery system. The function of the buffer tank is to allow the Heatsponge-Rainmaker to recovery the waste heat in the flue gas from the boiler regardless of current hot process water demand. During high hot process water demand the pre-heated water, supplied by the wastewater heat recovery system is well below the temperature needed to allow the economizer to operate in condensing-mode. At low process hot water demand, the economizer will naturally reduce the heat recovered from the flue gas as the temperature of the water in the buffer tank as the temperature rises and is recirculated through the economizer.

Data gathered during this monitoring period was the basis to examine the changes in load duty to both the boiler and the process hot water system along with the estimated increase in boiler efficiency for a selected production week. The boiler efficiency, averaged over a production week, is projected at 88.6 percent. This efficiency represents an increase of 6.6 percent above the value obtained earlier in the baseline testing of the boiler. This increase in boiler efficiency would result in projected yearly saving of 6,889 therms of natural gas and 55.2 metric tons of carbon dioxide emissions and a proportional reduction in NOx emissions at the current production rate at the facility. Figure 13 presents the load duty of the boiler and hot water system after installation of the Heatsponge-Rainmaker for a typical production week at the facility.

Figure 13: Post-Installation Load Duty

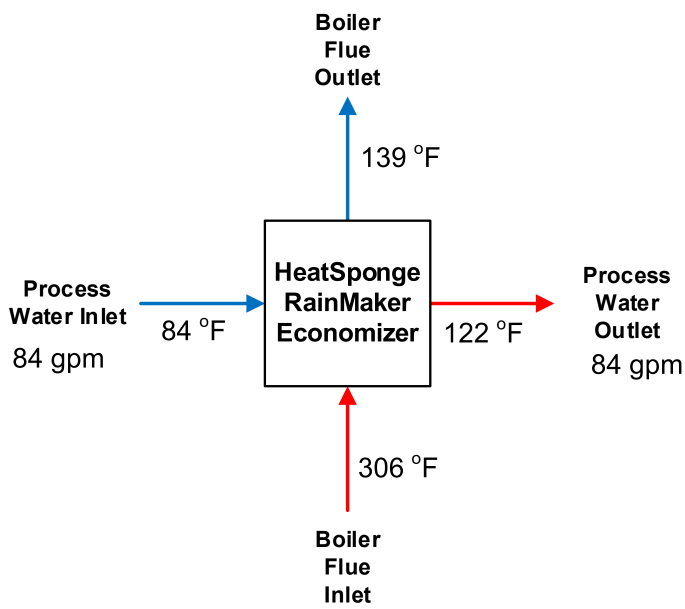


Source: Gas Technology Institute

The hot water use at the facility varies widely during each production day based on the time of day and type of equipment needed to meet the production mix for that day. The current production schedule is Monday through Friday with a single shift during the day. The facility boiler brought up to operating pressure starting about 2:00 am bring the steam system up to temperature. From this time to the start of production, the Heatsponge-Rainmaker is heating the water in the 1,000 gallon buffer tank and the steam heater is increasing the temperature in the 4,000 gallon hot water holding tank in preparation of the start of the production day.

The production day starts with the highest heat recovery conditions for the Heatsponge-Rainmaker in this application because there is minimal recovered heat from the wastewater recovery system available to preheat the water supplied to the economizer. To evaluate the performance of the economizer and better understand how it would perform in an application without any preheating of water the start-up operating conditions were extracted from weekly data. This data set provided the needed values for prior pre/post installation analysis. Figure 14 presents the average inlet and outlet temperatures based upon this data. Analysis of performance during these conditions confirmed that the economizer when provided with low inlet fluid temperature could provide excellent recovery of the boiler waste heat.

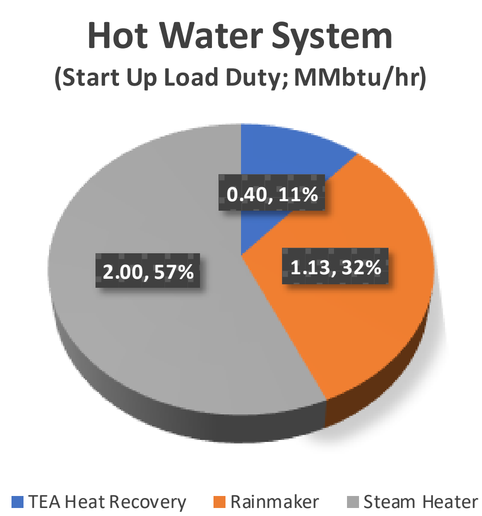
Figure 14: Average Start-Up Operating Conditions



Source: Gas Technology Institute

Figure 15 presents the heating duty of the hot water system during a daily system start-up in preparation of production. The data indicates that with an average inlet water temperature of 84°F that slightly over 1 mmBtu/hr of waste heat is recovered. To achieve optimal waste heat recovery requires the lowest inlet water temperature and a boiler firing rate that can provide the needed waste heat for recovery to raise the water temperature as desired.

Figure 15: Start-Up Load Duty



Source: Gas Technology Institute

Measurement and Verification

The goal of the measurement and verification plan and resulting data reporting was to validate the program's quantitative performance and to reduce uncertainty in baselines, engineering calculations, and equipment performance for the Heatsponge-Rainmaker technology. This was accomplished through a series of measurements that established operational parameters for the Heatsponge-Rainmaker technology. During this process the engineering, measurement parameters, and field conditions were documented and resulting calculations were performed to determine the efficiency gain from the heat recovery system. The following information was collected during the site investigation process:

- Instrumentation used during program verification, including calibration and accuracy of instrumentation.
- Data on frequency, type, and duration of measurements.
- Facility operating conditions during measurements.
- Method for estimating energy savings/efficiency (hourly, daily, and annual).
- Estimated levels of confidence and uncertainty.

The gas usage from the boiler was measured by a Dresser Roots Gas meter that has a temperature and pressure correction and data logging capabilities. Fuel data was collected monthly at the site by downloading data and correlating it with data collected by the integrated data system from the Heatsponge-Rainmaker installation. Data for the heat recover system was logged on a minute basis and was collected and normalized to represent annual values.

The boiler flue gas composition was established pre- and post-Heatsponge-Rainmaker installation and used to calculate combustion efficiency. Monthly flue gas monitoring was scheduled to document combustion efficiency. The boiler efficiency values were averaged, and an annual value was used in the calculation to determine the efficiency for the Heatsponge-Rainmaker and the heat recovery system. The results of this monitoring indicated an increase in boiler efficiency from 82 percent prior to installation of the Heatsponge-Rainmaker heat recovery equipment to a post-installation boiler efficiency of 88.6 percent.

The fuel use at the facility was established and used to calculate energy recovered by the Heatsponge-Rainmaker and energy delivered to the process. The results of these measurements and calculations confirmed that natural gas usage was reduced by 6.2 percent.

CHAPTER 4: Project Results

The goal of this project was to demonstrate the technical performance and cost effectiveness of an emerging heat recovery technology, as offered by Boilerroom Equipment Inc., for use in industrial steam applications that also have the requirement for hot process water.

The specific project goals were:

- Identify and overcome the operational and technical hurdles that may arise during a field-demonstration of the technology for use in steam applications, providing insight to guide decisions as the project team completes the deployment effort.
- Prove, via independent third-party measurement and verification, the ability of the system to achieve the stated performance objectives, while operating under real-world conditions at the end-user facility.
- Demonstrate the benefits of the heat recovery technology in terms of providing increased fuel efficiency, reduced greenhouse gas emissions, and reduced operating costs with a favorable economic payback.
- Disseminate the findings of this demonstration project and provide technology transfer to industrial users in California in order to increase public awareness and adoption of the heat recovery technology, and ultimately reduce natural gas consumption.

The project demonstrated the following results:

- Validated the ability of the technology to provide robust and reliable operation for steam boiler applications.
- Achieved an increase in boiler efficiency of 8 percent by recovering exhaust energy to generate hot water.
- Provided sufficient operational flexibility to match real-time variations in facility steam and hot water load demands.
- Demonstrated the cost-benefits of the technology by achieving a payback period of less than four years.

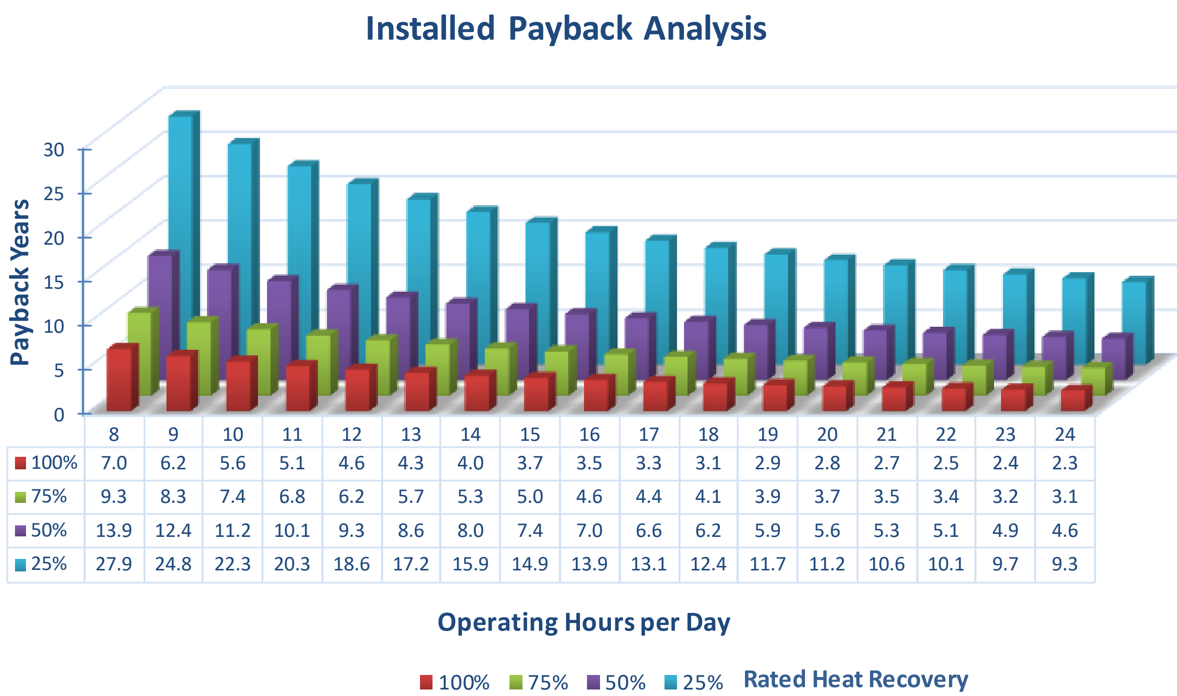
This project has demonstrated the technology can provide a robust and reliable operation when used with steam boiler or other natural gas combustion applications. The unit has been operating since installation last year integrated with the boiler and process heating water heating system without the need for any attention of plant personal. The simplicity of the required controls for operation along with the robust construction of the economizer provide for an easy to apply technology for heat recovery of waste heat from natural gas combustion products. The modular design approach allowed for simple selection of the economizer for the application.

Operation at the project site has demonstrated an increase of boiler operational efficiency from 82 percent to 88.6 percent at the current production rate at the Oxnard facility. The hot water usage at the facility varies based upon the type of equipment needed to meet the production scheduled for a given day. The current application came up 1.8 percent short of the stated goal of the project of an 8 percent increase of efficiency. This lower obtained efficiency increase is a direct result of the demonstration site's preexisting wastewater heat recovery system. One of the agreements with the host site was that installation of the Heatsponge-Rainmaker be configured in a way not to shift any heating load from the existing wastewater heat recovery system which provides more than half of the required water heating. The configuration of the economizer uses the preheated water from the wastewater recovery system and boosting the temperature reducing the amount of steam required to heat the water to the desired process temperature. Analysis of the start-up operation demonstrated that with the lower inlet water temperature the recovered waste heat rate greatly increases and would directly demonstrate how one would expect this technology could work on a system that did not have a system to preheat the water before the economizer.

The 1,000-gallon buffer tank allows the Heatsponge-Rainmaker to recovery the waste heat in the flue gas from the boiler regardless of current hot process water demand. During high hot process water demand the preheated water supplied by the wastewater heat recovery system at times is below the temperature needed to allow the economizer to operate in condensing-mode to meet the high flow demand. A low water demand the economizer will naturally reduce the heat recovered from the flue gas as the temperature of the water in the buffer tank rises and is recirculated through the buffer tank. During operation of this system, this design provided the flexibility and dynamically matched real-time variations in facility steam and hot water load demands. By reducing the steam required for water heating the system effectively increased the available steam capacity of the boiler and the combination of the Heatsponge-Rainmaker and buffer tank provided additional water heating capacity to easily handle any high hot water flow rates.

The energy recovery obtained represents 6.2 percent savings of the yearly projected natural gas energy used by the facility boiler. Based on these results, the estimated payback value is quite high at 23.6 years based upon the current single shift operation, production rate, and a cost of $0.80/therm of natural gas. The system does provide some additional economic benefits not included in the calculation. The primary of these would be effective increase in available steam and hot water capabilities and any avoided costs of increasing the capacity of the boiler or hot water system. Increased production at the facility, thus increasing the operating time of the system would decrease the payback value significantly. Based upon the operating data obtained the for three shift operation the simple payback value would drop to 7.8 years, still roughly twice of the stated goals of this project. Figure 16 presents a more detailed payback analysis for various percentages of rated the rated heat capacity, 82 percent boiler efficiency, and a cost of $0.80/therm of natural gas. The presented data assumes a 250 day production day per year and the installed cost of the Heatsponge-Rainmaker as configured for this project as a function operating hours per day. Analysis of the data indicates that depending on the application a four-year payback is achievable.

Figure 16: Operating Hours and Payback Years



	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
100%	7.0	6.2	5.6	5.1	4.6	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.8	2.7	2.5	2.4	2.3
75%	9.3	8.3	7.4	6.8	6.2	5.7	5.3	5.0	4.6	4.4	4.1	3.9	3.7	3.5	3.4	3.2	3.1
50%	13.9	12.4	11.2	10.1	9.3	8.6	8.0	7.4	7.0	6.6	6.2	5.9	5.6	5.3	5.1	4.9	4.6
25%	27.9	24.8	22.3	20.3	18.6	17.2	15.9	14.9	13.9	13.1	12.4	11.7	11.2	10.6	10.1	9.7	9.3

Source: Gas Technology Institute

The energy efficiency market continues to develop toward implementation of heat recovery systems that enable achieving higher efficiency and emission reductions in larger commercial and industrial applications. The Boilerroom Equipment Inc. Heatsponge-Rainmaker offers an option that, depending on the application offers an increase in efficiency typically in the 4 to 8 percent range. The expected savings and payback can vary dramatically based upon specific equipment configuration, installation requirements, and operating conditions. Based upon our experience with this technology the following are key considerations in evaluation of potential applications:

- Commercial or industrial steam boiler or industrial combustion application that has a need for larger volume water heating.
- Can supply the water to the economizer with inlet temperatures at or below 110°F.

- Avoided equipment cost related to the increased heating capacity due heating load shifted to the heat recovery system proposed.
- Heating requirements of water used in proposed system to determine cost and possible savings for comparison to project equipment and installation costs.
- Have available or obtain baseline boiler operating data including efficiency, flue temperatures, and annual fuel usage.

CHAPTER 5: Market Opportunity and Adoption

The first generation of this technology, the SideKick product by Boilerroom, Inc., was introduced around 2010. There have been several refinements and redesigns in the intervening years offered under different product names, with the latest being the Rainmaker. The technology in its current form has been available since 2012. Because the company is based in Pennsylvania, it partners with a distributor, California Boiler, for sales in California. California Boiler handles sales of the units to facilities across the state. There are many indirect contact economizers installed across California, including at military facilities, textile manufacturing, food processing plants, several industrial laundries, and hotels. Several of these installations have successfully applied for and received utility rebates through energy efficiency programs, sometimes totaling more than $100,000.

This technology presents a promising opportunity for improving efficiency and reducing natural gas consumption in industrial markets. It's unique approach of using predesigned modules and exclusive software to determine size and flow requirements allows for a semi-custom design to be readily prepared for a range of market applications. In California, the technology could be used in food processing, chemicals production, refining, minerals extraction, agriculture, and laundry services. California Boiler has identified two primary early target markets for this technology–food processing and textiles. These industries can use the exhaust from their processes and reuse the water through the economizer to increase efficiency. The technology's ability to handle much larger flow rates, such as those from process hot water use or from hydronic boilers, makes it a strong fit for these markets.

The California food processing industry uses a large amount of natural gas. The largest food processing sector is for fruit and vegetable processing, which consumes an estimated 300-400 million therms annually.[1] This is followed by cheese (43 million therms), rice (41 million therms), poultry (40 million therms), and milk powder/butter (33 million therms) processing. Natural gas use in food processing is primarily goes to pasteurization, heating systems, evaporators, dryers, and sterilization. It has been estimated that the value added from food processing brings an additional $63.9 billion – over double the value of the original, unprocessed food commodities. Approximately 55 percent of this value is from dairy processing alone, with considerable contributions from fruits and vegetables, beef and poultry, and wine.

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1 California Energy Commission. July 2006. *Technology Roadmap Energy Efficiency in California's Food Industry*. CEC-500-2006-073. Prepared by California Institute of Food and Agricultural Research, University of California, Davis.

The textiles industries of focus include both large commercial through industrial-sized laundries as well as textile manufacturing. These target laundries include on-premise laundries such as those that might be found at hotels, hospitals, prisons, live-in institutions etc. as well as industrial laundry operations, such as professional linen or uniform services. According to the most recent United States Economic Census, there were 226 industrial launderers and linen supply facilities in California as of 2012, in addition to 2,826 dry cleaning and laundry services (excluding coin-operated facilities). Within the commercial and industrial market, natural gas is estimated to account for 88 percent of energy consumption, largely to supply hot water for washing and hot air for drying. [2] As of 2015, the primary energy consumption for commercial laundry is estimated at 0.42 Quads/year.[2]

The 2012 United States Economic Census also estimates there are 320 textile mills in operation in California. The use of natural gas in textile manufacturing varies depending on the specific processes implemented at each mill. Mills that use wet-processing are a strong fit for this technology as they are a major thermal energy consumer in the textile industry, both of steam and heat. Wet-processing is done on manufactured fabrics and consists of pre-treatment, dyeing, bleaching, printing, and finishing. Manufacturing data indicates that 61 percent of the final energy used in the U.S. textile industry is from non-electric fuels, such as natural gas.[3] The U.S. textile industry also ranks as the 5th highest consumer of steam among 16 of the country's major industrial sectors.[3] Boiler losses alone account for 7 percent of the onsite energy losses at textile mills, making improving boiler efficiency an area of natural interest.[3]

GTI has focused its efforts on assisting Boilerroom Equipment, Inc., the technology provider and partner for this project, to develop and demonstrate a highly-efficient economizer in a real-world applications. The results of this project will be made available to the utility collaboratives GTI works with, specifically the Utilization Technology Development and Emerging Technology Program collaborative.

Established in 2004, Utilization Technology Development's goal is to identify, select, fund and oversee research projects resulting in innovative solutions which expands the use, cost effectiveness, and efficiency of natural gas utilization equipment. As part of the Utilization Technology Development collaborative, this technology was presented to approximately twenty utilities and stakeholders in the energy industry, most of which have energy efficiency programs that may be interested in developing programmatic rebates for this energy saving technology. Utilization Technology Development has Southern California Gas Company representation, which is also providing cost share and

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2 Department of Energy. June 2016. Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances (2015 Update). Prepared by Navigant.

3 Lawrence Berkeley National Laboratory. September 2010. Energy-Efficiency Improvement Opportunities for the Textile Industry. Prepared by China Energy Group.

is closely involved in this project. An overview of the technology was provided in its annual research project summaries report of 2017-2018., and in quarterly project update reports through June 2018.

Established in 2012, the Emerging Technology Program is a membership-based, utility collaborative that works to accelerate the market introduction and acceptance of new emerging technologies to feed utility energy efficiency programs. This collaborative consists of approximately twenty utilities and stakeholders in the energy industry. Southern California Gas Company and San Diego Gas & Electric are members of the Emerging Technology Program. A technology snapshot providing an overview of the technology is now available to Emerging Technology Program members and will be updated with the results from this demonstration. The technology was presented to Emerging Technology Program’s Industrial Committee in February 2019.

Thermal Energy International, Inc. (TEI) recently acquired Boilerroom Equipment, Inc. TEI will use their network and market expertise to deliver product line to the California market. Boilerroom Equipment, Inc will use the results of this project to promote their product line and increase market penetration. TEI’s Director of Corporate Accounts is based out of Sacramento, CA and is involved in commercialization efforts in the California market, and collaborates with third-party program managers working closely with utilities. TEI attends approximately ten trade shows annually in North America, including the Food Expo in Sacramento. TEI tends to have a booth and talk about their product line in these shows. TEI intends to present results from this project and details about this technology and its competitiveness compared with the current industry standards at these trade shows. Following the demonstration results from this project, TEI will be able to use their network to promote this technology. Vendors that TEI works closely with include California Boiler and Motion Industries’ Energy Services Team that will be interested in promoting these products.

CHAPTER 6: Benefits to California

The California market potential for improvements to commercial and industrial boiler efficiency technology is outlined in Table 2. Across the United States, the total nonresidential boiler capacity is 2,310,889 mmBtu/hr for boilers rated up to 250 mmBtu/hr. With California representing 12 percent of the United States' population, if one assumes 12 percent of the boiler population is installed in the state, the California commercial and industrial boiler capacity would be 277,307 MMBtu/hr for boilers rated up to 250 MMBtu/hr. With the assumption that the technology would capture 10 percent of the boiler replacement/retrofit market, this equals a total capacity of 27,731 mmBtu/hr.

Table 2: California Commercial/Industrial Boiler Market Potential for Indirect Economizers

Category	Value	Source/Basis
U.S. commercial and industrial boilers, number of units (≤250 MMBtu/hr capacity)	45,660	2005 EEA Characterization of the U.S. Industrial Commercial Boiler Population, submitted to Oak Ridge National Laboratory
California commercial and industrial boilers, number of units (≤250 MMBtu/hr capacity)	5,479	California represents 12% of U.S. population; assume boiler capacity scales comparably
California market penetration of indirect contact economizer technology	548	Assume 10% of CA boiler replacement/installation potential can be captured by target technology within first 10 years after commercialization

Source: Gas Technology Institute

The energy recovery obtained by the technology when demonstrated at Mission Linen Supply, Inc. represented 6.2 percent of the annual natural gas use by the facility's boiler. This savings resulted from an increased boiler operational efficiency from 82 to 88.6 percent. This increased efficiency represents a projected yearly savings of 6,889 therms of natural gas and a corresponding emissions reduction of 55.2 metric tons of carbon dioxide from the facility.

Considering the potential capacity that could be impacted by this technology, if it was adopted by industrial and industrial boilers in California with a 10 percent market penetration, would represent 127 mmBtu/hr of rated capacity. Based upon this capacity and assuming operation at 35 percent of rated capacity for 250 working days/year at an average of 12 hours a day, the addressable natural gas energy market in California for this technology is estimated to be 29,118,000 mmBtu per year. Based on the 6.2 percent natural gas savings demonstrated during this project would result in annual natural gas savings of more than 1,747,000 mmBtu throughout the California natural gas markets. Correspondingly, this would result in energy annual savings of over $11.4 million for California customers (assuming $6.5/MMbtu gas cost) with reduction of carbon dioxide of more than 102,199 tons and NOx of 20,106 lbs annually.

While there are a variety of boiler economizers on the market, the target technology offers the opportunity for greater energy savings than traditional economizers. Boilerroom Equipment, Inc is currently the only known manufacturer producing this type of economizer. They are a small manufacturer and has been accessing the California market through a single channel–the distributor California Boiler. However, recently acquired by Thermal Energy International, Inc. (TEI). TEI offers several industrial energy solutions, including the FLU-ACE direct contact condensing heat recovery system. TEI has experience accessing the California market, particularly through utility energy efficiency programs, and is expected to prepare a commercialization plan for the acquired indirect contact economizer. Branching beyond the single-distributor model will enable this technology to be adopted on a broader scale.

In addition to the quantitative cost and emissions benefits of the indirect contact economizer technology, there are qualitative benefits that are anticipated to further expand adoption by industrial customers. A core aspect of the technology is the straightforward customization and sizing of the units resulting from the exclusive software and modular component design. This intrinsic feature allows the technology to adapt to the customer needs, rather than forcing customers to adapt to the technology. Specifically, the units are custom-built to achieve maximal performance based on facility load demands and enable suitable orientation and placement of connections on the unit to provide seamless integration with existing facility infrastructure. This greatly reduces the complexities and costs of system engineering and installation.

The indirect contact economizer technology employs well-proven heat exchange design principals that can be understood by facility operations and maintenance personnel. The robust design is free of moving parts or additional energy inputs, as are required for the direct contact heat exchangers that are sometimes employed for similar applications. This results in low maintenance requirements and long product lifetimes, estimated at over 20 years.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
BHP	Boiler Horsepower (1BHP) is equal to a boiler thermal output of 33,475 BTU per hour
condensing	Change of moisture vapor into droplets of liquid water
economizer	mechanical device used to reduce energy consumption to recycle energy produced within a system or leverage temperature differences to achieve efficiency improvements
GTI	Gas Technology Institute a non-profit research and development organization
hydronic heating	heating that involves transfer of heat by a circulating fluid (such as water) in a closed system of pipes
inWC	inches of water column
latent heat	quantity of heat which is absorbed or released by a substance during a change of state (fusion or vaporization) at constant temperature
metric ton	unit of weight equivalent to 1000 kilograms
MMbtu	1 million British thermal units
NOx	oxides of nitrogen as atmospheric pollutants
payback	period of time required to recoup the funds expended
PPH	pounds per hour
therm	quantity of heat that equals 100,000 British thermal units
wastewater heat recovery	process of recovering heat from hot waste water streams with potential high energy content

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