Energy Efficiency Potential of Gas-Fired Commercial Water Heating Equipment in Foodservice Facilities

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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*Energy Efficiency Potential of Gas-Fired Commercial Water Heating Equipment in Foodservice Facilities* is the final report for the Energy Efficiency project (contract number 500-06-028), conducted by Pacific Gas and Electric Company and Fisher-Nickel, Inc. The information from this project contributes to the Energy Research and Development Division’s Building End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission’s website at [www.energy.ca.gov/pier](http://www.energy.ca.gov/pier) or contact the Energy Commission at 916-654-5164.
ABSTRACT

The Pacific Gas & Electric’s Foodservice Technology Center, operated by Fisher-Nickel, Inc., performed a technology evaluation of gas-fired water heaters for the California Energy Commission’s Public Interest Energy Research Program. This project conducted research to improve the efficiency of water heaters and distribution systems in foodservice facilities. Many energy efficiency strategies are applicable to the wider commercial and institutional sector.

The objectives were to characterize and inventory existing water heating equipment and foodservice segments in California. Field-monitoring studies were conducted to help estimate the gas use for each segment and total load for the sector. Mature and emerging technologies and research, development and demonstration opportunities were identified to estimate the energy efficiency potential. Lastly, a design guide was developed and key findings were presented at workshops to educate designers.

Water heaters are energy intensive appliances in commercial kitchens, estimated at using upwards of 340 million therms of natural gas annually in California. The annual savings potential through successfully implementing retro-commissioning and energy-efficient technologies was estimated at upwards of 120 million therms. The biggest potential for energy savings involves improving the operating efficiency of water heaters and incorporating solar and/or waste heat recovery systems in restaurants.

Keywords: water heating, hot water system, gas-fired, water heater, gas use, distribution system, efficiency, operating efficiency, restaurant, foodservice, foodservice, design guide, commercial kitchens, energy savings, heat recovery

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EXECUTIVE SUMMARY

Introduction

The PG&E Foodservice Technology Center (FSTC) estimated that commercial foodservice facilities consume upwards of 340 million therms of natural gas annually for water heating, which represents 16 percent of commercial gas usage in California, or 2100 million therms of natural gas per year. In full service and institutional kitchens with dishwashing operations, the water heating load can represent up to 20 percent of the total energy use and up to 50 percent of the total gas consumption for the facility. Despite the large operating cost associated with this energy use and the number of facilities that can benefit from energy efficiency measures and technologies, there has been little motivation to develop and promote high-efficiency, gas-fired water heating equipment and systems for the foodservice sector.

Commercial water heating systems fly under the radar and do not get adequate funding or attention in the building design process as compared to lighting systems and heating, ventilation and air conditioning systems. As a result, the burden of an inefficient system may be passed on to facility operators who essentially ignore the system unless there is a breakdown. Operators do not have a way for distinguishing gas usage for water heating from their energy bill or hot water usage from their water bill that would motivate them to seek and implement related efficiency measures. Due to historically low gas, water, and sewer utility costs and the lack of a distinct cost signal to the operator, hot water systems have not significantly evolved. There is immense potential for increasing the overall efficiency of water heaters, as the majority installed in foodservice facilities operate at the minimum efficiency standard and are paired with inefficient distribution systems. End-of-pipe fixtures, equipment and user practices, while a critical part of achieving gas use reductions, were not a focus of this project.

Project Purpose

The goals of this project were estimating the energy use of gas-fired hot water systems, identifying efficiency opportunities, and estimating savings if the leading measures were implemented in California. The overarching goal was to advance the industry forward toward using a systems approach in the design process and utilizing best available technologies.

The objectives of the gas-fired commercial water heating project were:

- Characterizing existing equipment in the foodservice industry.
- Inventorying existing commercial and institutional foodservice facilities and water heating equipment.
- Determining the water heating energy load for each segment and for the whole sector.
- Identifying future research, development and demonstration (RD&D) opportunities.
- Estimating the energy efficiency potential for the foodservice sector.
- Developing a design guide and conducting workshops to educate designers.
Project Results

It was estimated that gas-fired water heaters are installed in 85,500 foodservice facilities in California. The majority of these installations (new construction and replacement) are standard-efficiency storage heaters with an 80 percent thermal efficiency rating. Field-monitoring of 11 foodservice facilities by FSTC has shown a wide range in operating efficiency, from a low of 20 percent in a supermarket to a high of 90 percent in a quick-service restaurant.

Average daily hot water consumption per facility type was estimated to range from 100 to 2,000 gallons in the commercial segments and 3,000 to 22,000 gallons in the large institutional segments. After factoring in the average days of operation, temperature rise, and operating efficiency parameters, the annual gas-use for water heating in an average facility was estimated to range from 300 to 7,440 therms in the commercial segments and 12,160 to 63,850 therms in the large institutional segments. The gas use of 259 million therms annually in quick- and full-service restaurants accounts for three-quarters of the gas load for the entire foodservice sector. Consequently, the project focused on the energy saving potential in restaurants.

To save energy and improve the operating efficiency of hot water systems, mature and emerging technologies and future RD&D opportunities need to be implemented. The most promising opportunities included:

- Transforming the market to higher-efficiency water heaters.
- Applying optimized distribution systems strategies and moving away from continuous recirculation systems.
- Decentralizing water heating systems in kitchens by utilizing dishwashers with integrated heat recovery and point-of-use heaters at hand-washing sinks.
- Utilizing waste heat (e.g., refrigerant heat recovery) and renewable energy (e.g., solar thermal pre-heating).

The total savings potential through successfully implementing retro-commissioning measures and adopting existing and new energy efficiency technologies was estimated at 123 million therms annually.

Educational materials were developed, including a hot water system design guide and workshop presentations for educating the commercial foodservice and water heating community.

FSTC’s outreach was a great success, with half a dozen seminars completed in California in the past year. The outreach also reached a national audience, including presentations at conferences or workshops hosted by the American Council for an Energy-Efficient Economy (ACEEE), the National Restaurant Association, and the Consortium for Energy Efficiency (CEE).

This report highlighted the fact that water heaters are a major gas-using appliance in foodservice. In California full-service restaurants, the water heater uses more natural gas than any other piece of gas-consuming equipment. Site-monitoring of systems was fruitful and from analysis of the data, the main factors impacting operating efficiency were daily hot water use, water heater operating efficiency, and the length of the distribution system. In the foodservice sector, 16 segments were identified and systems characterized to estimate the
sector water heating gas load. The half dozen energy saving measures identified are estimated to reduce the gas load by 35%.

Further characterization and field monitoring of boiler-based hot water systems in large restaurants and institutional facilities is needed. Also, in-depth monitoring is recommended in restaurants to get data on hot water use and hot water temperature at each outlet. This data would be used to express the operating efficiency of the water heater and distribution operating efficiency separately.

Mature and emerging technologies and future RD&D projects should focus on restaurants, coffee shops, supermarkets, work cafeterias and nursing homes that incorporate similar hot water system components and designs and that collectively represent over 80% of the water heating gas load in the foodservice sector. In addition, the researchers recommend demonstrating net-zero energy hot water systems in selected segments. A final suggestion would be to develop modeling software to aide designers. The software would have the capability to discern various hot water system designs and system parameters for estimating operating efficiency and energy use and providing life-cycle cost assessments to help further optimize the design.

Benefits to California

This PIER project has already yielded benefits to California by educating the industry on opportunities for saving energy with hot water systems through seminars, conferences and advisory committee meetings. By quantifying the water heating gas load in foodservice and comparing it to the total gas load in the wider commercial sector, it has helped place the hot water system on the radar of energy efficiency professionals. The results from this project have influenced ACEEE, CEE, and ENERGY STAR efforts to create new efficiency standards for commercial water heaters, differentiate higher efficiency condensing models and position resources on reducing energy use in commercial foodservice.

The FSTC quantified the energy efficiency potential of condensing water heaters and is in the process of developing working papers to justify a utility rebate program. The design guide and seminars delivered across the state educated the industry on issues of conventional hot water system designs and provided insight and examples for designing advanced systems. Foodservice facilities stand to benefit the most with improved system efficiencies and hot water delivery, which lowers utility costs and meets customer expectations. California foodservice facilities will save an estimated $120 million annually from their energy bills if the recommended measures are adopted. This estimate is based on 2010 California nominal utility rates of $1.00 per therm for natural gas and $0.15 per kWh for electricity. Reducing water heater gas use in commercial foodservice facilities will also benefit Californians through a corresponding reduction in greenhouse gas emissions.
1.0 Introduction

The commercial foodservice water heating system is a complex system of interconnected components. Traditionally, water heating systems do not get adequate funding or attention with regards to energy efficiency in the building design process as compared to lighting systems or heating, ventilation and air conditioning systems that are also ubiquitous in buildings. The application of low-first cost (and low efficiency) water heating equipment with conventional distribution system design practices remains standard practice in foodservice facility design. The burden of an inefficient system may be passed on to the facility operators, who do not have a way to discern their water heating energy use and utility costs that might motivate them to seek and implement efficiency measures. Thus, many systems in foodservice facilities in California operate at low energy utilization efficiencies. The intent of this report was to characterize the types of gas-fired water heaters and hot water systems that are being specified. Field monitoring helped to estimate gas use in various types of facilities. Opportunities to reduce gas use were identified and the associated energy efficiency potential by implementing the recommended measures was quantified.

1.1 Background

The National Restaurant Association lists 945,000 foodservice facilities (including school and work cafeterias) currently operating in the United States [1]. The California Restaurant Association reports that there are more than 88,000 commercial foodservice establishments currently operating in the State [2]. However, this inventory neglects a portion of the institutional foodservice segment which provides dining services as a secondary or ancillary service to a primary service. The institutional segment includes, for the purpose of this study, educational services, health care and social services, corrections, and military. Industries such as lodging, recreation and gaming are also categorized as having institutional foodservices, as well as grocery and warehouse retail.

Gas is the preferred fuel source for water heating by operators in California due primarily to the lower utility cost. There are three main areas in a commercial foodservice facility that are typically powered by natural gas. Primary cooking appliances are responsible for up to 50% of the gas used. Water heating demands can drive 20%-50% of gas usage, while a smaller portion of gas energy use is attributed to space and ventilation air heating.

1.2 Project Objectives and Scope

The objectives of the gas-fired commercial and institutional water heating project were to:

- Characterize existing water heating equipment in California’s foodservice industry,
- Inventory existing foodservice facilities and water heating equipment,
- Determine the water heating energy load for each segment and for the whole sector,
- Identify future research, development and demonstration (RD&D) opportunities,
• Estimate the water heating energy efficiency potential for the sector, and
• Develop a design guide.

To accomplish these objectives, the project was divided into the following tasks and subtasks.

1. Characterize gas-fired commercial food-service equipment and systems by:
   – Conducting a literature review,
   – Developing a field monitoring test plan,
   – Monitoring three commercial foodservice facilities,
   – Analyzing site-survey experiences, and
   – Interviewing foodservice facility designers.

2. Prepare foodservice facility and water heating equipment inventory summaries by:
   – Establishing typical equipment lineups for different facility types, and
   – Developing spreadsheets that inventory existing equipment and facilities.

3. Determine the overall gas use per segment, and gas load of the sector.


5. Estimate the energy efficiency potential for the whole foodservice sector.

6. Present the results to the industry by:
   – Developing an online accessible “Hot Water System Design Guide”,
   – Conducting industry workshops, and
   – Continuing outreach and information dissemination.

1.3 Report Organization

In Section 2, Project Approach, each task is described in detail to include the approach taken to accomplish the larger project objective.

In Section 3-8, Project Outcomes, each task is given its own chapter to present the outcomes more clearly. This is a variation from the PIER style manual, but necessary for organizational purposes to reduce the number of sub-headings.

In Section 3, the report characterizes gas-fired water heating equipment and systems used in commercial and institutional kitchens.

In Section 4, the report presents the water heater equipment and food-service facility inventory.

In Section 5, the field-monitoring test plan and field studies are presented.

In Section 6, the sector gas load is calculated.

In Section 7, this report summarizes the “Future RD&D Opportunities for Gas-Fired Hot Water Systems” and estimates the energy efficiency potential if the suggested measures are adopted.

In Section 8, this report reviews the educational materials developed, including the “Hot Water
System Design Guide”, workshop presentations and summary of information dissemination.

In Section 9, Conclusion and Recommendations, the conclusions from the completed tasks and broader implications are presented. This is followed by recommendations on future research and how California could benefit from the results of this project.

In Section 10, the References are presented, followed by the Glossary in Section 11, the Bibliography in Section 12 and culminating with the Appendices.
2.0 Project Approach

2.1 Characterize Gas-Fired Water Heating Equipment and Systems

The characterization of existing water heating systems in the foodservice sector involves discussing each aspect of the system, from the different types of water heaters and the variety of distribution system strategies in use, with the goal of understanding the operating efficiency. Technologies involving waste heat recovery and renewable energy systems are covered briefly in this section as they are seldom found in existing foodservice facilities.

Gathering information through field monitoring, site-surveys and literature review were the primary sources of information for characterizing hot water systems in foodservice. Presenting research findings has created interest by various parties involved with hot water systems in foodservice, leading to educational seminars and stakeholder collaboration sessions that have been valuable in exchanging information, building consensus with existing findings and generating new research pathways.

The FSTC has been fortunate to work with foodservice industry designers and engineers covering quick-and full-service restaurants, supermarkets, and institutional facilities in characterizing hot water systems. Through collaboration during site-monitoring projects, seminars, advisory committee meetings, or at conferences, the opportunity to accrue knowledge and have dialogue on the design of hot water systems has been invaluable.

FSTC site surveys and analysis of plumbing layouts in building blueprints were the primary tools used to characterize water heating systems. The FSTC visits over 100 foodservice facilities annually in the commercial foodservice sector and periodically in institutional foodservice facilities including hotels, schools, universities, cafeterias, military facilities. This on-site experience helped shape an understanding of trends in water heating systems and emerging energy saving opportunities.

2.2 Water Heating Equipment Inventory

To estimate the sector gas load, the first step was to inventory the gas-fired water heating equipment. Before water heating equipment can be inventoried in each segment and the total number of gas water heaters tallied, the segments in the foodservice sector need to be identified.

2.2.1 Foodservice Sector Characterization

Relying on the FSTC’s experience, 16 major commercial and institutional segments that operate commercial kitchens where identified based on significant gas usage for water heating. The one indistinct segment titled “miscellaneous” encompasses seven smaller segments that collectively use a considerable amount of natural gas.

The second aspect of the sector characterization was to estimate the number of facilities under each of the 16 segments identified. The commercial and institutional foodservice segment counts are based on a recent California Energy Commission publication [3] titled, “Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment”. The
commercial segment counts are based primarily on a purchased 2007 ReCount database [4]. Institutional facility counts are based primarily on independent sources. One difference from the Appliance report is that bars and taverns are additionally characterized in this report. The ReCount data did not identify bar and tavern facilities that primarily serve alcohol and secondarily serve food. This study relied on 2007 U.S. Census data, which provided a conservative estimate of the bar and tavern establishments in California [5].

2.2.2 Proportion of Natural Gas Water Heaters

The percentage of facilities per segment that use gas-fired water heaters was based on FSTC site survey experience in combination with a review of blue prints of foodservice establishments and data from a 2007 report for the California Urban Water Conservation Council [6].

2.2.3 Gas-Fired Equipment Inventory Summary

Storage and tankless water heaters and boilers are the three types of gas-fired heaters inventoried. Estimations for the market share of each type and the average number of heaters installed per segment were based on site-survey experience. For the institutional facilities, where a boiler is usually specified, it was assumed that only one unit is installed to service the foodservice section of the facility.

2.2.4 Segment Characterization of Water Heating Equipment

Establishing a water heating equipment lineup for each segment was the last task of the inventory. The equipment lineup characterizes the typical water heater type, storage capacity, gas input rate and distribution system for each segment.

2.3 Field Monitoring

2.3.1 Field-Monitoring Test Plan

Monitoring water temperatures, water consumption, and energy consumption is fundamental to characterizing the performance and efficiency of hot water systems operating in the field. While there are standardized test procedures devised for controlled-condition laboratory testing to determine water heater steady-state thermal efficiency, protocols for testing real-world systems in the field must be tailored to satisfy existing field configurations with typically less elaborate and more compact instrumentation and data acquisition systems. When comparing hot water operating efficiency and energy consumption, care must be taken to normalize data to account for varying water inlet temperature and/or temperature rise while accurately integrating the energy delivered to the water on a mass-weighted basis. The normalization is necessary to make fair comparisons of different systems with varying conditions. Furthermore, given the dynamics involved and to achieve accurate results, it is important that data both be logged and integrated on as small of a time scale as is practical. For example, the operating characteristics of a tankless heater will warrant more frequent sampling than with a storage heater.

Field tasks in the test plan included installing monitoring equipment and characterizing the performance and efficiency of water heating systems. All instrumentation, including water and gas meters, temperature probes, and data acquisition systems were provided by the FSTC. The
systems were monitored for a minimum of four weeks to measure the performance of the hot water system. The data was analyzed to report on daily hot water and gas consumption, daily hot water and gas load profiles, water heating operating efficiency and projected annual cost of operation.

2.3.2 Field Monitoring of Three Commercial Foodservice Facilities

The objective of this field-monitoring task under the PIER project was to characterize the hot water use, energy consumption and associated operating efficiency of three gas-fired hot water systems in selected commercial facilities. The selection process involved finding viable commercial sites for end-use monitoring that characterize small, medium and large food-service facilities. Preference was given to larger hot water systems that utilized a recirculation loop. The final candidates in the study included quick-and full-service restaurants, a café and a supermarket. Under this PIER project and with collaborative support from PG&E’s Emerging Technology program, ten field-monitoring projects were carried out. The results formed the foundation for calculating the average gas use for commercial and institutional facilities.

2.4 Sector Gas Load Estimate

Segment specific data was collected from site surveys, monitoring projects and reviewing literature to characterize the foodservice facilities and water heating systems by the following parameters:

1. Average daily hot water use
2. Average operating days per year
3. Average temperature rise
4. Average operating efficiency

In the absence of hard data for a parameter in a specific segment, operating assumptions are made after analyzing the parameters in similar segments. By estimating the daily hot water use operating days per year, temperature rise, and operating efficiency, the gas used at the water heater was calculated. From this data, the following results were derived for each segment and segment gas use tallied to estimate the total sector water heating load:

1. Annual hot water use per facility
2. Daily gas use per facility
3. Annual facility gas use
4. Annual foodservice segment gas load
5. Annual foodservice sector gas load

The approach used to collect information for each of the four parameters is detailed:

2.4.1 Hot Water Use

Site monitoring in restaurants, coffee shops, a supermarket and a work cafeteria was used to estimate the average daily hot water use in the respective segments. In the three health care related segments and large correctional facilities, daily hot water use was based on the number
of beds or inmates and applying the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) estimates of hot water use per meal. For the rest of the segments, cursory estimates of hot water use were applied, as site surveys and studies on hot water use in these facility types are very limited. Furthermore, the foodservice portion of the hot water load cannot be easily differentiated from space heating, showers, laundry and other hot water uses in some of these multi-use facilities.

2.4.2 Annual Operating Days

The annual operating days of the average facility in each segment was estimated in order to calculate the annual hot water use of the facilities. Most foodservice establishments are operating over 360 days per year. The outliers are grade school cafeterias, higher education dining facilities and work cafeterias.

2.4.3 Temperature Rise

Calculating the temperature rise is a simple mathematical equation of water heater outlet temperature minus the cold water inlet temperature. The first step was to estimate an average inlet temperature of the supply water reaching the water heater. Based on reviewing previous literature, this study has taken into consideration a more recent report that published average annual water supply temperatures collected from a variety of water providers throughout the state. The second step involved evaluating the hot water needs and end-use equipment for each foodservice category to estimate the water heater outlet temperature.

2.4.4 System Operating Efficiency

Estimating the hot water operating efficiency of each foodservice category was more involved than the other variables. Some of the factors that influence the operating efficiency include: the type of heaters installed, segment installed base of standard efficiency and high-efficiency heaters, heater operating efficiency, type of distribution system and length of distribution system. Other factors considered are daily hot water use, usage profiles and effect on tank heat loss or off-cycle tankless losses. The average system operating efficiency for some of the segments is estimated based mainly on the site-monitoring work. The remaining segments leverage the knowledge gained from site surveys, literature review, and monitoring work for estimating the efficiency.

2.5 Energy Efficiency Potential Estimate

2.5.1 Overview

The first section provides an overview of ways that energy may be saved throughout the entire hot water system. Four components are characterized to arrive at the total projected energy efficiency potential of hot water systems. The first was to examine retro-commissioning opportunities in existing facilities. The second and third components included the characterization of mature and emerging technologies. The fourth component involved looking

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1 The temperature rise figures in this report do not take into account booster heaters for use in high-temperature dishwashers, which typically raise the temperature of water from the water heater from 60°C (140°F) to 82°C (180°F).
forward several years to identify research, development and demonstration (RD&D) opportunities and quantify the energy efficiency potential based on the existing gas load.

2.5.2 Energy Saving Potential from Retro-commissioning

Through site survey experience in commercial facilities, the FSTC has discovered that many water heating systems would benefit from simple operating efficiency measures implemented on existing equipment. A description of the retro-commissioning measures was summarized, and the energy saving potential of each individual measure was estimated. Thus, the energy saving potential in each segment was evaluated to estimate the total for the sector.

2.5.3 Energy Efficiency Potential of Mature Technologies

This section highlights mature products on the market that are ready to make an impact in new or existing facilities in the short term. A description of each measure was summarized, and the energy efficiency potential was estimated.

2.5.4 Energy Efficiency Potential of Emerging Technologies

This section highlights emerging technologies on the market that have not been widely embraced by the foodservice sector and require a few years to develop to become mature products. These technologies have to be validated for performance and energy savings in the foodservice sector and require an education and incentive program to demonstrate performance and financial benefits to gain a foothold in the sector. A description of each measure was summarized, and the energy efficiency potential was estimated.

2.5.5 Energy Efficiency Potential of RD&D Opportunities

This section examines longer term solutions that require investment in research and development in new energy efficient technologies. These technologies, once proven will require demonstration projects and incentives for a more rapid deployment of the products in the marketplace in order to deliver the next tier of energy efficient solutions for hot water systems. The energy efficiency potential results from these RD&D opportunities are summarized in this section. The full report, “Future RD&D Opportunities for Gas-Fired Hot Water Systems”, is provided as a downloadable attachment.

2.5.6 Total Energy Savings

By tabulating the savings from the four previous sections, the total natural gas savings potential in the foodservice sector was estimated.

Methods to reduce hot water use, while not a deliverable of this report, are by far the best approach to achieve energy savings with hot water systems inside foodservice facilities. Additionally, a reduction in hot water use saves energy upstream of the facility in procuring, treating and delivering portable water and downstream with wastewater treatment. The FSTC acknowledges that the hot water system energy savings from efficient end-use equipment is one aspect missing from the complete energy savings potential equation.

2.5.7 Net Zero Energy Water Heating

After saving as much energy as possible by reducing hot water use and making the gas-
fired water heating and distribution system as efficient as possible, the final step is to displace the burning of fossil fuels to approach or to achieve a net-zero-energy hot water system. This section outlines this path and provides a glimpse of what the future holds.

2.6 Educational Materials

2.6.1 Hot Water System Design Guide

The approach taken in writing the design guide was to review the fundamentals of the hot water system and describe the design process by working backward from the end-use equipment to the distribution system and finally the hot water generation components. Two restaurant design examples are provided at the end to apply the concepts introduced in the guide. The design guide is summarized in this section and has been provided as a separate downloadable attachment.

2.6.2 Workshop Presentation

The PowerPoint presentation is based on key sections of the design guide. Two seminars were conducted initially to educate the industry. The FSTC received feedback from the audience and used it to refine the presentation for use in future seminars. The most recent presentation has been provided as a separate downloadable attachment.

2.6.3 Summary of Information Dissemination

The methods by which the FSTC has had the opportunity to educate the foodservice and water heating community on hot water systems are summarized in the report and individually listed in the appendices.
3.0 Characterize Gas-Fired Water Heating Equipment and Systems

Conventional hot water systems consist of three fundamental components: a water heater with or without storage, a distribution system, and hot water using appliances and faucets. In advanced systems, a fourth component is added in advance of the heater to pre-heat the cold supply water by providing “free heating” through waste heat recovery or solar water heating.

The water heater receives supply water from the mains and heats the water to a preset temperature. Most water heaters are “storage” heaters as they are built with a tank to store the water at the preset temperatures until the time of use. Distribution systems consist of a network of copper piping, preferably wrapped in insulation to reduce heat loss. In moderate to large systems, a recirculation loop and pump are installed to maintain hot water in the pipes ensuring rapid delivery of hot water to appliances and faucets. Point-of-use equipment includes plumbing fixtures such as faucets, pre-rinse spray valves, and dishwashers. The use of this equipment is quite variable throughout the work day but peaks typically during the lunch and dinner rush. After hours cleaning of the facility and using the mop sink for filling mop buckets or attaching a hose for hosing down the facility can be a major hot water draw.

Figure 1 is an illustration of a typical commercial hot water system in a full-service restaurant consisting of two storage water heaters with a circulation pump that circulates water through the hot water supply line to the dishwashing station, bar, bathrooms, kitchen and back through the return line to the heater.

Figure 1. Typical water heating system in a full-service restaurant.
3.1 Water Heaters

The ideal water heater for use in foodservice provides hot water the instant it is requested, never runs out, has a long operating life, is affordable to install, does not take up much space in the kitchen, and is very efficient during standby and operation. A water heater with all these features does not exist, but strides have been made by manufacturers to incorporate many of these attributes. This section characterizes each water heater type and places emphasis on the rated thermal efficiency and operating efficiency.

3.1.1 Standard Efficiency Storage Heater

The standard in the foodservice industry is an atmospheric burner, storage tank water heater. It is designed to heat and store a large amount of water and simultaneously deliver hot water to the distribution system when there is demand at the tap. The burner cycles on and off as needed to maintain the set point temperature. The majority of the standard tanks in the field hold 65 to 100 gallons of water with energy inputs typically ranging from 65,000 to 400,000 Btu/h. They are low-cost and easy to specify, repair and replace.

When the burner fires, hot exhaust gases travel up the heat exchanger, transferring heat to the surrounding water. The heat exchanger in a standard efficiency heater is relatively inefficient causing the products of combustion, namely high temperature exhaust (360°F or higher) and water vapor to be discharged through the flue and vented through metal piping to the outdoors. Generally, 20% of the input energy to the water heater during the combustion process is lost from the flue gasses to the atmosphere. Standard efficiency heaters are generally rated at 80% thermal efficiency (TE). TE is the ratio of energy output to energy input under steady-state laboratory test conditions. Many standard efficiency commercial storage heaters have an automated flue damper that reduces standby losses after the heating stage by closing off the flue. This reduces the heat loss from the water that would otherwise travel up the flue when the burner is at idle.

3.1.2 Condensing Storage Heater

A high efficiency storage heater generally will utilize a power blower with a multi-pass heat exchanger design (as opposed to the single pass system). A condensing heater differs in its ability to extract energy from the flue gases, largely by recovering latent heat of vaporization when the flue gases cool below their dew point (e.g., 135°F). Thus, a larger portion of the energy from the combustion process is available to heat water. From field monitoring work, an energy savings of approximately 15 to 25% (10 to 20% increase in operating efficiency) can be gained by making the switch from standard efficiency heaters to condensing heaters [7].

Since the final exhaust has a lower temperature, a blower is required to expel it. However, a benefit of a lower temperature exhaust is that lower-cost exhaust piping can be installed. All condensing water heaters should be located near a floor drain to allow the condensate to drain (or use a pump). The majority of condensing heaters installed in the field hold 50 to 130 gallons of water with energy inputs typically ranging from 76,000 to 300,000 Btu/h. Condensing heaters themselves are more expensive, but they may have a lower installation cost in new facilities due to the reduced flue piping cost.
3.1.3 **Standard Efficiency Tankless Heater**

A tankless water heater does not have storage tank and must heat water on demand. The burner fires once a flow sensor is triggered after the minimum hot water draw of 0.4 to 0.7 gallons per minute is requested at the tap to heat the heat exchanger. Cold water begins to flow into the heat exchanger and heat is transferred into the water. There is a lag time from when hot water is requested to when it is flowing from the heater at the setpoint delivery temperature. The main advantages of tankless water heaters are their compact size and ability to provide a continuous supply of hot water at a certain maximum flow rate, which is dependent on the associated temperature rise between the incoming cold water to the outgoing hot water. The inherent energy saving feature of tankless water heaters is that they have no standby losses, but this may not be an advantage for foodservice applications, as the standby losses from the tank itself are a very small fraction of the overall water heating load [8]. Not having a storage tank, consequently limits their capacity to deliver hot water during transient periods of high water consumption. The majority of standard efficiency tankless heaters installed in restaurants have an energy input rating of 199,000 Btu/h, but commercial models range from 150,000 Btu/h to 380,000 Btu/h.

3.1.4 **Condensing Tankless Heater**

The higher efficiency of a condensing tankless unit is achieved by adding a second, condensing heat exchanger. This increases the TE from a typical standard efficiency tankless heater from 82% to 92%. Condensing units have only recently emerged in the United States market. Presently, six manufacturers offer condensing models compared to a few years back when there was a single model on the market. The majority of tankless condensing heaters installed in restaurants have an energy input rating of 199,000 Btu/h, but commercial models range from 150,000 Btu/h to 225,000 Btu/h.

3.1.5 **Hybrid Heater**

The hybrid water heater combines the water storage and circulation capability of a tank and endless hot water characteristics and the compact size of a tankless heater. The hybrid water heater is a newer technology and models and installations in foodservice facilities are limited. There is only one manufacturer that currently offers hybrid heaters. The TE of a standard efficiency models is 86%. Input rates range from 145,000 Btu/h to 236,000 but/h. To achieve a higher efficiency for a non-condensing unit, the advanced on-demand water heater incorporates a down-fired modulating infrared burner and advanced multi-pass heat exchanger [9]. On paper, the hybrid water heater shows promise in foodservice applications where space is a premium and circulation is required. It has the flexibility to excel with passive solar and heat recovery systems that function as pre-heaters by not exhibiting a reduction in TE due to the elevated inlet water temperatures. Recently, a condensing hybrid heater has been introduced by the same manufacturer, rated at a TE of 98%. A second manufacturer has introduced a condensing hybrid heater in 2010. The hybrid heater is not discussed any further in this report as the capabilities and operating efficiencies of the heater in a commercial kitchen have not yet been observed and documented through site monitoring.
3.1.6 Standard Efficiency Boiler

Conventional boilers have a TE range of 75 to 87%. Boiler efficiency depends on a number of factors including heat exchanger characteristics, fuel-air ratio, burner modulation and control systems. Modulating the gas input rate allows boilers to run for longer periods at a lower energy input to meet variable demand rather than at full input with frequent on/off cycles that increase the heat exchanger standby losses. Steam generating boilers can be found in very large facilities that utilize steam and hot water, such as large hotels, schools, hospitals, and correctional facilities.

3.1.7 Condensing Boiler

Condensing boiler efficiencies range from 90 to 98%. The most efficient boilers reach efficiencies in the high 90’s by using advanced controls to optimize the combustion process for clean and efficient combustion. The newer boilers are lighter, smaller, and stackable and have copper and stainless steel heat exchangers with a small thermal mass for quick start up and less standby losses as compared to bulky cast iron based boilers. Standard efficiency and condensing boilers are commonly found in commercial kitchens with energy inputs typically ranging from 250,000 to 2,000,000 Btu/h and paired with very large 200 to 500 gallon storage tanks.

3.1.8 Cogeneration Plants

A small number of institutions with commercial kitchens have chosen to operate natural gas powered cogeneration plants to produce electricity and useful heat. After the cogeneration system produces electricity, the recovered heat is used for space cooling or heating and to provide steam and hot water for the campus or establishment. Many types of facilities including schools, colleges and universities, nursing homes, hotels and hospitals have utilized cogeneration. A cogeneration plant at a facility is almost twice as efficient as receiving electricity from the grid through conventional generation and heat from a central boiler [10].

The importance of this is that designing new facilities or upgrading to high efficiency boilers in existing facilities may not be the best overall energy efficient or cost effective option in larger facilities. Installation of cogeneration systems is more commonplace in universities but, the tendency of these systems to be utilized to meet the needs of institutional facilities is still very low. Thus cogeneration is not additionally highlighted or accounted for in the estimation of the gas load and gas-fired boilers in this report are assumed to meet the water heating load.

Smaller systems, known as micro combined heat and power systems, including fuel-cell based systems, are emerging and potentially viable for hotels, large restaurants, cafeterias and nursing homes. These systems can be mated to large storage tanks and be designed to work 24 hours a day, continually heating water to meet the majority of the water heating load and produce electricity to reduce the baseline load and provide peak shaving during the daytime.

3.1.9 Thermal Efficiency versus Operating Efficiency

To get a better understanding of how a manufacturer’s rated efficiency relates to natural gas consumption in a facility, a comparison of thermal and operating efficiency is needed. The rated TE is a good ruler for comparing efficiencies between standard efficiency and condensing heaters. Based on the Air-Conditioning, Heating and Refrigeration Institute’s Appliance TE
ratings, condensing water heaters are 10 to 20% more efficient than non-condensing models [11].

The rated TE is not necessarily representative of the operating efficiency of a water heater as installed in a commercial kitchen. The operating efficiency is dependent on daily water use and profile. Particularly with condensing heaters, the given inlet and specified outlet water temperatures have an effect on the operating efficiency. Field testing of gas water heaters in restaurants [7] has documented operating efficiencies that are 10 to 25% lower than the rated TE of the water heater(s). Table 1 shows a comparison of the rated TE from manufacturers’ tests and operating efficiency from FSTC field monitoring.

![Table 1. Reported thermal efficiency [11] versus operating efficiency.](image)

<table>
<thead>
<tr>
<th>Water Heater Type</th>
<th>Rated Thermal Efficiency</th>
<th>Operating Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard-efficiency storage</td>
<td>78-82%</td>
<td>62-75%</td>
</tr>
<tr>
<td>Condensing storage</td>
<td>90-99%</td>
<td>80-94%</td>
</tr>
<tr>
<td>Standard-efficiency tankless</td>
<td>80-84%</td>
<td>73-78%</td>
</tr>
<tr>
<td>Condensing tankless</td>
<td>90-98%</td>
<td>75-90%</td>
</tr>
<tr>
<td>Standard-efficiency boiler</td>
<td>75-87%</td>
<td>Not tested</td>
</tr>
<tr>
<td>Condensing boiler</td>
<td>89-98%</td>
<td>Not tested</td>
</tr>
</tbody>
</table>

### 3.2 Distribution Systems

The majority of distribution systems installed are based on simple distribution (supply piping with no return loop) or continuous recirculation (supply piping with return loop and pump). Many of these systems operate inefficiently and may lack the hot water delivery performance desired in the foodservice environment. Distribution systems are a difficult component of the hot water system to retrofit due to their accessibility. This places all the weight of designing and installing an efficient distribution system on the initial build-out of the establishment.

The alternative to conventional systems is to design advanced distribution systems that offer energy savings, improved hot water delivery to hand sinks and water savings, but are unproven in this sector. Distributed generation (primary and point-of-use heating) systems are in use but are seldom found in foodservice facilities. Demand circulation systems are a second type of advanced distribution. These systems have not yet been installed in foodservice facilities, but it appears to be a promising alternative to continuous recirculation. At this time, demand circulation is only discussed as a RD&D opportunity in Appendix D, Section 1.

#### 3.2.1 Simple Distribution

Simple distribution systems in smaller facilities use a trunk, branch and twig piping configuration (Figure 2) to deliver water from the heater to the fixture requesting water. The distribution system terminates at the farthest fixture served by the trunk. The benefits of this
system are that it is very simple and reliable and is compatible with all water heaters without any modifications. The drawback is a potentially long hot water wait time, especially at first use or after periods when water cools down in the pipes.

Simple distribution systems are commonly used in low-water-use facilities where piping layouts are straightforward and compact including cafés, specialty shops and most quick-service restaurants. Not having adequate hot water at the hand-washing sinks or the dishwasher is a concern of food safety personnel. To design with a simple distribution system, the maximum length of each distribution line from the heater to the farthest fixture cannot exceed 60 feet. This regulation is in place to improve hot water wait times, but it is commonly ineffective. Hot water can take minutes to arrive at a heavily aerated faucet and users typically do not have time to wait for it, and rather will use the room-temperature water that immediately flows from the tap. If the farthest fixture is located more than 60 feet from the water heater, California food safety regulations require that a recirculation pump be installed on the distribution line [12].

Figure 2. Trunk, branch and twig distribution system configuration.

One strategy to not exceed the 60 feet guideline is to design with two or more distribution lines. Typically, one line provides hot water at 60°C (140°F) to the sanitation sinks and dishwasher, while a second line provides tempered (mix of hot and cold water, typically 100°F - 120°F) water to handwashing sinks to prevent scalding (Figure 3).
3.2.2 Continuous Recirculation

Continuously circulating hot water through the main distribution line and back to the heater ensures that there is hot water in the trunk line at all times, in essence moving the water heater closer to points of use. However, depending on the branch and twig pipe size (i.e., volume of water in the pipes between the trunk line and point of use) and fixture flow rates, this configuration does not always ensure immediate delivery of hot water to the faucet. This is particularly the case when low-flow faucet aerators have been specified. But regardless of how well the strategy works, water is being circulated at 60°C (140°F) (or more), continuously losing heat to the surroundings. The hotter the water is in the lines, and the poorer the insulation, the greater the heat loss and energy consumed by the water heater. A review of piping configurations from blueprints has shown that the length of hot water distribution systems in full-service restaurants can range from 100 to 800 feet of piping, necessitating the need for a recirculation system.

As the length of the recirculation system extends with the size of the facility, heat losses from the hot water supply and return piping further drive down the operating efficiency. In full-service restaurants, continuous recirculation can reduce the operating efficiency by up to 10 percentage points. In larger facilities such as supermarkets that use about half the hot water of full-service restaurants and have distribution systems that are three to four times the size, the operating efficiency can drop by 20 to 40 percentage points since a significant portion of the energy is dissipated from the pipes. The primary energy user in a hot water system of a supermarket may no longer be the dishwasher, sink or hose, but rather the distribution system.
3.2.3 Distributed generation

Distributed generation can be defined as generating and distributing hot water from at least two distinct locations within a facility. There are three main types of distributed generation systems. The first type is a 100% distributed generation system that is useful for small quick-service restaurants (i.e. sandwich shops) or smaller facilities with low water use and only a handful of hot water using fixtures. This system omits the traditional central water heater system design and uses only point-of-use electric heaters installed next to fixtures. Testing of a conventional system with a centralized storage heater and simple distribution system by a sandwich-type restaurant chain has showed that it used more energy and took on average 40 seconds to deliver hot water to the faucets wasting water and energy [13]. Due to their low water use, it was more cost-effective for the restaurant chain to incorporate point-of-use electric heaters in new installations or in replacement situations where local codes allow it.

The second type utilizes two or more primary heaters placed in strategic locations in the facility with independent distribution systems. Stepping down from one big recirculation system to several smaller simple distribution systems is useful for larger facilities like supermarkets to reduce pipe heat loss.

The third type relies on a hybrid hot water system which is a combination of simple distribution and distributed generation (Figure 4). The simple distribution system delivers water to all sanitation equipment and kitchen sinks, which are aligned in a cluster. Point-of-use on-demand or mini-tank electric water heaters are placed strategically at the farthest hand washing sinks and plumbed to the cold water line directly. This eliminates the need for hot water lines to remote locations in the restaurant entirely. This configuration improves hot water wait times at hand sinks without significantly impacting the installation or operating costs.
3.3 Free Heating Systems

To further reduce the energy load, the hot water system can include “free heating” technologies. Free heating technologies utilize renewable or waste heat to preheat water and thereby minimize the use of purchased energy. The most promising of these technologies for commercial kitchens include dishwasher heat recovery, refrigerant heat recovery, and solar thermal systems. Refrigerant heat recovery and solar thermal systems can raise the inlet water temperature mildly or significantly to reduce the primary water heater energy input requirements. Dishwasher heat recovery could reduce the hot water needs to the dishwasher from the hot water system up to 90% with existing models on the market, or completely with certain advanced models available overseas that connect to the cold water line only.

Heat recovery and solar thermal water heating may be viable in the design and build of new facilities and major retrofits of existing facilities. Retrofitting free heating technologies in existing facilities is difficult as kitchen space, equipment location and building configurations are limiting factors. Having roof space with access to the sun is a critical factor with solar thermal systems. Refrigerant heat recovery is best suited for new facilities as additional water and refrigerant lines are easily integrated in the build out of the facility and the water heater and compressor/condenser units can be placed in proximity of each other to reduce line losses. Research and development of free heating systems applied to foodservice applications is in its infancy. Several free heating systems are characterized in appendix D, Section 1 to provide background on new and existing technologies that are utilized in the calculation of the energy efficiency potential.
4.0 Water Heating Equipment Inventory

4.1 Foodservice Sector Characterization

The foodservice sector in California was broken down into 5 commercial and 11 institutional facility types. There are an estimated 96,860 commercial kitchens operating within these 16 segments.

Commercial facilities have been defined as retail foodservice facilities exclusively serving the public at standalone locations with individual water heating systems per facility. The commercial foodservice segment comprises of 76,750 establishments (Figure 5). The restaurants are classified under the quick-service or full-service category. The remainder of the facilities fall under the deli and sandwich, bar and tavern, or coffee and specialty segments. Coffee and specialty shops include chocolate, bagel, donut, tea, ice-cream, frozen yogurt, gelato and other specialty shops. Full-service restaurants account for 45% of the facilities.

Institutional facilities, for the most part, provide foodservice secondarily to their primary service in providing housing, health care, education, entertainment, recreation, detention and/or employment. Institutional facilities, displayed in Figure 6, account for an estimated 21% (20,110) of commercial kitchens. They typically have central water heating systems that are utilized for multiple uses. Commercial kitchens can be found in almost every type of commercial building. The 1,740 facilities in the miscellaneous category comprises independent catering operations, very small hospitals, county jails, small detention facilities, recreational facilities, golf courses and country clubs.

Figure 5. Commercial foodservice facility count.
There are several smaller foodservice categories, which have not been sufficiently accounted for and include foodservice facilities in malls, airports, sport arenas and on/offsite commissary production kitchens. The facilities in California’s major airports account for 230 foodservice facilities and are all operated by one company, HMS Host, with a small fraction appearing in the ReCount database. Less than half of the food court vendors and restaurants in malls are accounted for in the ReCount databases as well. Overall, the uncharacterized facilities mentioned do not have a significant effect on the aggregate water heating load estimates and subsequently have been omitted.

### 4.2 Proportion of Natural Gas Water Heaters

To move one step closer to the equipment inventory and gas load estimate, the proportion of gas-fired heaters and boilers in foodservice facilities is projected in Figure 7. The primary water heating source in California is natural gas, used by an estimated 88% of foodservice facilities. As the establishment gets larger, the trend to using natural gas is evident because, in most of California, it is the least expensive way to heat water.
Natural gas is the dominant fuel used to heat water followed distantly by electricity (natural gas used partially in generation), propane (separated from natural gas during production), combined heat and power (byproduct of natural gas consumption), refrigerant heat recovery (byproduct of electricity used in refrigeration) and solar thermal.

The larger institutional facilities tend to use natural gas exclusively. In rural areas, using propane or electricity might be the only two options available, in which case propane is often used. In the smaller facilities where daily hot water use is comparable to residential use, electric water heaters are found in greater numbers due to several factors. Electric water heaters can be installed in small spaces (e.g., above ceiling tiles) where they do not reduce work space in kitchens. They have a low installed cost and are sometimes the only choice in all-electric strip-malls where natural gas is not available. Some small to medium sized full-service restaurants, cafés, and supermarkets have been found with electric water heaters as well.

### 4.3 Gas-Fired Equipment Inventory Summary

The majority of water heaters installed (new construction and replacement) in foodservice facilities in California are standard-efficiency storage heaters with a maximum 80% TE rating. In large institutional facilities, central steam and water generating boilers with separate storage tanks are commonplace. Tankless heaters represent less than 5% of the market and most of the installed heaters are non-condensing units. Tankless units are gaining popularity in quick-service restaurants and other low-water-use facilities where kitchen space is at a premium.
To inventory the number of gas-fired water heaters in California, each foodservice segment was characterized for the market share for each type of gas-fired heater and the number of units installed in an average sized facility. The estimated market share of storage, tankless and boiler heaters in each segment is shown in Figure 8 and displayed in a table in Appendix A, Section 1. Boilers dominate the market share in large institutional facilities while storage heaters are commonplace in the other segments.

![Figure 8. Estimated installed base of storage, tankless and boiler water heaters.](image-url)
The inventory of water heaters in each segment was established (Figure 9) by multiplying the number of facilities (with gas heaters) by the market share and the estimated number of units of each water heater type servicing the kitchen. In full-service restaurants for example, 30,960 gas-fired water heating systems were estimated. The installed base observed was 90% storage, 5% tankless, and 5% boilers. In an average sized full-service restaurant, two storage, one boiler or four tankless heaters are typically installed. Therefore, the inventory of gas-fired heaters in full-service restaurants was estimated at 55,728 storage heaters, 6,192 tankless heaters and 1,548 boilers (Appendix A, Section 2). The estimated inventory of water heaters for the entire foodservice sector in California has 102,730 storage heaters, 11,900 tankless heaters and 9,000 boilers.
4.4 Segment Characterization of Water Heating Equipment

Drawing mainly from site survey experience, the prominent water heater type, typical storage capacity, gas-input rate and type of distribution system for each foodservice segment is displayed in Table 2. When foodservice was not the primary function of the facility, typical equipment lineups were based on the sizing of the hot water system to serve the kitchen and dining areas including associated lavatories.

Table 2. Segment characterization of water heating equipment.

<table>
<thead>
<tr>
<th>Foodservice Segments</th>
<th>Water Heater</th>
<th>Storage Capacity (gal)</th>
<th>Total Rated Input Rate (Btu/h)</th>
<th>Distribution System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deli + Sandwich</td>
<td>Storage Heater</td>
<td>75</td>
<td>75,000</td>
<td>Simple Distribution Line</td>
</tr>
<tr>
<td>Bar + Tavern</td>
<td>Storage Heater</td>
<td>75</td>
<td>75,000</td>
<td>Simple Distribution Line</td>
</tr>
<tr>
<td>Coffee + Specialty</td>
<td>Storage Heater</td>
<td>50</td>
<td>60,000</td>
<td>Simple Distribution Line</td>
</tr>
<tr>
<td>Quick Service</td>
<td>Storage Heater</td>
<td>100</td>
<td>150,000</td>
<td>2 Simple Distribution Lines</td>
</tr>
<tr>
<td>Full Service</td>
<td>2 Storage Heaters</td>
<td>150</td>
<td>400,000</td>
<td>Recirculation System</td>
</tr>
<tr>
<td>Independent + Assisted Living</td>
<td>Storage Heater</td>
<td>100</td>
<td>200,000</td>
<td>Recirculation System</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2 Storage Heaters</td>
<td>200</td>
<td>200,000</td>
<td>Recirculation System</td>
</tr>
<tr>
<td>Nursing Home</td>
<td>2 Storage Heaters</td>
<td>200</td>
<td>400,000</td>
<td>Large Recirculation System</td>
</tr>
<tr>
<td>Military Base</td>
<td>Storage Heater</td>
<td>100</td>
<td>200,000</td>
<td>2 Simple Distribution Lines</td>
</tr>
<tr>
<td>K-12 School</td>
<td>2 Storage Heaters</td>
<td>200</td>
<td>200,000</td>
<td>Large Recirculation System</td>
</tr>
<tr>
<td>Supermarket</td>
<td>2 Storage Heaters</td>
<td>200</td>
<td>400,000</td>
<td>Large Recirculation System</td>
</tr>
<tr>
<td>Work Cafeteria</td>
<td>2 Storage Heaters</td>
<td>200</td>
<td>400,000</td>
<td>Large Recirculation System</td>
</tr>
<tr>
<td>Hotel and Casino</td>
<td>Boiler</td>
<td>300</td>
<td>600,000</td>
<td>Large Recirculation System</td>
</tr>
<tr>
<td>Hospital</td>
<td>Boiler</td>
<td>300</td>
<td>600,000</td>
<td>Large Recirculation System</td>
</tr>
<tr>
<td>College + University</td>
<td>Boiler</td>
<td>400</td>
<td>800,000</td>
<td>Large Recirculation System</td>
</tr>
<tr>
<td>Correctional Facility</td>
<td>Boiler</td>
<td>500</td>
<td>1,000,000</td>
<td>Large Recirculation System</td>
</tr>
</tbody>
</table>
5.0 Field-Monitoring

5.1 Test Plan

The field-monitoring test plan in Appendix B lists equipment and procedures used to monitor various hot water systems in foodservice facilities.

5.2 Results

Under the PIER/ET collaboration, ten field-monitoring projects were carried out by the FSTC. The project results for daily hot water use, hot water operating efficiency, and the type of water heater and distribution system are listed in Table 3. Prior to the projects conducted under this collaborative, a study in a work cafeteria had been completed and is also listed [14]. These results form the basis for calculating the energy load. Several site monitoring projects listed on this table have been published independently (shown with an asterisk) and are publicly available [7] [8] [15].

Table 3. Field monitoring projects.

<table>
<thead>
<tr>
<th></th>
<th>Hot Water Use (gal/d)</th>
<th>Operating Efficiency</th>
<th>Heater Type and Rated Thermal Efficiency</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Café</td>
<td>150</td>
<td>62%</td>
<td>80% Gas storage</td>
<td>Simple distribution</td>
</tr>
<tr>
<td>Quick Service 1</td>
<td>550</td>
<td>71%</td>
<td>80% Gas storage</td>
<td>Simple distribution</td>
</tr>
<tr>
<td>Quick Service 2*</td>
<td>500</td>
<td>90% 78% 85%</td>
<td>95% Cond. storage 82% Gas tankless 92% Cond. tankless</td>
<td>Simple distribution</td>
</tr>
<tr>
<td>Quick Service 3</td>
<td>700</td>
<td>No Data</td>
<td>80% Gas storage</td>
<td>Recirculation system</td>
</tr>
<tr>
<td>Quick Service 4</td>
<td>1200</td>
<td>69%</td>
<td>80% Gas storage</td>
<td>Recirculation system</td>
</tr>
<tr>
<td>Full Service 1*</td>
<td>2100</td>
<td>68%</td>
<td>80% Gas storage</td>
<td>Recirculation system</td>
</tr>
<tr>
<td>Full Service 2*</td>
<td>2300</td>
<td>73%</td>
<td>80% Gas storage</td>
<td>Recirculation system</td>
</tr>
<tr>
<td>Full Service 3*</td>
<td>2500</td>
<td>71%</td>
<td>80% Gas storage</td>
<td>Recirculation system</td>
</tr>
<tr>
<td>Full Service 4*</td>
<td>3700</td>
<td>65%</td>
<td>80% Gas storage</td>
<td>Recirculation system</td>
</tr>
<tr>
<td>Supermarket</td>
<td>1050</td>
<td>43%2 20%3</td>
<td>95% Cond. boiler</td>
<td>Large recirculation system + refrigerant heat recovery</td>
</tr>
</tbody>
</table>

Site Monitoring Project Before PIER/ET Collaborative

| Work Cafeteria*      | 1800                  | 48%                  | 80% Gas storage                          | Large recirculation system   |

2 Measured operating efficiency with refrigerant heat recovery.

3 Estimated operating efficiency without heat recovery.
Looking at this data, patterns emerged that laid the foundation for the hot water system characterization. In smaller facilities with standard efficiency storage water heaters and simple distribution systems, the efficiency of the water heater is dependent on the hot water use. As the facility uses more water, the efficiency increases (e.g. 62% in a café and 71% in a quick-service restaurant), since the heat loss from the water heater accounts for a smaller fraction of the daily gas use. Analyzing another simple distribution system, this time in Quick Service 2, the operating efficiency increases when changing the water heater to a standard efficiency tankless (78%), then to a condensing tankless (85%) and finally to a condensing storage heater (90%).

Going from simple distribution to a recirculation system drives the operating efficiency lower (even though daily water use increases). This is because continuous recirculation systems add an additional component of heat loss (from the hot water pipes) to the system. In full-service restaurants, the same pattern is seen; hot water use increases, but operating efficiency decreases because the length of the recirculation system increases with the size of the facility. In the monitored supermarket, the water use was relatively low compared to the size of the recirculation system and even though a high-efficiency boiler was in place, the operating efficiency was much lower at 45%. This same pattern was seen in the work cafeteria as well.

From analysis of the data, the three main determining factors of operating efficiency are daily hot water use, the operating efficiency of the water heater and heat loss from the distribution system.
6.0 Sector Gas Load Estimate

6.1 Daily Hot Water Use

Site monitoring in quick-and full-service restaurants to measure the hot water use was very important as these restaurant types collectively represent over half of the foodservice facilities in California. In Figures 10 and 11, four full-and four quick-service restaurants were monitored. Daily hot water use averaged 2650 and 738 gallons respectively. In both cases, to develop the hot water use estimate, it is acknowledged that the national chain restaurants monitored may not be representative of the independent restaurant that experiences potentially less foot traffic. Thus the full-service water-use value was lowered to 2000 gallons per day and the quick-service was lowered to 500 gallons per day to be conservative in projecting the annual gas use.

Figure 10. Daily hot water use in full-service restaurants.

Figure 11. Daily hot water use in quick-service restaurants.
The site monitoring results in restaurants, coffee shops, a supermarket and a work cafeteria have been effective in estimating the average daily hot water use in the respective segments. For the military foodservice segment [16] [17], hot water use is based on the ratio of quick-and full-service restaurants located on the base and also taking the mess halls into consideration.

Hospitals, independent and assisted living facilities and nursing homes are segments where hot water use in the kitchen was estimated based on the average number of beds per facility. The estimation in large correctional facilities is based on the average number of inmates and staff in state and federal facilities in California. Estimating daily hot water use in these four segments relies on ASHRAE estimates of hot water demand in foodservice establishments [18], stated at 2.4 gal/average meals/day. For example, in Table 4 the average nursing home in California has 100 beds [19], at three meals, daily; the average California nursing home would use 700 gallons per day. Similarly in hospitals with an average of 210 beds [20], the hot water use is estimated at 1,500 gallons per day.

For the independent and assisted living segment, only larger facilities with at least 10 beds are considered [3], which accounts for 2,040 of the 13,370 facilities in California. Facilities with fewer than 10 beds were considered to be akin to a residential home. With the large correctional facilities, the assumption was made that commercial kitchens were less hot water intensive than medical or elderly care facilities and equivalent to serving 2 meals daily instead of three. In an average large correctional facility with 4,000 inmates and 600 staff [21] [22] [23], at two meals per day, the hot water use is estimated at 22,000 gallons per day.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Average Number of Beds</th>
<th>Nominal Hot Water Use (gal/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent + Assisted Living</td>
<td>60</td>
<td>450</td>
</tr>
<tr>
<td>Nursing Home</td>
<td>100</td>
<td>700</td>
</tr>
<tr>
<td>Hospital</td>
<td>210</td>
<td>1,500</td>
</tr>
<tr>
<td>Large Correctional Facility</td>
<td>4,000 + 600 staff</td>
<td>22,000</td>
</tr>
</tbody>
</table>

Table 4. Daily hot water use based on ASHRAE estimates.

Hot water use varies dramatically across the foodservice sector and is dependent on the menu, reusable or one-time use eating and drinking utensils, number of patrons per day, the number and types of hot water use fixtures and equipment installed and staff operating practices in the facility (Figure 12).
Average hot water use in the commercial sector ranges from 100 to 2,000 gallons per day and is overshadowed by commercial kitchens in the four largest institutional facilities (3,000-22,000 gallons), including hotel and casino kitchens, hospitals, colleges and universities and large correctional facilities. At first glance, judging by water use per facility, one might deduce that institutional facilities are a major gas user for water heating in commercial kitchens on an aggregate basis. In fact, these four institutional facility types collectively only represent 10% of the water heating gas load in foodservice.

### 6.2 Operating Days per Year

The annual operating days of the average facility in each segment was estimated in order to calculate the annual hot water use of facilities (Appendix C, Section 1). All commercial facilities were standardized at 363 days of operation. Institutions like hospitals, senior living facilities, military bases, hospitality, and grocers are open every day. Major variation is exhibited with grade school cafeterias, which operate for 180 days per year [24]. Likewise, higher education dining facilities are open during the school year with five weeks off for fall, winter, and spring breaks. Half of the dining facilities are estimated to remain open through the summer break (11 weeks) for a total of 290 days of operation [25]. Work cafeterias typically operate for a total of 250 days per year (open five days a week and are closed for 10 holidays).
6.3 Annual Hot Water Use

The annual hot water use is calculated by multiplying average daily use by days in operation (Figure 13). It closely reflects the daily hot water use for most of the facilities except for the schools and work cafeterias as their days of operation are limited.

![Figure 13. Annual hot water use.](Image)

### Correctional Facility: 8,030,000

### College + University: 2,320,000

### Hospital: 1,095,000

### Hotel and Casino: 1,095,000

### Work Cafeteria: 500,000

### Supermarket: 435,600

### K-12 School: 180,000

### Military Base: 365,000

### Nursing Home: 255,000

### Miscellaneous: 182,500

### Indep + Assist Living: 164,250

### Full Service: 726,000

### Quick Service: 181,500

### Coffee + Specialty: 54,450

### Bar + Tavern: 72,600

### Deli + Sandwich: 36,300

6.4 Temperature Rise

The temperature rise is defined as the water heater outlet temperature minus the cold water supply or inlet temperature. Annually, the supply water temperature is warmer in San Diego, averaging 24°C (76°F). In Los Angeles, the temperature cools a bit to 23°C (73°F), and gets colder in San Francisco at 20°C (68°F) [26]. More recent data from a 2007 report estimates the average annual supply water temperature in California at 19°C (66°F) [6]. Therefore, a nominal average supply water temperature for the state of 18°C (65°F) was used as a baseline for estimating the average temperature rise for each facility type in this report.

To estimate the outlet temperature, many plumbing layouts in the building blue prints were studied and combined with the FSTC site survey experience. Each category was characterized by their hot water needs and end-use equipment to estimate the water heater outlet temperature and then calculate the temperature rise (Appendix C, Section 1).

A deli and sandwich shop without a dishwasher only needs to deliver 49°C (120°F) water to kitchen equipment and sinks. In full-service facilities with dishwashers, the water temperature that is typically required is 60°C (140°F). A common practice is to raise the thermostat...
temperature higher on the water heater for better dishwashing performance, to account for distribution line water temperature losses, or for a presumed increase in hot water capacity. It is not surprising to find the hot water thermostat set in the 71°C (160°F) range in full-service restaurants. For the calculation of outlet temperature, a thermostat set point increase of 3°C (5°F) from the typical delivery temperature at the tap is used for all facilities. For example, in a full-service restaurant, with a water heater outlet temperature of 63°C (145°F) (approximate delivery temperature of 140°F) minus inlet temperature of 18°C (65°F) yields a temperature rise of 44°C (80°F).

6.5 Operating Efficiency

The “real world” operating efficiency of a gas fired hot water system is defined as energy transferred to the water divided by the energy consumed by the water heater. The energy to water is calculated by multiplying the water flow rate, temperature rise between the inlet and outlet of the water heater and specific heat and density of water. The operating efficiency accounts for the heat loss from the tank, but not the heat loss from the piping in a simple distribution system. In a system with recirculation, the operating efficiency accounts for the heat loss in the supply and return distribution pipes since the water that is returning back to the tank must be reheated. Measuring the operating efficiency in this way is valuable as it corresponds to actual gas consumption.

The operating efficiency for each foodservice category is defined as the average daily operating efficiency over a one year period. The average operating efficiency calculation for each category includes a combination of a high percentage of facilities with standard efficiency systems and a small percentage of high efficiency systems with condensing heaters (Appendix C, Section 2).

Condensing storage heaters are found in quick-and full-service establishments, but represent only 5% of the water heater installations in restaurants by FSTC estimates.

Quick-service restaurants are highlighted as an example of how the average operating efficiency was estimated using the data from the site-monitoring studies. It is estimated that 95% of the restaurants use standard efficiency heaters at an estimated operating efficiency of 70%. Therefore, only 5% of the restaurants use condensing heaters at an estimated operating efficiency of 90%. The two estimates yield an average operating efficiency of 71%, which is consistent with the field-monitoring results.

The operating efficiency is lower in full-service restaurants as the heat loss from the distribution system is factored in. The full-service restaurant segment estimate of 65% efficiency is lower than the average of 69% in our monitored facilities to account for facilities that receive less foot traffic and older buildings that were not monitored. In these facilities, the daily heat loss would account for a larger percentage of gas used. In characterizing miscellaneous and independent living facilities, the operating efficiencies are lower due to the low water use and extended periods of standby.

In the institutional facilities, operating efficiencies are lower, estimated in the 60% range as many heating systems incorporate older boilers and extensive distribution and circulation systems that reduce the operating efficiencies. It is important to note that deriving operating efficiency estimates, especially for the institutional facilities, is difficult without site
monitoring. Thus, cursory estimates of operating efficiency are utilized. It is conceivable that a large portion of boiler based systems exhibit operating efficiencies below 50%.

### 6.6. Sample Calculation for Annual Gas Use

The calculation of annual gas use for water heating for the largest segment, full-service restaurants, is presented to demonstrate the methodology and operating assumptions that were made to calculate the total foodservice sector gas water heating load in California.

**Full-Service Restaurants**

1. 2007 ReCount data (database of restaurants listed by address) → 34,400 facilities
2. 90% of facilities use gas-fired water heaters → 30,960 gas–fired systems
3. Average daily hot water use → 2000 gallons per day
4. Average of 363 days of operation per year → 726,000 gallons per year
5. Average temperature rise (145°F Outlet - 65°F Inlet) → 27°C (80°F)
6. Average operating efficiency (site-monitoring) → 65%
7. Daily water heating gas load
8. Annual facility gas use
9. Annual segment gas load

### 6.7 Facility Gas Use and Sector Gas Load

The above calculation was performed for all 16 segments defined in this study and the results are summarized in a spreadsheet in Table 5. The total sector gas load for water heating in foodservice facilities was estimated at 341 million therms.

**Table 5. Foodservice sector water heating gas-load summary.**

<table>
<thead>
<tr>
<th>Foodservice Category</th>
<th>Facilities With Gas Heating</th>
<th>Daily Hot Water Use (gal)</th>
<th>Annual Use (gal)</th>
<th>Temperature Rise</th>
<th>Nominal Operating Efficiency</th>
<th>Facility Gas Use (therms/y)</th>
<th>Segment Gas Use (million therms/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deli + Sandwich</td>
<td>4,125</td>
<td>100</td>
<td>36,300</td>
<td>33°C (60°F)</td>
<td>60%</td>
<td>300</td>
<td>1</td>
</tr>
<tr>
<td>Bar + Tavern</td>
<td>2,513</td>
<td>200</td>
<td>72,600</td>
<td>33°C (60°F)</td>
<td>60%</td>
<td>600</td>
<td>2</td>
</tr>
<tr>
<td>Coffee + Specialty</td>
<td>9,440</td>
<td>150</td>
<td>54,450</td>
<td>36°C (65°F)</td>
<td>60%</td>
<td>490</td>
<td>5</td>
</tr>
<tr>
<td>Quick Service</td>
<td>19,530</td>
<td>500</td>
<td>181,500</td>
<td>39°C (70°F)</td>
<td>70%</td>
<td>1,510</td>
<td>29</td>
</tr>
<tr>
<td>Full Service</td>
<td>30,960</td>
<td>2,000</td>
<td>726,000</td>
<td>44°C (80°F)</td>
<td>65%</td>
<td>7,440</td>
<td>230</td>
</tr>
<tr>
<td>Independent + Assisted Living</td>
<td>1,836</td>
<td>450</td>
<td>164,250</td>
<td>33°C (60°F)</td>
<td>60%</td>
<td>1,370</td>
<td>3</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1,653</td>
<td>500</td>
<td>182,500</td>
<td>33°C (60°F)</td>
<td>60%</td>
<td>1,520</td>
<td>3</td>
</tr>
</tbody>
</table>
Figure 14 graphically represents the sector load and the imbalance in gas consumption in the sector. Quick- and full-service restaurants combined use 259 million therms of gas annually and account for three-quarters of the gas load for water heating. Consequently, the focus of this project has been on saving energy in quick-and full-service restaurants.
This report along with the foodservice appliance report (appliance load estimate of 480 million therms) highlights the significant gas load of foodservice facilities in California, estimated at 820 million therms annually. The total gas load estimate could easily approach 1 billion therms if space heating in foodservice facilities was included.

### 6.8 Previous Estimates of Natural Gas Usage in Restaurants

A previous report for the California Energy Commission titled, “California Commercial End-Use Survey” by ITRON in March 2006 estimated annual natural gas usage for water heating in restaurants at 72.4 million therms and in all commercial building types at 406.7 million therms [27]. The gas use estimate in this report for quick-and full-service restaurants is 3.5 times larger than the ITRON study at 259 million therms annually. Additionally, the estimate of gas load at 341 million therms rivals the total gas load for the entire commercial sector in the ITRON study.
7.0 The Energy Efficiency Potential

After determining the aggregate gas load, the next task was to quantify the energy efficiency potential of hot water systems in the foodservice sector. The aim was to deliver a road map of opportunities to save energy with gas-fired systems and stimulate market transformation. The movement towards net-zero-energy water heating systems will be explored briefly.

To derive the energy efficiency potential for the sector, full-service restaurants were isolated from the other 15 segments to investigate and quantify the potential independently. The savings were then extrapolated across the entire sector. This approach leveraged FSTC experience in this key segment, which by itself, represents two-thirds of the water heating load (Figure 15).

The discussion of energy efficient system components begins with identification of mature products that could be implemented immediately. However, these products may require marketing and promotion to gain a sufficient market share. First is a discussion of retro-commissioning projects that are applicable to existing facilities. Second is a discussion of mature “on the shelf” technologies that are poised to have a major impact in reducing the gas load. Third, demonstration projects are required to push-start emerging and financially viable technologies that can reach maturity in the market in several years. Finally, the future RD&D opportunities will be characterized that will bring together the desired system-wide innovations to foster the development of the next generation of efficient hot water systems.

Additional characterization of several technologies in Appendix D, Section 1 provide background on new, less established or less common components of the hot water system. These include: advanced distribution systems, refrigerant heat recovery, and solar water heating.

7.1 Overview

Beginning upstream at the cold water supply pipe, solar preheating and refrigerant heat recovery systems could be used to raise the temperature of the incoming supply water by 6 to
28°C (10 to 50°F) depending on the size and type of system. This in turn reduces the load on the primary heater accordingly.

At the water heater itself, the operating efficiency could be increased by 15 to 20% by opting for a high-efficiency condensing model. Basic analog controls on standard efficiency heaters may lead to elevated temperature setpoints and erratic outlet temperatures. Adding advanced thermostat controls and remote monitoring available on some condensing heaters would allow for an estimated thermostat setpoint reduction of 3°C (5°F), translating to a 6% reduction in energy use.

Moving downstream to the distribution system, fully insulating the lines from the outlet pipe of the heater to the point-of-use would return a 2% operating efficiency increase. If the recirculation system is operating 24 hours daily, adding a recirculation pump timer to turn off the pump when the restaurant is closed would yield another 2% increase in operating efficiency. However, a better strategy might be to eliminate the recirculation system and replace it with an optimized distribution system. This is estimated to return a 5% operating efficiency increase. Recovering heat from refrigeration or sanitation systems is a great strategy. The high-temperature dishwasher is a source of waste energy for preheating the supply water. Dishwasher heat recovery systems could raise the temperature of cold supply water to the dishwasher by 22 to 33°C (40 to 60°F).

The total energy saving potential by implementing an assortment of measures described above is not necessarily accumulative. Some measures are incompatible with each other, e.g. flue damper and condensing heater, while other measures if jointly implemented, e.g. solar preheating, heat recovery and condensing heater, experience a mild decrease in their accumulative efficiency potential. The estimated gas savings from each energy efficiency measure implemented in a typical full-service restaurant that consumes 7440 therms annually is displayed in Figure 16. 4

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4 Condensing heaters (6) and refrigerant heat recovery systems (21) and their corresponding efficiency potential percentages have been identified independently through lab and field monitoring. Pipe insulation, pump timer, and flue dampers have been tested accumulatively through field monitoring, but these measures would benefit from more individualized testing to adjust estimates. Dishwasher heat recovery, solar preheating, and optimized distribution have not been tested in restaurants sufficiently and require additional monitoring to refine estimates.
7.2 Energy Saving Potential through Retro-commissioning

Many hot water systems would benefit from simple efficiency measures applied to existing equipment. Through site survey experience in commercial facilities, the FSTC confirmed that many hot water systems are candidates for system improvements. These retro-commissioning measures are described in the following subsections.

7.2.1 Pipe Insulation

Adding pipe insulation to all accessible portions of hot water piping is one of the simplest retrofit measures. Many facilities have long runs of supply and return piping that is not insulated.

7.2.2 Automatic Flue Damper

Flue dampers are placed on top of the flue on some standard efficiency storage water heaters, especially on larger commercial units, to minimize the convective heat loss through the heat exchanger. Flue dampers have been added to improve the standby rating of commercial water heaters. The FSTC site-survey experience and feedback from the plumbing trade has indicated that automatic flue dampers are sometimes disabled during installation to minimize service calls. Historically, some of the models on the market initially where known to fail. If the damper fails in the closed position, the heater will not fire. The owner is left with the choice to replace the damper, force the mechanism open, or bypass the automatic function. If the damper fails in the open position, the condition will usually go unnoticed. To commission the automated flue damper, set it on auto (open only in heating mode) instead of the open position.

7.2.3 Recirculation Pump Timer

The task of the circulation pump is to maintain hot water in the pipes near all required draw points such as hand sinks and dishwashers. As the hot water circulates continuously
to maintain elevated temperatures, it loses heat more rapidly through the piping to its surroundings. Stopping the flow with a circulation pump timer (time controls) during unoccupied periods will reduce daily heat loss.

7.2.4 Aquastat

Circulation loop aquastats sense hot water return line temperatures and switch the pump off once the return water temperature reaches the upper set point temperature of the aquastat (temperature controls). Once the return temperature falls below the lower setpoint due to pipe heat loss, the recirculation pump is powered on.

7.2.5 Summary of Retro-Commissioning Measures

Table 6 provides a list of retro-commissioning measures along with their applicability in facilities and their energy savings potential based on site monitoring experience [15]. To improve operating efficiency, retro-commissioning practices bundled together could yield up to 10% savings [8]. But in reality, the average savings will be less because all of the measures may not be applicable or feasible for existing hot water systems.

Table 6. Retro-commissioning measures and energy savings potential.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Applicability</th>
<th>Energy Savings Potential</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Insulation</td>
<td>Partially applicable, easy to add insulation to exposed piping leading from the tank, but may be impractical to add insulation to pipes behind walls.</td>
<td>1% or less in most retrofit cases, as most of the piping is behind walls and not accessible to insulate.</td>
<td></td>
</tr>
<tr>
<td>Automatic Flue Damper</td>
<td>Only applicable to standard efficiency water heaters designed for operation with a factory installed damper.</td>
<td>Up to 2%, typically 0.5% in facilities with long operating hours.</td>
<td></td>
</tr>
<tr>
<td>Recirculation Pump Timer</td>
<td>Applicable to all systems that have continuous recirculation pump (provided foodservice is not a 24/7 operation).</td>
<td>Up to 8%, 1.5% in facilities with longer operating hours.</td>
<td>Reduces stratification in the tank thus increasing hot water capacity.</td>
</tr>
<tr>
<td>Aquastat</td>
<td>Applicable to facilities that undergo engineering review and establishments that calibrate the thermostat after installation to reap the energy savings.</td>
<td>Up to 2%, typically 0% if the thermostat is not adjusted down to the original set point leading to increased outlet temperatures from the tank.</td>
<td>Increases stratification in the tank, reducing hot water capacity, 2% efficiency increase may be nullified by the increased outlet temperatures, essentially having no effect on gas use.</td>
</tr>
</tbody>
</table>
7.2.6 **Energy Saving Potential of Retro-Commissioning Measures**

A more conservative savings estimate of 3% was applied to most categories to calculate the energy savings potential (Appendix D, Section 2). The annual savings potential of retro-commissioning practices in the foodservice sector if 35% of the facilities adopted the measures is estimated at 3.4 million therms.

7.3 **Energy Efficiency Potential of Mature “Off-the-Shelf” Technologies**

Short-term projects include products or technologies that already are being manufactured and have penetrated the U.S. market. They also have been demonstrated in foodservice facilities to perform and save energy. The final step is to market and incentivize the products to achieve market transformation and sustained energy savings.

7.3.1 **Condensing Storage and Condensing Tankless Water Heaters**

The heat exchanger in a standard efficiency heater is relatively inefficient causing the products of combustion, namely high temperature exhaust (360°F or higher) and water vapor to be discharged through the flue (Figure 17). Generally, 20% of the input energy to the water heater during the combustion process is lost with the flue gases. A high-efficiency condensing heater differs in its ability to extract more energy from the flue gasses, largely by recovering latent heat of vaporization when the flue gases cool below their dew point (e.g., 135°F). Thus, a larger portion of the energy from the combustion process is available for heating water, reducing exhaust flue gas temperatures to as low as 56°C (100°F). From field monitoring work, an energy savings of approximately 15 to 25% (10 to 20% increase in “real-world” operating efficiency) can be gained by making the switch to condensing heaters [7].

![Figure 17. A simplified heat exchanger design of a standard efficiency (left) and condensing storage heater (right).](image)
High-efficiency commercial storage heaters are a mature technology and proven in the foodservice environment. Although condensing models are offered by all the major manufacturers, the penetration within the California foodservice industry is limited. FSTC site survey experience suggests that market share of high efficiency heaters in California restaurants is less than 5%. This estimate is consistent with other industry estimates. It was suggested at a forum of water heater stakeholders that a 3 to 5% market share of condensing heaters in restaurants in California is an appropriate estimate. California sales of condensing storage water heaters in the wider commercial sector is approximately 20% of the market, which is far below the 50% national sales average for condensing models.

There are several hurdles to the penetration of condensing heaters in foodservice facilities. The operator is not educated on the water heater options or the cost of hot water. In an existing facility, the water heater remains transparent in the eyes of the operator until the water heater fails. In replacement situations, several factors heavily steer the operator towards the installation of standard-efficiency heaters. This includes the low purchase price and availability of atmospheric-burner heaters, the propensity that many installations are brought by a water heater failure requiring an emergency “same day” change out, and additional installation requirements of condensing heaters requiring non-corrosive venting materials and a condensate drain. The installation of condensing heaters is more prevalent in new facilities. The sale of condensing heaters may also be hindered by existing utility incentives for non-condensing 82% plus TE water heaters that are marketed as high-efficiency. This includes non-condensing tankless heaters and, more recently, standard efficiency storage heaters. The incentive may have produced the opposite effect in driving buyers away from truly efficient water heaters to purchasing incentivized standard efficiency models.

A scenario that may push condensing heaters to the forefront and increase market share in California is regional air quality. Nitrogen oxides (NOx) emission regulations in several major air quality districts in California will require commercial storage water heaters to meet tougher emission standards of 20 parts per million or 14 nanograms per joule. The air quality districts [28] highlighted in red (Figure 18) cover approximately 60% of the foodservice facilities in the state.

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5 Comments from CEC-PIER Project Advisory Committee Meeting #2 at FSTC on September 16, 2008.
6 Sales data from a major commercial water heating manufacturer, July 23, 2009.
7 Bay Area, Santa Barbara, San Joaquin Valley, South Coast, Sacramento Metropolitan and Yolo-Solano air quality districts enacted similar NOx regulations on commercial water heaters with start dates spanning from 2010 to 2014.
Figure 18. Air quality districts that have ratified stricter nitrogen oxides emission standards.

Photo Credit: California EPA

The technology to meet the tougher emission standards for large water heaters and small boilers rated above 75,000 to 2 million Btu/h is currently available on condensing heaters. Manufacturers may save on research and development (R&D) costs, increase volume sales of condensing heaters, and provide a safer and efficient product to the consumer. Manufacturers of storage heaters will hopefully use existing high-efficiency condensing technology already on the market to meet the 20 parts per million NOx requirements, rather than add upgrades to lower efficiency fan-vented or low-cost atmospheric heaters. There are two important considerations before a wholesale shift to condensing heaters in these air quality districts is foreseeable. Will a storage water heater manufacturer pursue meeting the NOx regulations with non-condensing heaters to capture market share of sales for existing facilities that prefer to keep installation costs low by not having to remove existing Type B venting materials? Tankless heater manufacturers have already reacted to the upcoming regulations. At least one manufacturer has brought to market several condensing tankless heaters that meet the 2012 NOx emissions standards set by South Coast Air Quality Management District.

By removing the sales of existing commercial atmospheric storage heaters from the marketplace in several major California air quality districts by 2010-2013, the door is open for market adoption of condensing heaters.

8 Based on an interview with a major condensing storage water heater manufacturer, July 2009.
A state-wide energy efficiency mandate in the same timeframe for the installation of condensing heaters in new building and major retrofits in existing commercial forward message to manufacturers and ease the program rollout across the state and institutional facilities would dovetail with the air-quality regulations. With the aid of the air-quality regulations, the energy efficiency potential of condensing heaters in ten years is significant. If condensing models obtain 80% of the installed base in full-service restaurants the energy efficiency potential is estimated at 34 million therms annually statewide (Table 7). However, condensing water heaters need aggressive marketing, education programs and incentives to jump start market adoption across the state before the air-quality mandate in certain districts comes online.

### Table 7. Gas savings from condensing heaters in full-service restaurants.

<table>
<thead>
<tr>
<th></th>
<th>Standard Efficiency</th>
<th>Condensing</th>
<th>Energy Efficiency Potential (million therms/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water use (gal/d)</td>
<td>2000</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Temperature rise</td>
<td>44°C (80°F)</td>
<td>44°C (80°F)</td>
<td></td>
</tr>
<tr>
<td>Operating efficiency</td>
<td>0.65</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>Gas use (therms/y)</td>
<td>7440</td>
<td>6050</td>
<td></td>
</tr>
<tr>
<td>Gas savings (therms/y)</td>
<td>-</td>
<td>1390</td>
<td></td>
</tr>
<tr>
<td>Existing installed base</td>
<td>95%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Future installed base</td>
<td>20%</td>
<td>80%</td>
<td><strong>34.1</strong></td>
</tr>
</tbody>
</table>

#### 7.3.2 Refrigerant Heat Recovery Systems

Refrigerant heat recovery systems (RHRS) or desuperheaters are a mature technology in the supermarket and dairy industry but have not been embraced by the foodservice sector. The technology preheats cold water leading to the water heater saving energy and reduces refrigeration operating costs by exchanging heat from the hot refrigerant to the cold water. By reducing the heat in the vapor refrigerant leading from the compressor, the condenser fan works less to remove the necessary heat from the refrigerant improving condenser capacity and potentially prolonging compressor life. The best application of refrigerant heat recovery in restaurants is mating it with remote condensing units associated with walk-in coolers, walk-in freezers and ice makers as they operate continuously throughout the year (Figure 19).
This technology, which never took hold in the foodservice industry in the last two decades, needs another push-start. The FSTC first reported on this technology in 1993 in a field monitoring report [14] and calculated a simple payback period of four years. Using existing energy rates, the higher energy costs associated with water heating and refrigeration have cut the payback period of this technology in half. This 1993 report showed that the installation of a RHRS reduced the water heating load by four therms per day and the electricity consumption of the refrigeration system by five kWh per day.

Based on the measured savings in the report in a work cafeteria that has a water heating load comparable to a full-service restaurant, the annual energy saving potential of this technology implemented in 15% of the estimated 32,680 facilities is 7.3 million therms of gas savings from water heating and 8.9 million kWh of electricity savings from the refrigeration systems (Table 8). The penetration rate of this technology will be low as retrofitting RHRS in existing facilities is difficult and only viable in a small number of applications.

**Table 8. Energy efficiency potential of refrigerant heat recovery systems in full-service restaurants.**

<table>
<thead>
<tr>
<th></th>
<th>Conventional System</th>
<th>Refrigerant Heat Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water use (gal/d)</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Temp rise required</td>
<td>44°C (80°F)</td>
<td>36°C (64°F)</td>
</tr>
<tr>
<td>Preheat temperature rise</td>
<td>-</td>
<td>9°C (16°F)</td>
</tr>
<tr>
<td>Operating efficiency</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>Water heater gas use (therms/y)</td>
<td>7440</td>
<td>5950</td>
</tr>
<tr>
<td>Facility gas savings (therms/y)</td>
<td>-</td>
<td>1490</td>
</tr>
<tr>
<td><strong>Energy efficiency potential (million therms/y)</strong></td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td><strong>Energy efficiency potential (million kWh/y)</strong></td>
<td>8.9</td>
<td></td>
</tr>
</tbody>
</table>
7.4 Energy Efficiency Potential of Emerging Technologies

Emerging technologies are defined as technologies or products that have not significantly penetrated the commercial foodservice market in the U.S. They may be existing products or technologies that have been applied to the residential or non-foodservice sector in the past. These technologies have to be validated for performance and energy savings in the foodservice sector. Demonstrating these technologies in real-world restaurants is essential, followed up with educating the sector on the applicability, energy savings, return on investment and performance benefits.

7.4.1 Exhaust-Air Heat Recovery Dishwashers

Commercial dishwashers have evolved tremendously over the last five years, offering lower water and energy usage. This is best exemplified by high-temperature dishwashers that have incorporated exhaust-air heat recovery (EAHR) units. The EAHR unit can be very effective at condensing the rising steam from the dishwasher and transferring the heat to the incoming cold water instead of venting the waste heat to the outdoors. A sketch of a flight dishwasher in Figure 20 illustrates the flow of water through an EAHR unit. Cold inlet water at 16°C (60°F) is preheated to 43°C (110°F) under steady operation by the EAHR unit and sent to the booster heater to heat the water to at least 82°C (180°F) for the sanitizing rinse. The heat recovery unit in this example displaces up to 60% of the energy delivered by the hot water system to the dishwasher.

![Figure 20. Temperature of water as it flows through a flight-type conveyor with exhaust air heat recovery.](Photo Credit: Champion)
It is important to recognize the other features that are built-in on efficient dishwashers to deliver energy savings. In conveyor machines, to reduce the amount of hot water used per rack, an auxiliary rinse preheats the crockery and functions as the primary rinse, followed by a sanitizing rinse that achieves sanitization with limited fresh water use. This two step rinse maximizes the use of fresh water through the conveyor while maintaining rinse and sanitation performance. An electronic controller saves resources as it only activates the wash and final rinse when a rack is in place. Double-wall insulated construction complements the heat recovery system by retaining heat inside the machine and helps maintain water temperatures. A highly effective filtration system that enables more wash cycles saves resources as less dumping and refilling of the wash tank is required.

Energy Savings

Calculating the potential energy efficiency potential of EAHR dishwashers installed in the full-service restaurant segment involves the modeling of conventional and advanced conveyor and door-type dishwashers (Appendix D, Section 3) that are found in the majority of facilities.

Estimate of Market Share and Energy Efficiency Potential

In the foodservice industry, low-temperature machines represent 50 to 70% of the market. In full-service restaurants, approximately 70% of the dishwashers are leased [29] and it is assumed that the current market share of dishwashers is 67% low temperature and 33% high temperature. Conveyor dishwashers have a 23% market share in 6,500 chain full-service restaurants and an 11% rate in 27,900 independent restaurants for a total market share of 13% in California [30]. If EAHR dishwashers penetrated 25% of the eligible 4,565 full-service restaurants amounting to 1600 installations, then the annual energy saving potential is 2.4 million therms of gas, but with an increase in use of 6.7 million kWh of electricity (Table 9).


<table>
<thead>
<tr>
<th></th>
<th>Exhaust Air HR</th>
<th>High Temp</th>
<th>High Temp ENERGY STAR</th>
<th>Low Temp</th>
<th>Low Temp ENERGY STAR</th>
<th>Energy Efficiency Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated flow (gal/rack)</td>
<td>0.35</td>
<td>1.13</td>
<td>0.70</td>
<td>1.23</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Existing installed base</td>
<td>0%</td>
<td>27%</td>
<td>7%</td>
<td>53%</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>Future installed base</td>
<td>25%</td>
<td>20%</td>
<td>5%</td>
<td>40%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Gas savings (million therms/y)</td>
<td>-0.1</td>
<td>0.7</td>
<td>0.1</td>
<td>1.5</td>
<td>0.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Electricity savings (million kWh/y)</td>
<td>-20.5</td>
<td>10.0</td>
<td>1.4</td>
<td>1.7</td>
<td>0.7</td>
<td>-6.7</td>
</tr>
</tbody>
</table>

Door-type dishwashers are the most common type installed in restaurants. The market share of single and double door-type dishwashers in 34,400 full-service restaurants is 77%, equating to 26,490 door-type dishwashers in operation [29]. If EAHR dishwashers penetrated 25% of the
eligible restaurants amounting to 9,270 installations, then the annual energy efficiency potential is 10.2 million therms, but with an increase in use of 42.8 million kWh of electricity (Table 10).

Table 10. Energy efficiency potential of exhaust-air heat-recovery door-type dishwashers.

<table>
<thead>
<tr>
<th></th>
<th>Exhaust Air HR</th>
<th>High Temp</th>
<th>High Temp ENERGY STAR</th>
<th>Low Temp</th>
<th>Low Temp ENERGY STAR</th>
<th>Energy Efficiency Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated flow (gal/rack)</td>
<td>0.73</td>
<td>1.44</td>
<td>0.95</td>
<td>1.85</td>
<td>1.10</td>
<td></td>
</tr>
<tr>
<td>Existing installed base</td>
<td>0%</td>
<td>27%</td>
<td>7%</td>
<td>53%</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>Future installed base</td>
<td>25%</td>
<td>20%</td>
<td>5%</td>
<td>40%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Gas savings (million therms/y)</td>
<td>-0.3</td>
<td>2.6</td>
<td>0.4</td>
<td>6.5</td>
<td>1.0</td>
<td>10.2</td>
</tr>
<tr>
<td>Electricity savings (million kWh/y)</td>
<td>-82.4</td>
<td>32.4</td>
<td>5.9</td>
<td>1.2</td>
<td>0.0</td>
<td>-42.8</td>
</tr>
</tbody>
</table>

With a 25% installed base, the estimated gas savings in full-service restaurants of door-type and conveyor EAHR dishwashers is 12.6 million therms per year. Although, EAHR high-temperature machines use less electricity to heat water compared to conventional and ENERGY STAR high temperature machines modeled in this example, the change out of 25% of the low temperature machines to EAHR models with electric booster heaters contributed to an additional use of 49.5 million kWh of electricity.

Market Barriers and Trends

Low-temperature dishwashers offered as a part of a service and chemical supply agreement may be a barrier to the advance of EAHR models. A large portion of the chemical supplier’s profits are pegged on the sale of cleaning chemicals, so there is a natural resistance to offer models that use less water and don’t require sanitizer. Other barriers especially in existing buildings include the first cost and the need for a ventilation system (conveyor models only) when changing from a low-temperature to a EAHR high-temperature machine. Of particular importance is undertaking a field-monitoring study that focuses on resource use and the life-cycle cost of conventional and advanced dishwashers and weighs in on performance, maintenance and other outliers that might influence the operator’s purchasing and operating decisions.

This trend of integrating EAHR technologies by manufacturers has accelerated in the last two years, similar to the introduction of hybrids to the automotive industry. This technology has the potential to transform the commercial dishwasher market. Available models in the U.S. that offer this technology as an optional add-on or integrated into the dishwasher include: Meiko [single-tank, multi-tank and flight conveyor], Champion [flight], and Hobart [flight, door type].
7.4.2 Solar Preheat Systems

Applying solar-thermal technology for water preheating may be one of the most cost-effective solar applications after pool heating. Solar-preheat systems are defined as either integrated-collector-storage (ICS) or thermosiphon systems (Figure 21) consisting of the collector and water storage both installed on or nearby the roof and directly piped to the existing water heater. These systems are reliable since they supply preheated water without any pumps, controls, thermostats, sensors, wiring or electricity. A recent study by Sandia National Laboratory found that ICS and thermosiphon systems had a much lower failure rate over a 10-year period than active systems that have mechanical components, namely valves that have been credited to cause most of the failures [31]. They are typically less expensive to purchase, install and maintain and are suitable for retrofit in existing facilities due to their minimal kitchen footprint. The potential of freezing and bursting of piping has limited the market penetration to areas that experience very mild periods of freezing temperatures.

![Figure 21. Polymer-based ICS system (left) and thermosiphon system (right).](image)

Photo Credit: Harpiris Energy, AMECO Solar

Adding freeze protection to these systems may increase the market penetration; current solutions still require further testing to deliver a proven solution to the market [32] [33]. A California manufacturer of solar preheat systems has developed a low-cost polymer-based ICS panel utilizing PEX piping. Freeze protection in this ICS system can handle 18 straight hours at a temperature of -10°C (14°F). It includes a freeze protection warranty, available for install locations in California below 1000 feet of elevation. The manufacturer claims that the combination of plastic panels and PEX piping are superior in freeze tolerance to other solar-preheat systems [34].

Thermosiphon systems have higher efficiency collectors, well insulated storage tanks, and are more expensive than ICS systems. They have the capability to function as the primary heater in small foodservice facilities. Some systems are more prone to freezing as the solar collectors do not have the thermal mass as in the integrated ICS systems and are therefore only applicable to zero-freeze parts of California. In freeze prone areas, the collectors can be filled with an antifreeze solution that transfers the heat to the water with an indirect storage tank.
Testing is needed to measure the performance and energy saving potential of solar-preheat systems with standard and condensing heaters in foodservice applications. Heating with active solar systems like drainback or glycol systems should be considered (background to the various systems applicable to commercial kitchens is provided in Appendix D, Section 1). In full-service restaurants, the energy saving potential of solar preheat systems in elevating the daily supply water temperature by an average of 11°C (20°F) with an projected installed base of 20% is estimated to save 12.2 million therms (Table 11).

Table 11. Energy efficiency potential of solar water heating systems with a 20% market share in full-service restaurants.

<table>
<thead>
<tr>
<th></th>
<th>Conventional System</th>
<th>Solar Water Heating</th>
<th>Energy Efficiency Potential (million therms/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water use (gal/d)</td>
<td>2000</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Temp rise required</td>
<td>44°C (80°F)</td>
<td>33°C (60°F)</td>
<td></td>
</tr>
<tr>
<td>Preheat temperature rise</td>
<td>-</td>
<td>11°C (20°F)</td>
<td></td>
</tr>
<tr>
<td>Operating efficiency</td>
<td>0.65</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>Water heater gas use (therms/y)</td>
<td>7440</td>
<td>5580</td>
<td></td>
</tr>
<tr>
<td>Facility gas savings (therms/y)</td>
<td>-</td>
<td>1860</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Historically, the return-on-investment on solar thermal systems has been unappealing to restaurateurs. The existing federal incentives and accelerated depreciation coupled with the new California incentives can reduce the installed cost by upwards of 60%, making the financial investment much more rewarding. In fact, the California Public Utilities Commission forecasts that the lodging, health and restaurant sectors have the greatest potential for solar water heating market growth [35].

### 7.5 Energy Efficiency Potential of RD&D Opportunities

The results of a supporting document titled *Future RD&D Opportunities for Gas-Fired Hot Water Systems* are summarized in this section. This document is available as a separate report and is referenced in Appendix D, Section 4.

Three RD&D opportunities are discussed in the report. These technologies will work in unison, require a systems approach, and require innovations to the water heater, distribution system designs and end-use components. The most promising product is the smart condensing heater. It is an intriguing concept that reduces gas use by functioning as the hot water system control and monitoring center by incorporating optimized distribution system controls to extract additional efficiencies. Optimized distribution systems will be incorporated that are less expensive to install, reduce heat loss from piping and improve delivery performance. Next-generation heat recovery dishwashers that are already on the market overseas have wide applicability and the ability to work only off the cold water line. This will transform the design of future hot water systems to operate with less dependency on recirculation systems. In total, the energy efficiency potential of these three measures will save close to 15 million therms in full-service restaurants.


7.6 Total Energy Savings

Collectively, the energy efficiency potential of all gas-saving opportunities has the potential to save 81 million therms per year in full-service restaurants. This incorporates savings from mature products, emerging technologies and RD&D projects, which are displayed in Figure 22. Mature products that are readily available in the market and can be quickly implemented include high-efficiency condensing heaters and RHRS. A marketing and promotion program that increases the installed base of mature products may save an estimated 41 million therms annually. In the medium term, emerging technologies that utilize dishwasher heat recovery or solar energy to preheat the water collectively account for an annual energy saving potential of 25 million therms. In the long term, RD&D measures, specifically smart condensing water heaters, optimized distribution systems and next generation dishwashers with dual heat recovery will save an additional 15 million therms annually.

As a secondary benefit to the addition of refrigerant heat recovery systems and optimized distribution systems, the energy efficiency measures can save approximately 24 million kWh of electricity annually (Figure 23). This savings is offset by the EAHR dishwashers that use an additional 47 million kWh per year because they rely more on electric booster heating. Overall, there is an annual electricity loss of approximately 22 million kWh (energy equivalent of 1% of gas savings). Thus, the overall impact of gas saving measures on electricity use is negligible.
Figure 23. Resulting annual electricity savings from energy efficient opportunities.

Full-service restaurants represent two-thirds of the water heating load in the commercial foodservice sector and the energy saving potential at 81 million therms represents a 35% load reduction. The energy efficient technologies mentioned for the formidable segment are very applicable to other segments including supermarkets, coffee shops and quick-service restaurants that consume an additional 60 million therms for water heating. The energy saving technologies reviewed in this report may overstate the potential in smaller facilities such as coffee shops and quick-service restaurants, since these facilities rarely use dishwashers or recirculation systems. Similarly, the savings potential may be understated in the larger institutional facilities where refrigerant and dishwasher heat recovery play a bigger role and dishwashers are heavily used. Hence, the savings in full-service restaurants are projected to be reflective of the entire foodservice sector. Overlaying the 35% gas load reduction across the sector, the total annual energy efficiency potential is estimated at 120 million therms (Figure 24).

Figure 24. Annual gas load and energy efficiency potential in the foodservice sector.
Consequently, the total natural gas savings potential in the foodservice sector through the successful implementation of retro-commissioning, mature technologies, emerging technologies and RD&D projects has been estimated at 123 million therms. If the opportunities are realized, a gas load reduction of 36% amounts to savings in the California foodservice sector of approximately $120 million annually on their energy bill. In summary, the most promising opportunities to save energy and improve the operating efficiency of hot water systems include:

- Transforming the commercial water heater market from a majority share of standard efficiency units to condensing and future smart condensing heaters,
- Shifting away from continuous recirculation systems to reduce pipe heat loss and improve hot water wait times by using optimized distribution systems strategies,
- Decentralizing water heating in kitchens by utilizing high-temperature dishwashers with integrated heat recovery systems and point-of-use heaters at hand washing sinks, and
- Utilizing waste heat with refrigerant heat recovery systems and solar energy with solar thermal and photovoltaic/thermal systems.

### 7.7 Net Zero Energy Water Heating

The restaurant sector is five times as energy intensive per square foot than most other commercial sectors. The economic feasibility of new restaurants achieving net zero energy (NZE) by 2030 [36] is in question due to their inherent energy intensity. Nonetheless, strides can be taken to approach this and a first step on this course is to achieve NZE water heating, which is viable with existing technology. The design path for net zero energy water heating begins with reducing the hot water load by reducing hot water consumption by upwards of 50% from conventional restaurants. In full-service restaurants, installing emerging technologies like dishwashers with integrated heat recovery is a solid step. Optimized distribution systems can increase operating efficiency by approximately 5%, leaving less than half of the initial hot water load to be heated by active solar and refrigerant heat recovery systems with adequate storage tanks for reserve capacity.

In many facilities, there is plenty of heat being wasted off the cooking line that should be redirected to a flue-gas heat exchanger. In certain types of facilities, (i.e. a burger chain with a conveyor broiler or Asian inspired restaurant with wok stoves) recovering heat through flue gas heat recovery has the potential to meet all the water heating needs.

To operate a NZE water heating system, solar photovoltaic (PV) panels are necessary to displace the electricity used in the hot water system (water pumps, system controller, dishwasher booster and wash tank heaters) and additional generation to cover the cloudy days when electric backup heating is needed.
8.0 Educational Materials and Outreach

Developing education materials was a primary objective of this PIER study. Tasks included developing a web downloadable design guide, creating a hot water system presentation, and sponsoring workshops in California to educate the foodservice and water heating community. The FSTC’s outreach on high performance hot water systems has been a success with half a dozen workshops completed in the past year within California. The outreach has continued to grow and is now reaching a national audience.

8.1 Design Guide

A design guide (Figure 25) is provided in a separate document (Appendix E, Section 1). The hot water system design guide for commercial kitchens provides key information to restaurant designers and engineers to achieve superior performance and energy efficiency with their systems. This guide reviews the fundamentals of commercial water heating and describes the design process, including (1) reducing hot water use of equipment while maintaining performance; (2) increasing the operating efficiency of water heaters and distribution systems; (3) improving hot water delivery performance; and (4) incorporating “free-heating” technologies, such as waste heat recovery and solar pre-heating.

![Design Guide](Image)

Figure 25. Front page of design guide (left) and industry workshop presentation (right).

8.2 Hot Water System Seminar

Two industry workshops were initially conducted on “Energy Efficient Water Heating and Distribution for Commercial Foodservice” in March 2009 (Cover page displayed in Figure 25). Both workshops were three hours in duration and targeted end users, foodservice consultants,
kitchen designers, utility account representatives, and plumbing professionals. Since the initial workshops, more workshops were conducted in 2009 and 2010 in California. A copy of the most recent PowerPoint presentation from a workshop in March 2010 titled, “Designing Hot Water Systems for Restaurants” is available and referenced in Appendix E, Section 2.

8.3 Summary of Information Dissemination

In the past few years outreach opportunities have included writing conference papers, being published in periodicals, presenting at industry conferences, and hosting industry seminars and advisory committee meetings. The FSTC has had the opportunity to broaden its influence on a national level presenting PIER research at conferences or workshops hosted by the American Council for an Energy-Efficient Economy, the National Restaurant Association, and the Consortium for Energy Efficiency. In the coming year, the FSTC will continue to present at conferences and put on seminars in California and use new avenues to educate the industry on the national level via short online videos, participating on the United States Green Business Council’s Leadership in Energy and Environmental Design for Retail committee on Existing Buildings Operations and Maintenance and participating on several ASHRAE technical committees on water heating and chairing the Handbook subcommittee on the Service Water Heating Chapter in the Heating, Ventilation, and Air Conditioning Applications Handbook. The list of outreach events and leadership positions can be viewed in Appendix E, Section 3.
9.0 Conclusions and Recommendations

9.1 Conclusions

The application of a low-first cost water heater rated at the minimum TE paired with a poorly performing distribution system remains standard practice in foodservice facility designs. The design of hot water systems has largely been overshadowed and has not evolved significantly as compared to other building systems like lighting and heating, ventilation, and air conditioning. Site surveys have shown that penetration of energy-efficient products are under 10%, despite a decent product base in the last couple decades including condensing heaters and refrigerant heat recovery systems.

Out of the 16 commercial and institutional segments identified, the target segment is full-service restaurants as they are responsible for one-third of the facilities and two-thirds of the gas load in the foodservice sector. Consequently, the focus of this project has been principally on saving energy in restaurants and other segments that share similar system configurations. Field-monitoring of facilities has shown a wide range in operating efficiency and hot water use between facilities. Hot water use is the biggest determining factor on gas use followed by the operating efficiency. The main determining factors on operating efficiency are the water heater thermal efficiency and the type and size of the distribution system.

The potential to reduce gas use in commercial kitchens is immense. With mature technologies that we have on the shelf today and emerging technologies that are reaching the marketplace, it is possible to reduce the hot water load by approximately 30%. The foodservice sector can be a leader in the broader commercial and institutional sector to foster innovation with hot water systems by demonstrating significant energy savings and a favorable return on investment.

Advancing the design of hot water systems that are efficient and meet the expectations of users and operators involves advocacy with the foodservice sector and supporting trades (i.e., engineers, designers, plumbing professionals, and electricians). Public speaking has been one way to engage these groups as well as the publication of the hot water system design guide. Continued research, advocacy and incentives for the first movers are needed to continue market transformation to high-performance systems.

9.2 Recommendations

General hot water use monitoring for total daily hot water use and operating efficiency in the larger segments not previously monitored is recommended to refine the estimations in this report. Gathering information on the length and type of distribution systems and developing representative daily hot water use profiles for the foodservice section of institutional facilities and for the whole facility would be beneficial. Site monitoring of boiler based hot water systems in restaurants and especially larger multi-use facilities is essential to get a balanced picture of
operating efficiency.

Since restaurants represent the majority of the hot water load in the foodservice sector, in-depth characterization of hot water systems in restaurants is needed. Monitoring projects are needed to gain information on the system efficiency and hot water delivery performance. By additionally measuring outlet temperature and hot water use at each point of use, this data would provide the best comparison of system efficiency between hot water systems regardless of the type of distribution system or water heater installed. In depth monitoring would be able to present the operating efficiency of the water heater and distribution system separately and provide data on hot water use at each outlet.

The RD&D focus needs to be on restaurants, coffee shops, supermarkets, work cafeterias and nursing homes that collectively represent over 80% of the sector load. Targeting these segments specifically, which incorporate similar hot water system components and designs, allows for the streamlining of RD&D efforts. It is recommended to identify the most promising energy efficiency measures and clarify the efficiency potential estimates individually and in combination with other measures through laboratory testing. Quantifying how each measure’s energy savings correlates with various hot water system designs and daily water use profiles is needed to fully characterize their energy saving contribution to develop incentive programs. Further monitoring is recommended to measure hot water wait times at hand-washing sinks in existing and high-performance systems. High-performance systems in foodservice facilities need to deliver hot water to the tap in 10 seconds and incorporate advanced technologies seamlessly while being economically viable. This monitoring study would be a three-year study and require an estimated funding level of $500,000 to $1,000,000.

Using demonstration projects in influential segments to disseminate information learned from R&D projects clearly to the food-service sector is a critical step for market adoption. A two to four year study (estimated funding level of $500,00 to $1 million) to demonstrate net-zero-energy hot water systems in critical segments including quick-service restaurants, full-service restaurants and supermarkets is suggested to set benchmarks for the foodservice sector. Systems that are economically and operationally feasible will hopefully move the market and spur competition between progressive restaurants to: reap first-mover advantage in green marketing, reduce water heating costs, and take advantage of existing financial incentives for solar water heating.

Another recommendation is to use the knowledge gained from RD&D projects to develop new simulation tools and software for kitchen designers and engineers to design efficient and high performing hot water systems and perform accurate installed and life-cycle costing for their clients. The development of tools and software is estimated to take one to two years and cost $100,000 to $400,000.

9.3 Benefits to California

This PIER project has already yielded benefits to California by quantifying the gas load of water heating in foodservice and educating the industry on opportunities to save energy through seminars, conferences and advisory committee meetings. By comparing the water heating gas
use in foodservice to the total in the commercial sector, it has helped place the hot water system on the radar of energy efficiency professionals. Based on the interim recommendations of this project, the Energy Commission has already developed requests for proposal to start on the next round of PIER projects. The results gained from this project has influenced ACEEE, CEE, and ENERGY STAR efforts to create new efficiency standards for commercial water heaters, differentiate higher efficiency condensing models and position more resources on reducing energy use in commercial foodservice facilities. By quantifying the energy efficiency potential of condensing water heaters, California foodservice facilities will benefit from significant incentives on the purchase of a high-efficiency heaters (beginning in PG&E territory and potentially expanding to other utilities). Achieving gas savings at the water heater is only one way to save energy and this report broadens the emphasis by highlighting the energy efficiency potential of free heat systems and distribution systems. One of the viewpoints conveyed was an attempt to help industry professionals gravitate from a discussion of simply improving the thermal efficiency of the water heater, towards taking a systems approach to reduce energy use by optimizing the entire system.

The results of this project are intended to assist policy makers to pursue all available avenues with a diverse set of policy instruments for achieving higher performing commercial hot water systems. The educational materials, namely the design guide and seminars delivered across the state will educate the industry on pitfalls of designing conventional hot water systems and provide them with solutions for designing advanced systems that incorporate high-efficiency heaters, optimized distribution systems and lower water use appliances. Californians could benefit in the long term with improved system performance and reduced hot water use that would lower operating costs and conserve energy. The goal is to have higher efficiency systems be the norm in designing new establishments and net zero-energy hot water systems a reachable and economically viable option. Harvesting solar energy to heat water and using waste heat from the kitchen could be the catalyst for designers to set more aggressive targets in developing net-zero-energy foodservice establishments.

One ancillary benefit of improving distribution system efficiencies and improving hot water delivery performance simultaneously is that it would reduce the potential for food borne illnesses in foodservice establishments. The majority of food-borne illnesses in commercial foodservice can be traced back to improper hand washing for which timely delivery of hot water can play a big role. County and state food safety officials could be a strong partner to optimize distribution systems while advancing their goals to minimize food borne illnesses.
REFERENCES


Conference, Seminar 21.


GLOSSARY

ACEEE American Council for an Energy-Efficient Economy
ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc
Btu/h British thermal unit per hour
CEE Consortium for Energy Efficiency
FSTC PG&E Foodservice Technology Center
HR heat recovery
ICS integrated collector storage
kWh kilowatt-hour
PG&E Pacific Gas & Electric Company
PIER Public Interest Energy Research
PV solar photovoltaic
NOx nitrogen oxides
NZE net zero energy
R&D research and development
RD&D research, development and demonstration
RHRS refrigerant heat recovery system
TE thermal efficiency
therm 100,000 Btu/h
WH water heating


# Section 1. Facility Count and Market Share

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Appendix B. Characterize Gas-Fired Water Heating Equipment and Systems

Site-Monitoring Instrumentation and Procedures

The instrumentation package used for field testing included a diaphragm type positive displacement gas meter with a 1 pulse/ft³ output, a multi-jet turbine water meter with a 1 pulse/gal output (20 pulse/gal for tankless heaters) installed on the cold water supply line and thermocouple temperature probes located at the water inlet and outlet piping. In a tested boiler system with refrigerant heat recovery and separate heat reclaim tank, reclaim tank outlet temperature was also measured. A data acquisition system, operating with a 5-second scan interval and a 5-minute recording interval (1-minute recording for tankless heaters), logged the average temperature measurements and cumulative water and gas consumption from the meter pulse outputs.

Measurement points:
- Water inlet temperature
- Water outlet temperature
- Hot water return temperature
- Reclaim tank temperature (in boiler system with refrigerant heat recovery)
- Water flow
- Gas flow

Instrumentation:
- Thermocouples probes were affixed to the outer copper pipe walls and the interface treated with heat-sink compound, wrapped with tape and covered with foam pipe insulation
- Gas meter: Diaphragm type positive displacement gas meter with a 1 pulse/ft³ output
- Water Meter: Multi-jet turbine water meter with a 1 pulse/gal output (20 pulse/gal used for tankless heaters)
- Data Logger: Configured to record thermocouple and flow meter inputs at 5-minute intervals (1-minute for tankless heaters)

Calculations:

Operating efficiency for this test protocol is defined as the heat energy transferred to the water passing through the heater (or system) divided by the gas energy consumed by the water heater.
Specifically, it is defined as the amount of energy required to heat a volume of water by a measured temperature rise (the temperature difference between the hot outlet and the cold supply inlet) divided by the gas energy consumption of the water heater. Standby losses of the heater and the entire heating and circulation system (when recirculation loop is used) are also taken into account. Operating efficiency was calculated using the following formula.

Where:

\[ \text{Mass}_{\text{water}} = \text{Water Flow [gal]} \times \text{Density}_{\text{water}} \times \text{Density}_{\text{water}} \times 8.33 \text{ lb/gal} \]

\[ \text{C}_{\text{p,water}} = 1 \text{ Btu/lb} \times \text{°F} \]

To calculate operating efficiency on a day-to-day basis, the Energy into Water numerator was computed for each data interval. The individual data interval products were summed for each day and divided by the daily gas energy. A higher heating value of 1020 Btu/ft³, representative of gas supply in the area, was used for all calculations. The reported operating efficiency for each heater configuration was determined from the daily efficiency versus daily hot water use curve at the point where the curve intersected the average daily hot water use value.

Reported mass-weighted inlet and outlet temperatures (representing the bulk water temperatures in and out of the heater) were calculated by dividing the daily summed data interval Masswater * Twater products by the daily Masswater total. Projected annual gas use calculations were normalized to a 42°C (75°F) temperature rise (to account for varying inlet temperatures and/or thermostat setpoints) and to the average daily hot water use of the facility using the following formula:

Where:

\[ \text{Mass Flow}_{\text{water}} = \text{Average Hot Water Use [gall/d]} \times \text{Density}_{\text{water}} \times \text{Density}_{\text{water}} \times 8.33 \text{ lb/gal} \]

\[ \text{C}_{\text{p,water}} = 1 \text{ Btu/lb} \times \text{°F} \]

\[ \Delta T_{\text{water}} = \text{normalized temperature rise} \]

\[ \text{Operating efficiency} = \text{Efficiency curve intersected at the average hot water use value} \]
## Appendix C. Sector Gas Load

### Section 1. Hot Water Use, Days of Operation, Temperature Rise

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<th>Days Per Year</th>
<th>Water Use (gal/y)</th>
<th>Average Inlet Temp (°F)</th>
<th>Average Outlet Temp (°F)</th>
<th>Temperature Rise (°F)</th>
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**Weighted Temperature Rise (°F) Across Sector**: 77
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**Weighted Operating Efficiency Across Sector**

| Weighted Operating Efficiency Across Sector | 64% | 65% |
Appendix D. Energy Efficiency Potential

Section 1. Characterization of Technologies

Advanced Distribution Systems: Demand Controlled Pumping

Instead of circulating hot water continuously in the ceiling above a fixture, there are several ways to save energy and improve hot water wait times to kitchen hand sinks and bathroom lavatories. Demand circulation only operates the water pump just before hot water is needed. The system features an integrated pump and temperature sensor that circulating hot water down to the sink only when the water has cooled in the hot water pipes and there is a demand for hot water, shown in the following figure. The hot water wait times is greatly improved to plumbing fixtures, namely hand sinks and lavatories.

![Diagram of Demand Controlled Pumping System](image)

Photo Credit: Taco Inc.

The pump circulates the room temperature water into the cold water line or dedicated cold-water return line returning back to the heater until the temperature sensor detects a temperature rise, at which point it turns off the pump (1). This pump can be triggered to operate via an occupancy sensor placed in the hallway leading to the bathroom, and hot water may reach the lavatory faucet by the time a person approaches. The figure below is an example of how demand-circulation may be implemented in a quick-service restaurant to improve hot water wait times.
Demand-circulation pumps

*Heat Trace*

Yet, another way to improve the performance of the distribution system is to add electrical heat trace systems that use electricity to maintain the heat of the water in the delivery pipes, instead of circulation. A heating cable, shown below, runs the length of the pipe under the insulation and maintains the temperature of the hot water by passing heat through the pipe into the water, counteracting the heat loss through the pipe and insulation. The inherent disadvantage of this method is that the water is heated a second time.

Photo Credit: Tyco Thermal Controls