Boiler Related EE Measure Assessment

Project Number ET22SWG0004

GAS EMERGING TECHOLOGIES PROGRAM (GET)

Prepared by ICF for submission to Southern California Gas Company

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Acknowledgements

ICF is responsible for this project. This project, ET22SWG0004, was developed as part of the Statewide Gas Emerging Technologies Program (GET) under the auspices of SoCalGas as the Statewide Lead Program Administrator. Saurabh Shekhadar conducted this technology evaluation with overall guidance and management from Steven Long, ICF Technical Lead. For more information on this project, contact steven.long@icf.com.

Disclaimer

Abbreviations and Acronyms

Name	Abbreviations
Add-on Equipment	AOE
Air Conditioning, Heating and Refrigeration Institute	AHRI
Air Pollution Control Districts	APCD
Air Quality Management Districts	AQMD
American Boiler Manufacturer Association	ABMA
American Society of Heating, Refrigerating and Air-Conditioning Engineers	ASHRAE
Annual Fuel Utilization Efficiency	AFUE
California Air Resources Board	CARB
California Energy Data and Reporting System	CEDARS
Department of Energy	DOE
Domestic Hot Water	DHW
Emerging Technology	ET
Energy Efficiency	EE
Environmental Protection Agency	EPA
Exhaust Vent Condenser	EVC
Flash Recovery Energy Management Equipment	FREME
Flue Gas Recirculation	FGR
Gas Emerging Technology	GET
Investor-Owned Utility	IOU
Measure Package	MP
Multifamily	MF
Regional Energy Network	REN
Technical Resource Manual	TRM
Total Dissolved Solids	TDS
Transport Membrane Condenser	TMC
Variable Frequency Drive	VFD

Executive Summary

This Gas Emerging Technologies (GET) project researched energy efficiency measures related to boiler accessories in California. Rather than focusing on entire boiler retrofits, which are already a part of the IOU portfolio, this study will investigate the potential for add-on and maintenance EE measures for the boiler of the heating, hot water, or process heating part of the system.

The project was completed through a combination of customer surveys and boiler manufacturer interviews. The attributes of boiler-centric technologies were thoroughly investigated, including applications, physics behind the technology, advantages, and high-level energy savings. The scope of this project covers boiler(s) installed in residential, industrial, and commercial sectors. The following aspects were investigated:

a) Estimated number of boilers in California by sector and end usage

b) Historical IOU program participation data analysis to determine the prevalence of measures related to boilers and accessories

c) Customer surveys – methodology and data analysis

d) Evaluation of boiler-centric technologies and add-on measures that should be added to, or optimized for, program delivery

e) Identification of market barriers or gaps in measure implementation

f) Recommendations for future projects and follow-up considerations

Project Findings:

- Survey responses and conclusions: 46 customers responded to online survey
- Number of boiler manufacturers and distributors interviewed: 25
- A proposed Measure Table was developed, which consisted of:
  - Number of boiler add-on related measures identified from the literature review and U.S. DOE tip sheets: 10
  - Number of boiler add-on related measures identified from the manufacturer interviews: 11
  - Estimated efficiency increases for the identified commercially available technologies and products ranged from 1% to 8% (non-cumulative)
- Main barriers for adoption of emerging technologies/new products related to boiler add-ons: space constraint, variability in size of boilers, installation limitations, high upfront costs, and general adverse environment for implementing gas technologies

- Publicly available and standardized third-party performance data is lacking for many technologies, which also makes energy savings or cost effectiveness analysis challenging

Project Recommendations:

Based upon this study effort, the team offers the following recommendations based on the findings.

The GET Program recommends measure package development for the following identified technologies or new products:

1. Combustion air positive shutoff
2. Combustion fan VFD
3. Parallel positioning controls, O2 trimming
4. Installing turbulators in boiler tubes (for fire tube boilers)

Publicly available and standardized third-party performance data is lacking for many technologies, which also makes energy savings or cost effectiveness analysis challenging. The following technologies or products are promising and commercially available; and follow-up field or lab testing is recommended:

1. On-demand economizer
2. Transport membrane condenser technology
3. Rainmaker economizer (for hot water boilers)
4. Multi-stage economizers with side-by-side design (for hot water boilers)
5. Exhaust vent condenser
6. Energy recovery using a flash vessel
7. Flash recovery energy management equipment
8. Installing two element water level control
9. Dual returns and smart plate heat exchanger

The following measures are not viable for measure package development and not recommended for further analysis. This is due to either no or little impact on energy savings and/or negative impact on reducing NOx emissions.

1. Combustion air preheater
2. Flue gas recirculation (FGR)
3. Remote boiler controller
4. Glycol Scavenging Systems

Project Background

This study aimed to research energy efficiency (EE) measures related to boiler accessories through a combination of customer surveys and boiler manufacturer interviews. This project covers boiler(s) installed in multifamily, industrial, and commercial sectors. Numerous groups promoting EE (including DOE) have published recommendations for common measures that can be implemented for existing boilers. These measures are meant to make existing boilers more efficient. Most of these measures are not currently in the IOU prescriptive portfolios.[1]

The most relevant prior study is the 2019 California Statewide Multifamily (MF) Boiler Market Assessment, which provided recent technical potential data for multifamily boiler end uses, estimated boiler quantities and estimated boiler life. The 2021 industrial and agriculture potential study provides data for process heat – primarily food processing – and cited DOE data for importance of boilers and heat recovery.[1]

There are other related studies, but they are either outdated, do not cover the items of interest, or present information at a national level versus specifically focused on California. Beyond the Multifamily study, none of these studies has data specific to common recommended measures beyond boiler retrofits. This study identified some but not all the measures of interest. The industrial study noted previously had process related measures on their list.

Assessment Objectives

The objectives of this study were:

- Perform a literature search to identify existing data for California IOU boiler counts and installation of related measures, and potential barriers. Summarize results in a table.
- Review current program offerings and estimate uptake levels from CEDARS data.
- Draft a list of potential measures with the relative parameters (barriers, potential code impacts, cost effectiveness, estimated counts, etc.) for each measure, including sector and/or end use variances. Create a draft populated table.
- Conduct customer surveys to understand customer's input on the installed boilers and add-on measures. Collected data, from virtual and on-site surveys, would include nameplate info, installed measures, costs, installation dates, maintenance intervals, loads served, and operational characteristics.

[1] The custom measures can address any type of measure, but few were seen during the claims analysis.

- Provide comprehensive information on emerging technologies in boiler accessories including flue gas economizers, burner upgrades, condensate recovery etc.
- Provide further recommendations for evaluation of emerging technologies and follow up studies in boiler accessories segment.

Introduction

Boiler systems are used to produce steam and/or hot water which is used for several primary purposes such as multifamily and commercial space heating, multifamily and commercial domestic and service hot water uses, multifamily and commercial pool heating, commercial and industrial process loads, etc. This project will review the currently implemented energy saving measures and emerging technologies related to the use of natural gas boilers in the California IOU territory. This was done through a combination of literature review, customer surveys and boiler manufacturer interviews.

Implementing cost effective measures for enhancing boiler efficiency and reducing carbon emissions still poses a challenge to the energy efficiency industry. While the path of an entire boiler retrofit would lead to the highest efficiency gains, this involves major infrastructural changes and capital investment. This study focuses on the boiler add-on measures and not on the entire boiler retrofits. It also only focuses on these measures at the boiler and not the balance of the hot water or steam system. The boiler accessories or add-ons are auxiliary devices which are installed either inside or outside the boiler. The boiler accessories are then used to enhance the efficiency of a boiler system and help to run the system efficiently. Different types of boiler accessories are used. Some of them include, economizer, advanced technologies in burners and improvising controls etc.

Some of the proposed measures include condensing economizer, improvising burner controls and other emerging technologies in emissions and/or natural gas reduction. The target list was formulated by subsequent customer and/or vendor surveys.

Industrial boilers include the category of boilers used in industry to provide steam, hot water and/or electricity. This would encompass the boilers in manufacturing, food, paper, chemicals, and refining industries. Whereas commercial boilers are used in hotels, restaurants, stores, multi-family housing and office buildings to provide steam and/or hot water primarily used for heating and/or multifamily and commercial domestic and service hot water needs. The boilers installed in medical centers, universities, schools, and government buildings can also be categorized as institutional boilers. Agriculture boilers (and related add on measures) are not part of this study. This study consists of a literature review of the current boiler market in California and the lessons learned from energy efficiency programs in other states. Most of the previous similar studies are either outdated or not specific to California, which makes this project more relevant and unique.

The project involves a preliminary analysis of historical participation data and current program offerings. Additionally, the study involves surveys of customers to determine which boiler related measures are more prevalent and understand barriers in implementation.

This project also involves research of emerging technologies in the segment of boiler accessories through interviews of boiler manufacturers and distributors, and publicly available information. The attributes of emerging technologies and new products were thoroughly investigated, including applications, physics behind the technology, advantages, and high-level energy savings.

Table 1 shows the emerging technologies or new products in the boiler accessories that were evaluated in this study.

Table 1: Summary Table of Evaluated Emerging Technologies and New Products

Technology or Product Category	Brief Description
Boiler economizers and alternative configurations	A boiler economizer exchanges heat between boiler flue gas and the cold feedwater.
Blowdown heat recovery and alternative configurations	A blowdown heat recovery system uses the boilers' blowdown water to preheat the cold feedwater.
Energy recovery from flash steam	Energy from the flash steam for the deaerator can be recovered and used to preheat the cold boiler feedwater.
Advanced burner related technologies	The advanced burner control related technologies can be used to measure and maintain an optimum air-fuel ratio in a combustion zone.
Combination boiler plants with dual returns	In hydronic systems with different loops, returns are disaggregated for improving the performance of a condensing boiler system.
Remote boiler controller	Remote boiler monitoring system allows for the control and maintenance of multiple boilers remotely.

Literature Review

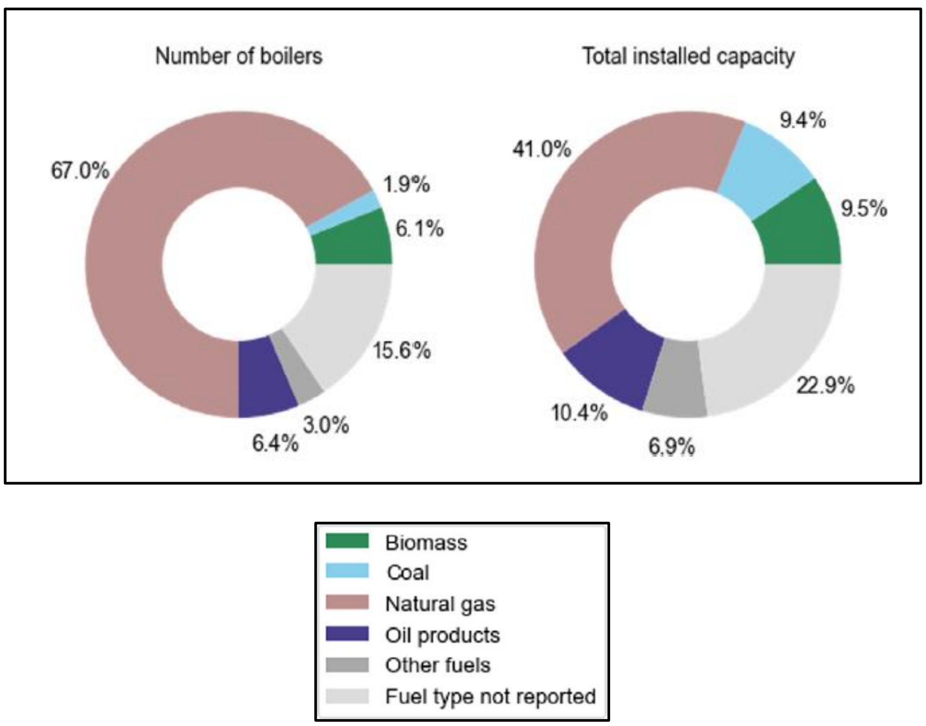
A) Boiler Market Characterization in the U.S. and California

This literature review section outlines the boiler market characterization in the U.S. and specifically California. The majority of boilers in California are in the multifamily space, followed by commercial and industrial applications as indicated in the two sections below. Additionally, these sections also discuss the lessons learned from the boiler studies conducted in other states.

1. Boiler Market Data in the U.S.

The total inventory of reported industrial boilers with complete information on location, sector, capacity, and fuel type amounts to **18,954** units. Combining the estimate of non-reported units such as low-capacity boilers which are not surveyed or monitored in the emission databases, the total number of industrial boilers is estimated to be **38,537** [1].

Figure 1: Categorization of industrial boilers in the U.S. as per sector [1]



As indicated in Figure 1, natural gas is the pre-dominant fuel type among industrial boilers in the U.S. While the number of gas boilers in the U.S. is high, they are lower-capacity boilers compared to other fuel types. The average installed capacity of natural gas fired boilers is 30 MMBtu/hr. On the other hand, the number of coal-fired boilers is low, but most of the boilers have capacities over 100 MMBtu/h [1].

Figure 2: Color map depicting the distribution of industrial boilers in the U.S. [1]

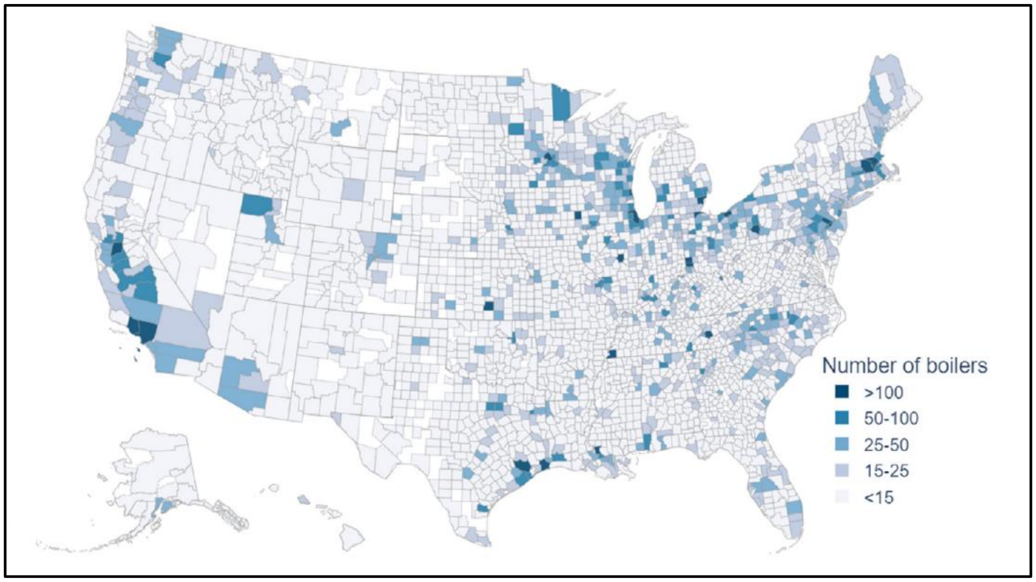


Figure 2 demonstrates the distribution of the industrial boilers in the entire nation. The color map depicts that most of the industrial boilers are concentrated in California, Mid-west, and Northeast region.

2. Boiler Inventory Data Categorization in California

This section discusses the estimation of the overall boiler inventory in California and its categorization into different sectors. Multiple sets of data were leveraged to provide updated estimates for the boilers[2].

The state is divided into numerous Air Pollution Control Districts (APCD) and Air Quality Management Districts (AQMD), which are also called air districts. The California Air Resources Board (CARB) is the lead agency for climate change programs and oversees all air pollution control efforts in California to attain and maintain health-based air quality standards. These agencies are county or regional governing bodies that have primary responsibility for controlling air pollution from stationary sources, such as boilers. The first source is the use of publicly available boiler licensing data. The commercial and industrial boiler inventory is estimated from the boiler inventory shared by 10 AQMDs in California.

The second is the Multifamily Market Assessment Study conducted by Cadmus which projected the total count of boilers in the Multifamily sector [2].

[2] The existing data sets were used without any adjustments to address either New Construction or electrification of existing boilers.

The third set of data was used to project the various sectors for the non-multifamily boilers by using nationwide industrial boiler data and extrapolating it to California as indicated below.

Industrial Boilers

The U.S. Environmental Protection Agency published a rule for mandatory reporting of GHG emissions that emit 25,000 or more metric tons of carbon dioxide equivalent per year. An estimated 85-90% of the total emissions are covered by the Greenhouse Gas Reporting Program. Figure 4 categorizes the estimated industrial boiler count according to the sector. About 116 natural gas boilers reported emissions through this program in California for the 2011-2020 cycle. Most of the boilers were used to generate steam in power plants and the chemical industries.

Figure 3: Estimated number of reported industrial boilers under EPA Program [3]

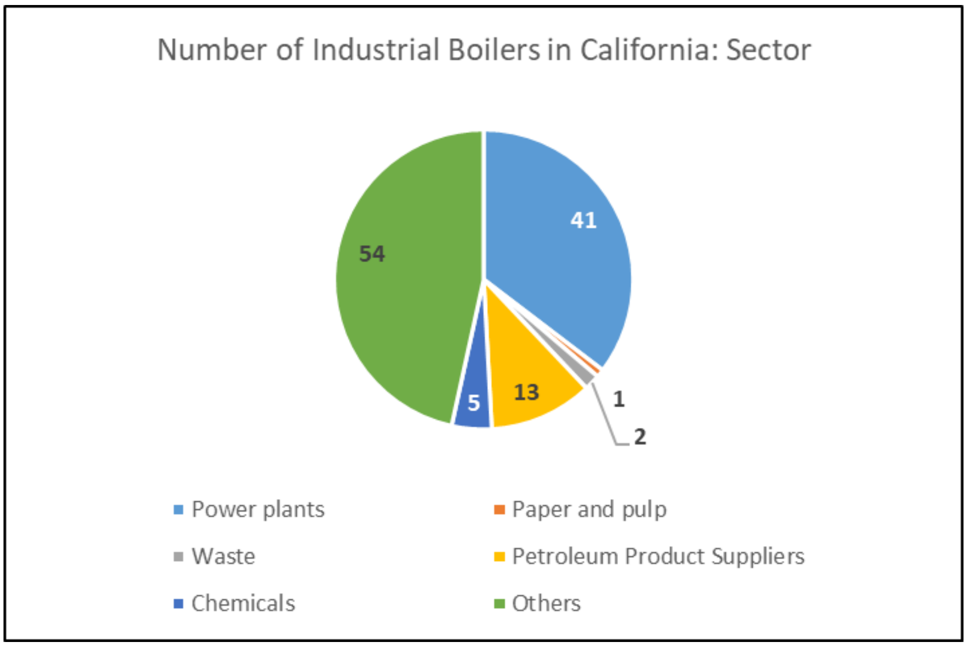


Figure 4 shows the estimated industrial boilers in the U.S. and California state. The numbers are derived from the analysis of industrial and commercial boilers conducted by Energy and Environmental Analysis, Inc. for the Oak Ridge National Laboratory (ORNL) in 2005. The estimated number of industrial boilers from California GDP is close to the actual number of industrial boilers pulled from the AQMD records.

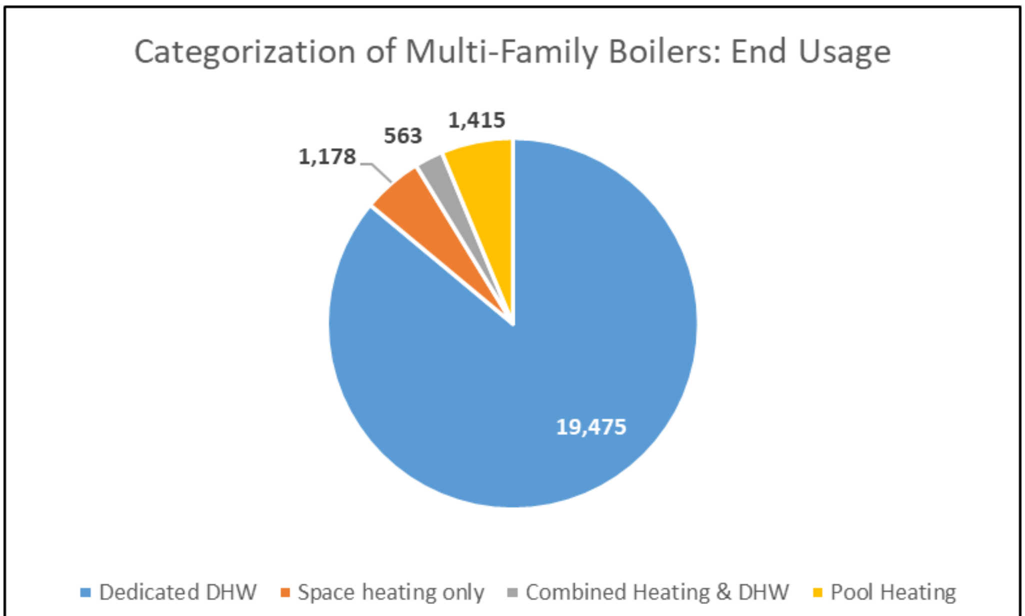
Figure 4: Estimated industrial boilers in California (2005) [2]

INDUSTRY	CAPACITY FACTOR (%) R449 (CHAPTER 2)	NUMBER OF BOILERS (TOTAL U.S.) R449 (TABLE 2-1, PAGE 2-1)	CA INDUSTRY GDP AS % OF TOTAL U.S. INDUSTRY GDP (2006) R500	ESTIMATED # OF BOILERS IN CA	WEIGHTING FACTOR (%)
Food	31%	10,610	9.7%	1,030	25.7%
Paper	66%	3,460	4.3%	149	3.7%
Chemicals	50%	11,980	8.8%	1,055	26.2%
Refining	25%	1,200	21.5%	258	6.5%
Metals	47%	3,330	4.5%	150	3.7%
Other	44%	12,435	11.1%	1,374	34.2%
Total		**43,015**		**4,016**	**100.0%**
Average Capacity Factor	43.8%				
Weighted Average Capacity Factor	41.9%				

Multifamily Boilers

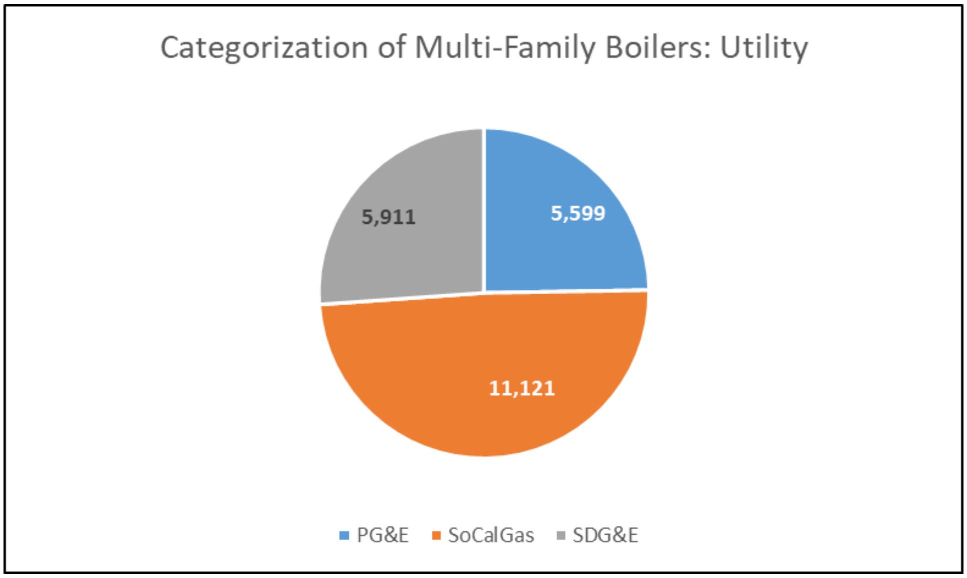
The Multifamily boiler market assessment study conducted by Cadmus for California Multifamily housing focused on large buildings [2]. These Multifamily buildings were 40 units or larger and were built prior to 2021. The study included central gas boilers and small commercial water heaters that are used in the Multifamily buildings. The total number of Multifamily boilers in California IOU are categorized as per the end usage in Figure 5. The end-usage most often served is domestic water heating. Pool heating is the next prevalent end use.

Figure 5: Multi-family boilers as per end usage [2]



The utility boiler counts breakout is summarized in Figure 6. It indicates that SoCalGas territory has the highest number of Multifamily boilers among the three utilities in California.

Figure 6: Multifamily boilers utility wise [2]



The boiler data was categorized as per the building vintage, type, and efficiency. As indicated in Figure 7, dedicated DHW boilers are more efficient on average than the boilers used for space heating and pool heating applications.

Figure 7: Efficiency of Multi-family boilers with vintage, utility, and end usage [2]

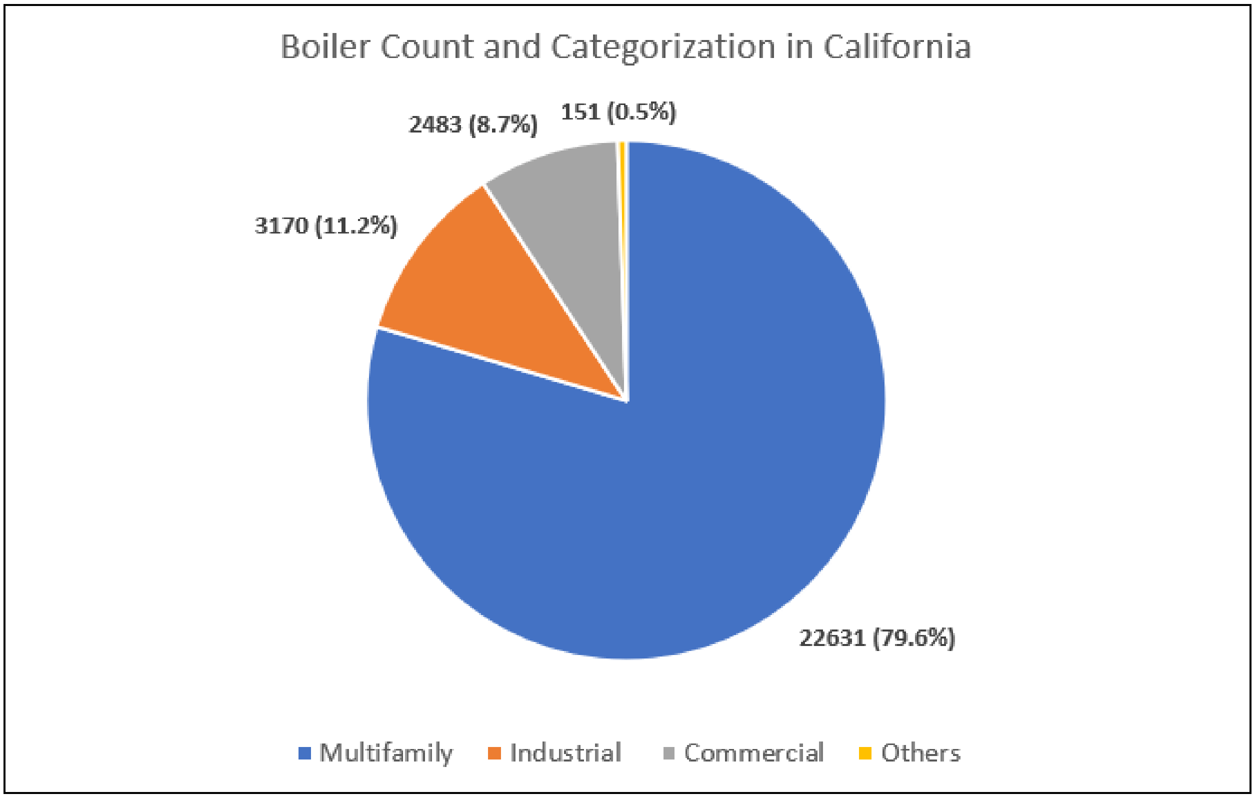
Table 35. Average Rated Thermal Efficiency for Equipment Behind Sampled Meters (n=110) [(1)(2)]

IOU	Building Age	Average Thermal Efficiency				
		Dedicated DHW	Space Heating Only	Combined Space Heating & DHW	Pool Heating	All End Uses
PG&E	1960 and before	86%	81%	-	-	86%
	1961 - 1980	86%*	89%	-	81%	86%**
	1981 - 2000	84%*	-	-	-	84%*
SoCalGas	1960 and before	81%	-	-	-	81%
	1961 - 1980	83%**	81%	85%	81%	82%**
	1981 - 2000	87%*	84%	-	82%	86%**
SDG&E	1980 and before	93%**	83%	82%	84%	91%**
	1981 - 2000	80%	-	-	-	80%
Overall Average		86%**	84%	84%	81%	86%*

(1) Cadmus indicated the precision of each estimate at a 90% confidence level using the following asterisks: *** for ±5% precision or better, ** for ±5.1-10% precision, * for ±10.1-15% precision, and no label when precision was over ±15%.
(2) The total number of meters included is less than 139 because Cadmus could not determine the thermal efficiency of boilers in some sites or found the efficiency expressed in a metric other than thermal efficiency.

Figure 8. summarizes the estimated boiler inventory data categorization in California.

Figure 8: Boiler inventory data categorization in California



3. Lessons Learned from Boiler Studies Conducted in Other States

A review of other studies done in other states was imitated to understand if there were similar trends.

a) Oregon

Cadeo conducted a high-level boiler survey of Oregon state in 2020 [4]. The research aimed to characterize the commercial and industrial natural gas boiler market to identify program opportunities for the Energy Trust of Oregon.

Oregon Boiler Market Characterization Findings:

- The boilers are categorized by fuel type. About 86% of the boilers are natural gas boilers. After analyzing the natural gas boilers by the end usage, it was found that about 70% of the gas boilers are used for producing hot water and 26% of them are used for steam production.
- The study also found that most commercial boilers are hot water boilers and only 10% are steam.

- The survey indicated that about 63% of the boilers were already of condensing type.
- About 88% of the commercial boilers are in schools, so focusing on schools in future energy efficiency programs would be key. The authors recommend focusing on measures such as sequencing, burner staging, digital controls, and temperature resets.

As a part of the research, the subject matter experts in the boiler systems were also interviewed. The following is the summary of the interview findings:

- Retrofitting the oversized boiler with modulating burner and digital controls would allow the boilers to operate more efficiently. The buildings might also use the excess boiler capacity for other uses such as producing domestic hot water.
- It is recommended that the program should focus on improving the design and performance of condensing boilers rather than focusing on the purchase of new condensing boilers.

b) Minnesota

To address the uncertainty around the cost effectiveness and energy savings of condensing boilers, a research team monitored 13 condensing boilers in Minnesota [5]. The field monitoring indicated that the on-field operation had better than expected space heating performance.

Minnesota Boiler Market Characterization Findings:

- The space heating efficiencies were observed between 86% and 95%, with an average annual efficiency of 90%.
- The average Annual Fuel Utilization Efficiency (AFUE) was 94%, in line with the expected efficiency of well-installed condensing boilers.
- The condensing boilers are expected to achieve 14% heating energy savings over a baseline boiler installation.
- The interview findings of the contractors cited the usage of outdoor reset control as an external control device on installed condensing boilers. It is possible that the large range of temperatures in Minnesota, very cold design conditions and moderate shoulder seasons make outdoor resets more common in Minnesota.

4. Conclusions from Boiler Market Characterization

Previous studies indicated that many of the conventional boilers in the U.S. are concentrated in California, Midwest, and Northeast region.

The following table summarizes the boiler count in California, and it categorizes the inventory into different sectors such as Industrial, Commercial and Multifamily. The records shared by 10 AQMDs in the state are analyzed to estimate the commercial and industrial boiler inventory [6]. The market assessment study by Cadmus (2019) is used to estimate the number of Multifamily boilers in California.

Table 2: Boiler inventory categorization in California [6]

	Sector	Number of Estimated Boilers
1	Multifamily	22,631
2	Industrial	3,170
3	Commercial	3,483
4	Others	151

The results of the Multifamily Boiler Market Assessment Study conducted by Cadmus indicated that most of the boilers are used for producing domestic hot water. These boilers are more efficient than the boilers used for space and pool heating applications.

The results of the Boiler Market Study conducted by Cadeo in Oregon state indicated that most of the boilers were used for producing domestic hot water. The interview findings advise focusing the program efforts on low pressure and light boilers.

Previous studies indicate that interviews with subject matter experts and vendors, customer participation is crucial in drawing reasonable conclusions.

Review of U.S. DOE Tip Sheets: Boilers and Accessories

U.S. DOE has published several tip sheets for boiler accessories. This section outlines a summary of energy saving potential of boiler accessories and some rules of thumb in the industry.

It should be noted that the savings for these measures may not be cumulative as some of them address the same efficiency improvements and/or have interactive effects with one another. While many of these are well established measures, it should be noted that most of them do not have measure packages, and their claims in custom projects appears to be limited, indicating that there may be some additional opportunities to claim these measures in existing programs.

A tip sheet on the usage of vent condenser indicates that the flash steam comprises of 10% to 40% energy content of the condensate [7]. The tip sheet and available literature shows a quick payback for the measure. Table 3 indicates the energy recovery potential of a vent condenser.

Table 3: Energy Recovery Potential of Vent Condenser [7]

Energy Recovery Potential of a Vent Condenser

Pipe Diameter (inches)	Energy Content, MMBtu/year*				
	Steam Velocity, feet/min				
	200	300	400	500	600
2	90	140	185	230	280
4	370	555	740	925	1,110
6	835	1,250	1,665	2,085	2,500
10	2,315	3,470	4,630	5,875	6,945

*Assumes continuous operation, 70°F makeup water, and condensed steam at 100°F.

Table 4 demonstrates the energy content of boiler blowdown. The energy content or recoverable heat is a function of steam pressure and boiler blowdown rate. These values are based on a steam production rate of 100,000 lb/hr, 60°F makeup water and 90% heat recovery.

A tip sheet on boiler blowdown highlights the fact that any boiler with continuous blowdown exceeding 5% of the steam rate is a good candidate for installing a heat recovery system [8].

Table 4: Energy Recovery Potential of Boiler Blowdown [8]

Recoverable Heat from Boiler Blowdown

Blowdown Rate, % Boiler Feedwater	Heat Recovered, Million Btu per hour (MMBtu/hr)				
	Steam Pressure, psig				
	50	100	150	250	300
2	0.45	0.5	0.55	0.65	0.65
4	0.9	1.0	1.1	1.3	1.3
6	1.3	1.5	1.7	1.9	2.0
8	1.7	2.0	2.2	2.6	2.7
10	2.2	2.5	2.8	3.2	3.3
20	4.4	5.0	5.6	6.4	6.6

Based on a steam production rate of 100,000 pounds per hour, 60°F makeup water, and 90% heat recovery.

A tip sheet on energy efficient burners states that a burner retrofit should also be considered if the current one is characterized by high repair costs, reliability concerns and emissions requirements. The completed site visits highlighted that AQMD NOx emissions requirements were the primary driver for retrofitting energy efficient boiler burners, which might raise free ridership concerns for custom projects; however, these mandatory efforts also provide an opportunity for EE focused activity to occur while the other work is being done. An energy efficient burner provides the optimum air-fuel ratio over the range of firing rates. Table 5 states the energy savings potential of energy efficient burner.

Table 5: Energy Savings Potential of Burner Retrofit [9]

Energy Savings Due to Installation of an Energy-Efficient Burner

Burner Combustion Efficiency Improvement, %	Annual Energy Savings, MMBtu/yr	Annual Dollar Savings, $
1	6,250	50,000
2	12,345	98,760
3	18,290	146,320

A tip sheet on installing a condensing economizer was referred to learn about energy efficiency improvements. This can help improve overall heat recovery and steam system efficiency by up to 10%. The condensing economizer recuperates both sensible and latent energy from flue gas by cooling below its dew point. The following table demonstrates the estimated increase in boiler efficiency after installing feedwater and condensing economizer. Refer to Table 6.

Table 6: Energy Savings Potential of Economizer [10]

System	Combustion Efficiency @ 4% Excess O^2 (%)	Stack Gas Temperature °F
Boiler	78 to 83%	350 to 550°
– with Feedwater (FW) Economizer	84 to 86%	250 to 300°
– with FW and Condensing Economizer	92 to 95%	75 to 150°

A tip sheet on installing turbulators demonstrates a simple, easy to install and low-cost design improvement substitute for economizers or air preheaters. Turbulators are cost effective way of reducing the flue gas stack temperature and increasing the efficiency of fire tube boilers. Turbulators comprise of small baffles, angular metal strips or coiled wires, are inserted into boiler tubes to increase turbulence of the hot combustion gases and overall heat transfer. Installation of turbulators increases the boiler efficiency by 2-3% on a high-level estimate. Additionally, the installed cost of each turbulator is around $15 [11].

Historical IOU Participation Data Analysis

1. CEDARS Claim Analysis

This section discusses the historical IOU participation data analysis. The year-on-year comparison on a measure level determines which boiler energy efficiency measures are implemented more compared to others. Also, the existing deemed measure packages were also studied.

California Energy Data and Reporting System (CEDARS) manages California Energy Efficiency Program data reported to the Commission by IOUs and RENs. Data available on this website are submitted in the form of budget filings, quarterly savings claims and report summaries [12]. The summary reports page provides program-level reports by year combining data across the CEDARS budget filing. The claims submitted during the period of last 5 years, starting 2018 were analyzed. Power pivot tables were used to sort and analyze the data. Refer to Table 7 for the summary table below.

Table 7: Summary of CEDARS Claim Analysis for Boiler related measures

Year	Number of claims made	Measure(s)	Measure Classification		Commercial	Residential	Agricultural	Industrial	Measure type
			Deemed	Custom					
2022	18	Boiler Replacement: Commercial, Residential, Process	0	18	6	12	0	0	Add-on equipment measures: 0
2021	1190	Boiler Replacement: Commercial, Residential, Process Boiler upgrade to Condensing Tank-type Water Heaters, VSD DHW recirc controls Boiler Demand Controls Process Boilers, Feedwater Economizer, NC Process Boilers, Condensing Economizer, AOE MF Central Boiler Dual Setpoint Temperature Controller_OAT Reset	1148	48	1102	84	2	2	Add-on equipment measures: 33 % AOE: 3 % Economizers: 9 MF Central Boiler Dual Setpoint Controller: 20 Others: 4
2020	759	Boiler Replacement: Commercial, Residential, Process Replacement with Condensing Boilers	731	28	706	51	1	1	Add-on equipment measures: 4 % AOE: 1 % Economizers: 1 Others: 3
2019	676	Boiler Combustion Air Fan VFD W/H- Boiler Controllers Boiler Replacement: Commercial, Residential, Process Central Hydronic Boiler DHW Recirculation Controls	613	63	127	533	7	9	Add-on equipment measures: 478 % AOE: 71 % Boiler Combustion Air fan VFD: 1 W/H Boiler Controllers: 477
2018	69	W/H- Boiler Controllers Boiler Replacement: Commercial, Residential, Process Central Hydronic Boiler DHW Recirculation Controls	10	59	25	35	2	7	Add-on equipment measures: 9 % AOE: 13 % Economizers: 2 Steam traps: 1 Others: 6

Summary of the claim analysis for boiler related measures:

- The claims data of 2022 is partial as of the start date for this study.
- More than 90% of the claims submitted during the years 2019-21 were for deemed measures. The year-to-year comparison of deemed measure claims is discussed in the section below.

- A significant number of claims are submitted under the target sector of Commercial and Residential buildings compared to Agricultural and Industrial sector.
- Many existing deemed boiler related measures focus on the entire boiler retrofit, except for the year 2019. There is a significant opportunity for measure package development related to boiler add-ons.
- However, Table 8 shows a very high AOE (Add-on Equipment) implementation rate in the year 2019 compared to other years.
- The measure(s) enlisted in the second column of Table 8 are not the only claims reported in that fiscal year; but those are the representative measure(s) implemented.

The electronic repository of California's energy efficiency measure data is compiled in the eTRM. This was developed by CalTF (California Technical Forum) [13]. The remarks related to measure packages for boiler related measures are compiled in Table 8.

Table 8: Summary of existing measure packages for boiler related measures

Measure ID	Measure Description	Applicable Building Types	EUL	Measure Application Type
SWWH005-06	Boilers, Commercial	Any DHW application of Industrial or commercial	15 years	NR, NC, AR
SWWH010-02	Boilers, Multifamily	Multifamily properties; boilers meeting minimum AQMD regulations	20 years	NR, NC, AR
SWWH008	Boilers, Process	All existing commercial, agriculture and industrial buildings; exclusions of DHW and space heating	20 years	NR
SWPR007-01	Steam Boiler Economizer, Industrial	Steam boilers with firing rate <= 20 million BTU/h; mostly all applicable for all industrial boilers and commercial	15 years	NC, AOE
SWHC004	Space Heating Boiler, Commercial & Multifamily Controlling strategies of supply water temperature based out of OAT	Commercial & Multifamily space heating boilers	20 years	NR, NC
SWWH024	Central Boiler Dual Setpoint Temperature Controller, Multifamily	Central hot water boilers of multifamily residences (less than 500,000 BTU/h and installed before 2005)	15 years	AOE
SWWH017	Hot Water Pipe Insulation, Nonresidential and Multifamily	Commercial, agriculture, industrial or multifamily building	11 years	AOE

- Seven existing measure packages related to the boilers are summarized in Table 8.
- The measure packages are elaborated with their description and the applicable building types.

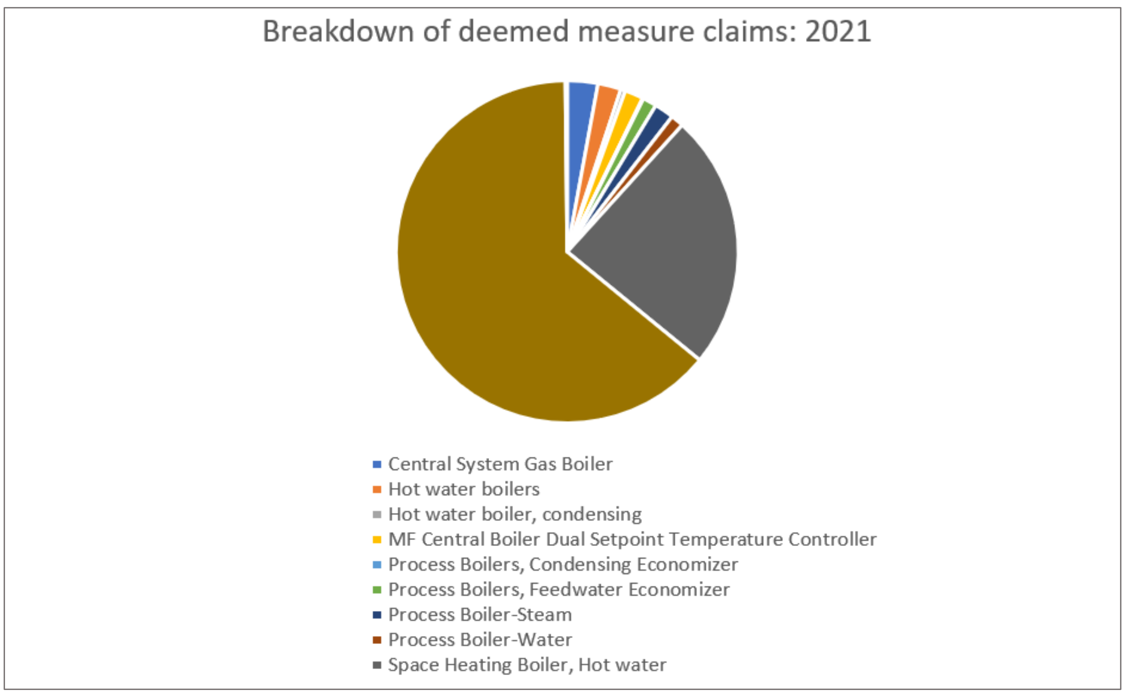
2. Breakdown of deemed measure claims

The deemed measure claims are split into different measures to understand the contribution of measures such as, economizer, boiler replacement and boiler controllers etc. Figures 9-11 also help understand the split up of claims into hot water and steam boiler types.

a. Year 2021

- 64% of the deemed measures consist of space heating condensing, hot water measure and about 24% of the deemed measure claims are for the space heating boiler, hot water measure.
- The year-to-year comparison of the deemed measure claims demonstrate the increasing popularity of condensing boiler measure replacements.

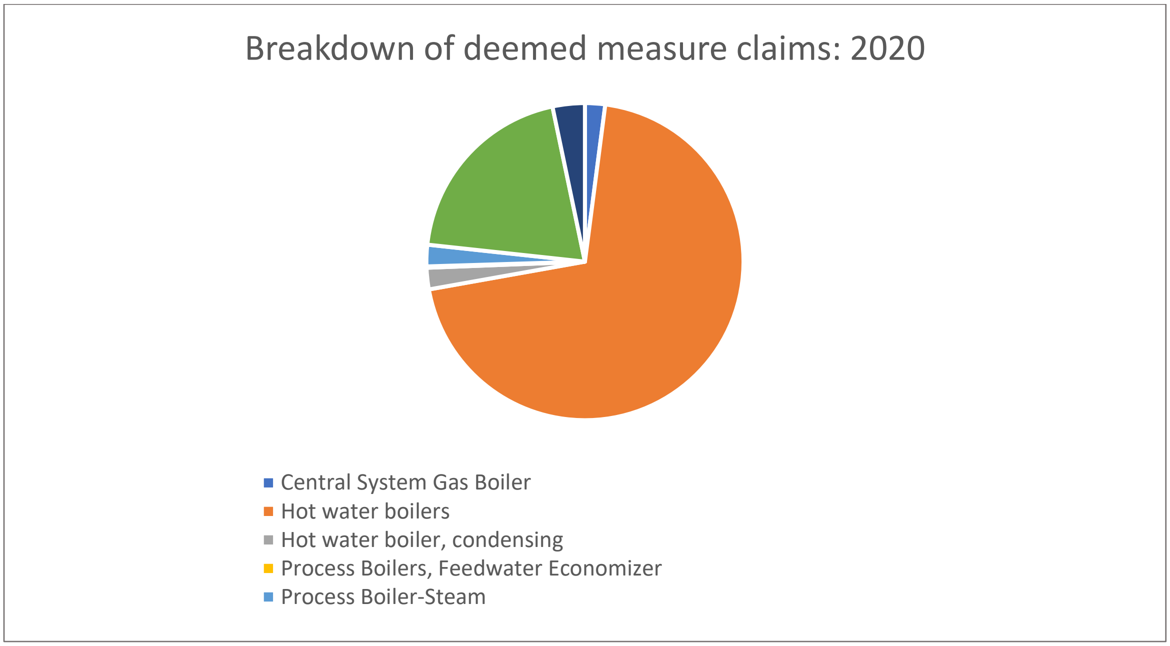
Figure 9: Breakdown of deemed measure claims: 2021



b. Year 2020

The claims data of 2020 indicate that about 70% of the deemed claims were for the hot water boiler replacement.

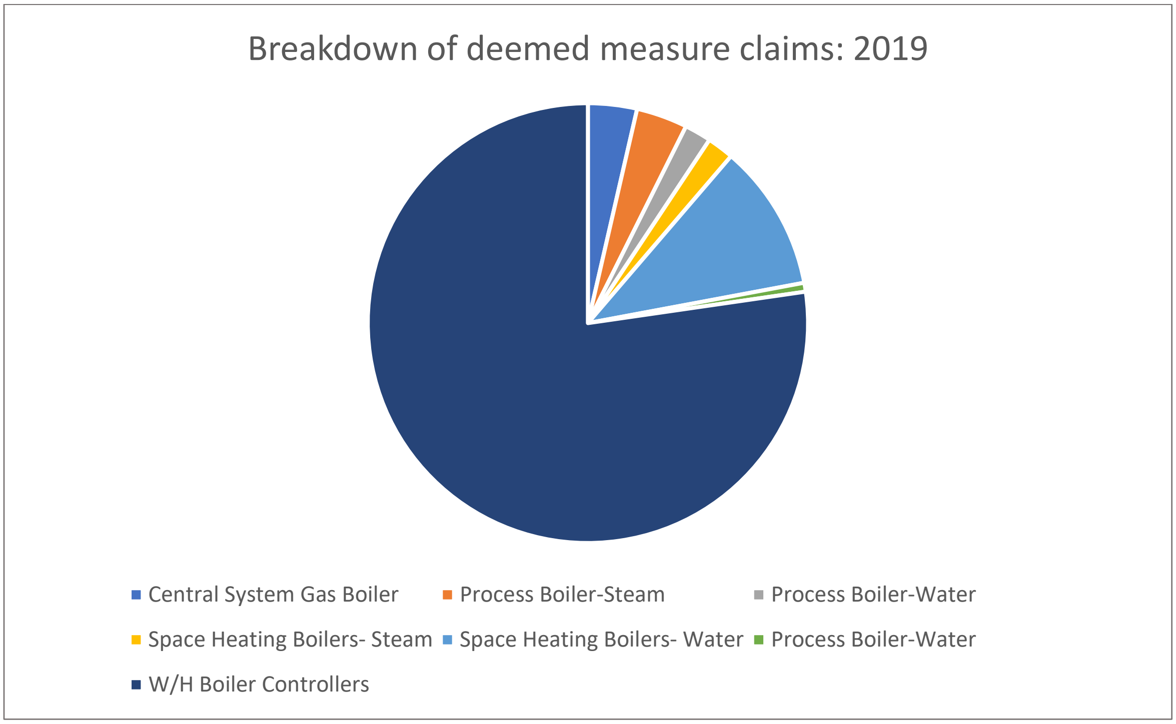
Figure 10: Breakdown of deemed measure claims: 2020



c. Year 2019

About 77% of the deemed measure claims were made for the AOE: W/H Boiler controllers.

Figure 11: Breakdown of deemed measure claims: 2019



Customer Surveys

1. Objective

The objective of conducting customer surveys was to collect information about their installed boiler(s) and implemented energy efficiency measures. The survey also aimed to collect data regarding type of boiler(s), primary end usage and prior participation data.

2. Customer Data Screening and Outreach

With the collected customer data, the goal was to acquire primary information about boiler(s), which boiler related measures are more prevalent and gauge customer interest for a potential site visit.

Table 9 summarizes the customer data and its aggregation with respect to a source of information. We obtained additional AQMD data but focused on the two largest AQMD districts- Bay Area AQMD and South Coast AQMD.

Table 9: Customer Data

Source	Number of contacts
Bay Area AQMD	444
South Coast AQMD	2,962
SoCalGas	1,001*
Total	4,407*

* *Note: Some of the contacts in the SoCalGas dataset may overlap with one or more AQMD datasets.*

3. Online Survey Instrument

See Appendix A: Customer Survey Instrument for the snapshots of the online customer survey instrument.

4. Survey Data Analysis and Results

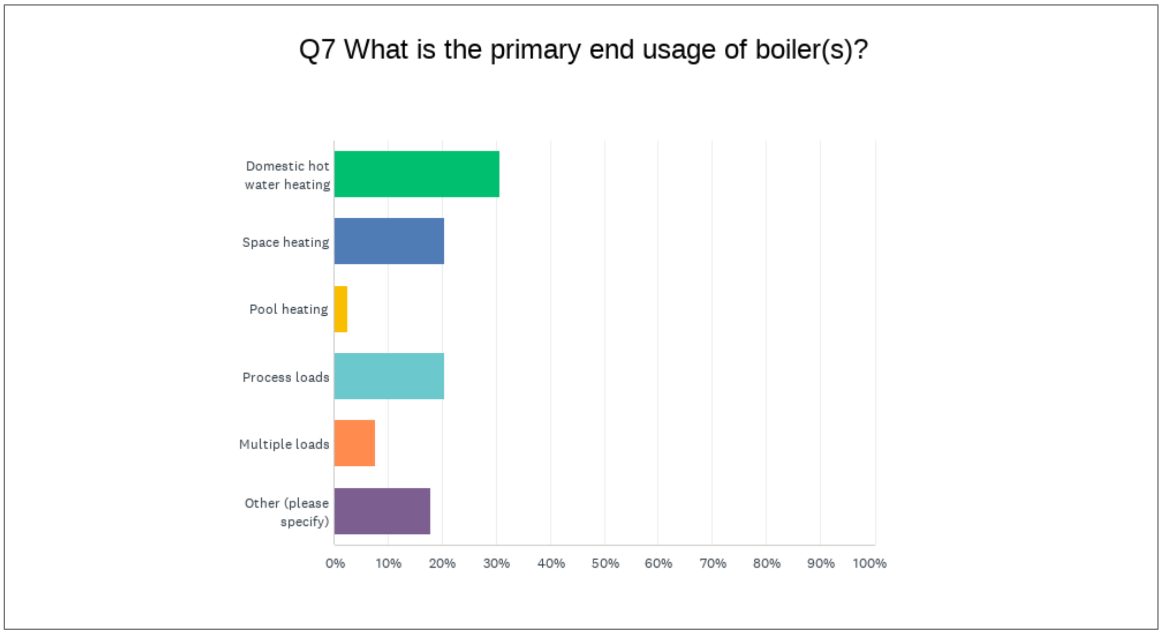
As of April 30, 2023, 46 customers responded to the survey and 21 out of them accepted the gift cards. As indicated in Table 10, the response rate is 1%. All the responses are summarized in Appendix B: Survey Responses.

Table 10: Response Rates

Total Contacts	4,407
Survey Responses	46
% Response Rate	1%

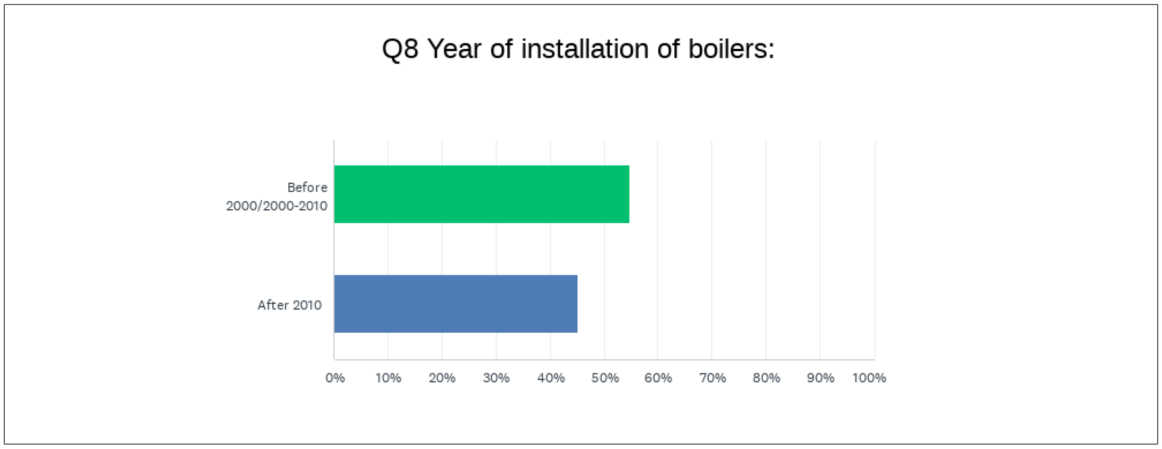
Figures 12-15 demonstrate the collected data for 46 survey respondents in bar graphs.

Figure 12: Primary End Usage of Boilers



The primary end usage for 30% of the boilers is Domestic Hot Water (DHW). The other significant end usage is space heating. The initial literature review and analysis of Multifamily boilers in California also highlighted that about 85% of the boilers are dedicated to DHW. The second significant end usage indicated in the same study is also space heating.

Figure 13: Year of Installation of Boiler(s)



The boiler(s) were categorized as per installation year. More than 50% of the boiler(s) were installed after the year 2000. The objective of collecting information about boiler installations was to correlate the boiler ages with the building construction and program participation during the site surveys. However, the literature review summarized that there was no correlation found between the boiler installations, building constructions and program participation. There were no significant differences found between boiler ages in buildings of different ages for Multifamily boilers in California. However, the sample size of completed site surveys in this study was not statistically significant to draw similar conclusions.

Figure 14: Type of Boiler(s)

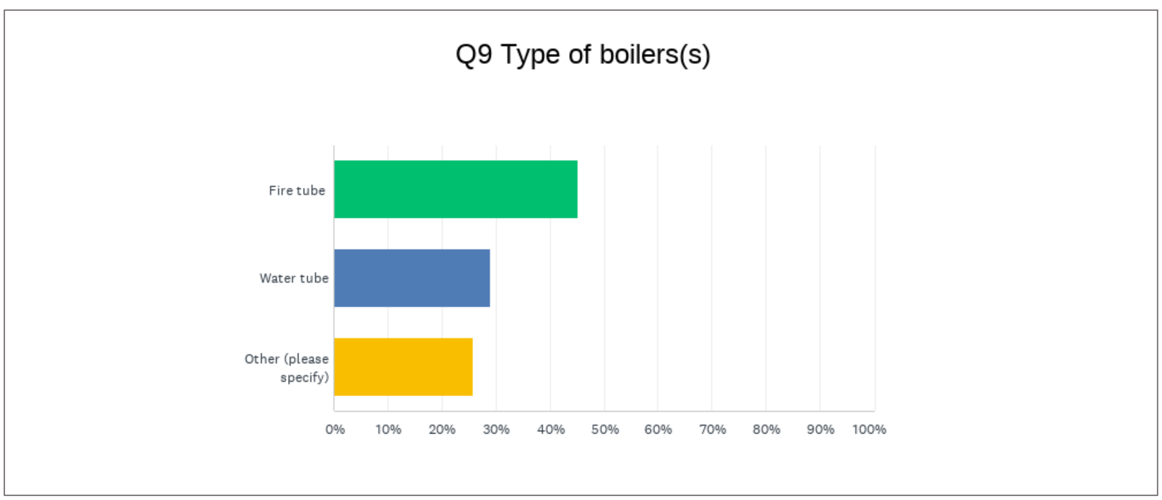
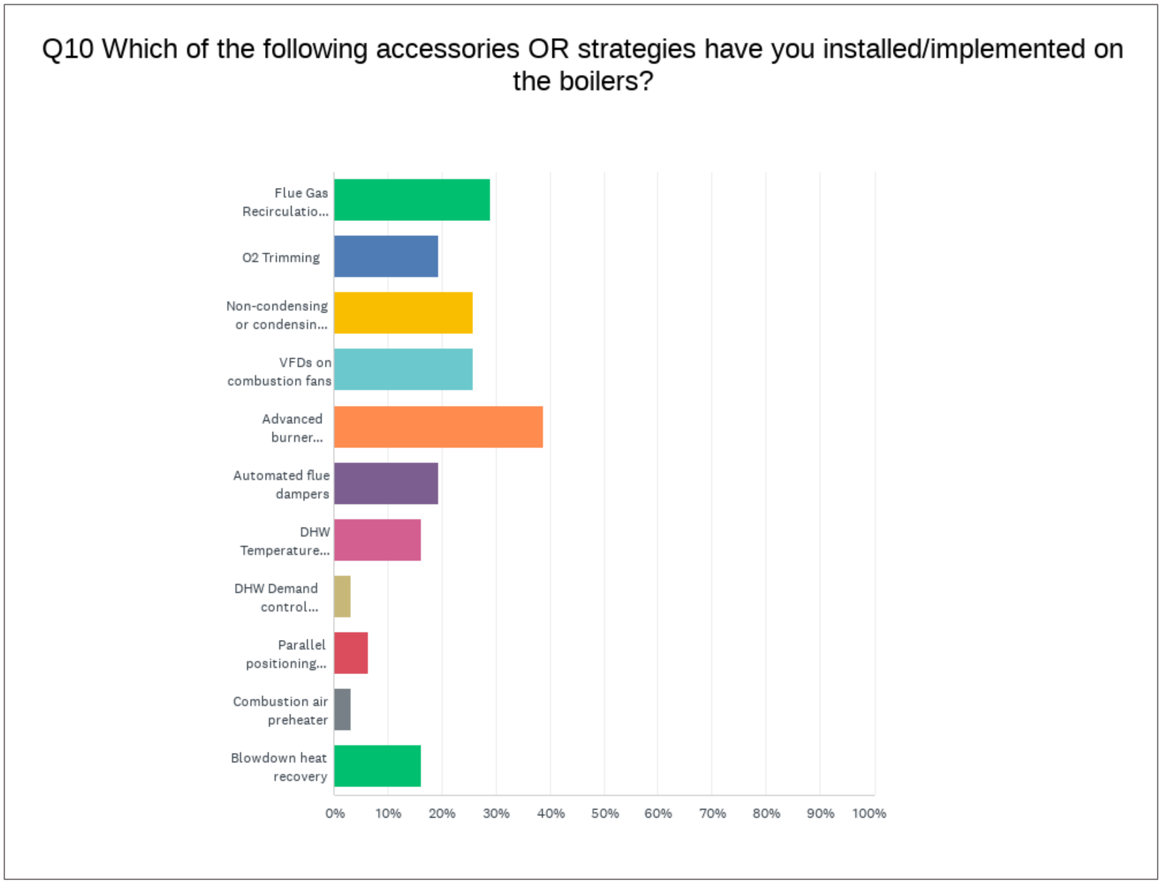


Figure 14 indicates that more than 40% of boilers were of fire tube type. The 'other' category includes categorization into horizontal and vertical boilers, condensing and non-condensing boilers etc.

Figure 15: Implemented Measure(s) related to the Boiler(s) and Add-ons



The measures such as Advanced burner technology, Flue Gas Recirculation (FGR) and VFDs on combustion fans were found to be more prevalent compared to other measures. In the previous sections, the CEDARS claims analysis demonstrated a significant percentage of deemed claims for the entire boiler retrofit. More than 90% of claims were made under the deemed category during 2018-2021 period. However, some of the custom category claims included measures such as VFDs on combustion fans, installing variable speed recirculation pumps, installing stack economizers and system insulation etc. Thus, these add-on measures including FGR[3], VFDs on combustion fans, installing stack economizers and installing automated flue dampers seem to be potential areas for measure development.

[3] Flue Gas Recirculation (FGR) is primarily used to reduce NOx emissions but has little or negative impact on energy efficiency (EE) savings.

5. Site Survey Instrument

The interested customers were shortlisted for conducting site surveys. The objective of conducting site surveys was to understand the characteristics of existing boiler system and collect data regarding the implemented EE measures. Another important goal was to understand the customer pain points or constraints in installing these add-on related measures. During site visits, data regarding operating characteristics of boilers and burners, prior participation in EE programs and implemented add-on measures was collected in a tabular format.

Following is the questionnaire developed for the site surveys:

- Can you share more information about the building and installed boiler(s)?
- Have you participated in prior EE programs?
- Can you share more information about end usage of boiler(s), type of boiler, efficiency, and repair history (if any)?
- Can you provide more details on burner specifications and related measure(s) implemented?
- Have you implemented any of the following add-on related measures?
- Economizer, Automated flue dampers, Oxygen trimming, Advanced burner technologies, VFDs on combustion fans etc.

Refer to Appendix A: Customer Survey Instrument for snapshots of the site survey instrument.

6. Site Survey Data Analysis and Results

Due to customer concerns and limited interest, only 5 site visits were completed. These include visits conducted in 3 commercial and mixed-use buildings and 2 Multifamily buildings.

All the three commercial and mixed-use building sites seem to have more awareness about energy efficiency programs, AQMD requirements and carbon emission reductions as compared with Multifamily building sites. All the sites requested the GET Program to share the project summary with them. Two of the commercial/mixed use facilities had retrofitted their burners with low NOx ones to meet the Bay Area AQMD requirements on carbon emissions. This was noted as one of the best practices implemented on-site. One of the sites had retrofitted their old boilers with packaged hydronic non-condensing boilers in 2012. Non-condensing boilers were preferred over condensing because of the cost difference and concerns about system reliability during peak loads. All the three commercial/mixed use facilities had a periodic schedule setup for conducting combustion tests, boiler tune up and maintenance.

The two multifamily building site managers shared limited information about their boiler systems. Additionally, broken system insulation was a common observation. Also, the records regarding the combustion tests and boiler maintenance schedule were not in place or were not shared with the GET program.

The remarks on the completed site visits are compiled in a tabular form in Appendix B: Site Survey Responses.

7. Boiler Manufacturer and Distributor Interviews

The boiler manufacturer and distributors were interviewed to understand emerging technologies and new products in boilers and accessories. The outreach or recruitment mechanism of vendors included email or phone surveys and in-person meetings at ASHRAE Expo 2023. About 25 boiler manufacturers and distributors were interviewed during November 2022 – April 2023 period.

Questionnaire for boiler manufacturer and distributor interviews

Following is the questionnaire developed for the interviews:

- Can you talk a bit about your presence in the U.S.? Which of the boiler manufacturers/distributors do you work with? How big is your California market?
- Are you into all markets- Industrial, Commercial and Multifamily boiler market?
- What's the normal size of boilers do you work with?
- Can you provide more insights into your product offerings and new products/technologies?
- Can you share insight on the recent trends in boiler accessories?
- What are you folks working on, that could be innovative for California?
- Can you share your insight on barriers in implementation of measures related to different boiler add-on/accessories? Why do some add-ons get installed and some don't?
- Which type of boiler market has a greater potential of implementing deemed energy efficiency measures? In cases of multiple boilers in a plant, are there new strategies or technologies for effective boiler sequencing/operation or use of smaller modular boilers?
- Are there any opportunities for installing carbon capture systems to the boiler systems to meet the emission standards in California?

- How often do you find the following add-on equipment OR boiler accessories in the field that improve system efficiency? (On a scale of 1 to 5)
  - Automated flue dampers
  - Condensing and non-condensing economizers
  - Flue gas recuperators
  - VFDs on combustion fan
  - DHW temperature modulation control
  - DHW demand control
  - DHW measures with continuous monitoring, low NOx burners
- Why don't these add-on equipment components get installed more often?
  - Cost
  - Space
  - Complexity
  - Possible electrification
  - Renovation/New boiler plans
  - Regulations
  - Benefits are unclear
- What would help drive the adoption of these technologies?
  - Lower cost
  - Incentives
  - More compact
  - Ease of installation
  - Ease of maintenance
  - Better ROI
  - More understanding of their value

Note: The interview approach was more focused on conducting conversational type of interviews vs a Likert scaling type of interview.

Summary of New Products and Emerging Technologies in Boiler Accessories

This section provides a comprehensive overview about new products and emerging technologies in the boiler accessories segment. This information is summarized from the boiler manufacturer and distributor interviews. As previously noted with the DOE Tip Sheet section, the noted savings may not be cumulative.

1. Use a Vent Condenser to recover flash steam energy

A vent condenser condenses the flashed steam and transfers the heat to the incoming boiler feed water. In most cases, the flash steam is vented, and the energy contained is lost to the atmosphere. However, energy can be recovered by installing a heat exchanger in the vent. Energy is recovered in two forms: increased temperature of boiler makeup water and distilled condensate for use by the boiler. This improves the steam system efficiency and reduces blowdown of the boiler.

Figure 16 demonstrates the functional diagram of manufacturer A's Exhaust Vent Condenser (EVC). This works at atmospheric pressure. It is manufactured in stainless steel with thermal expansion bellows, using corrugated tubes with low pressure drop designed to increase turbulence and heat transfer.

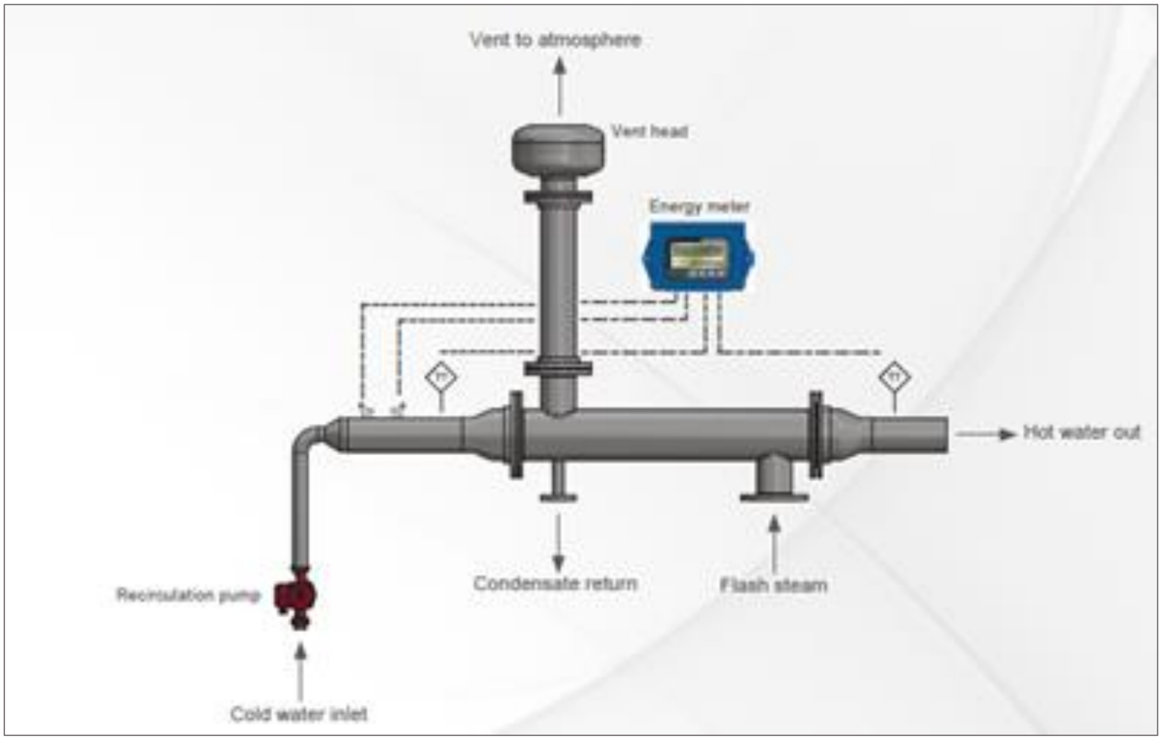
The installation of EVC reduces steam generation costs, increases boiler efficiency, and reduces boiler blowdown. This also reduces or completely removes the flash steam from the system. Additional advantages of installing EVC are reduced make-up water and chemical requirements.

Following are the two major applications of a vent condenser:

a. Flash steam recovery from condensate receiving tanks
b. Heat recovery from pressurized deaerators. A deaerator removes dissolved gas from boiler to prevent corrosion of feed pumps and boilers due to presence of oxygen and carbon dioxide.

Note: Depending on the application, material for vent condenser can be selected. For deaerator tanks, stainless steel is recommended for heat exchanger material to avoid corrosion due to the high concentrations of gases. For condensate receiving tanks, mild steel can be used.

Figure 16: Exhaust Vent Condenser Functional Diagram [14]



General rules of thumb of industry (shared by manufacturer A) are 1% fuel and 1% water savings. Every 500 lb/hour of recovered flash steam provides 1 gallon per minute of distilled water.

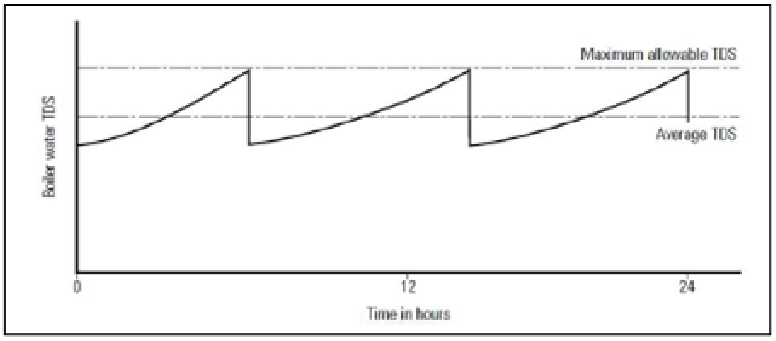
2. Recovering energy from boiler blowdown

Boiler water is blown down to control the total dissolved solids (TDS) in the boiler. This discharged water is pressurized, hot and dirty. This means that this water is unsuitable for other applications and may present a disposal problem. Additionally, this water creates significant amounts of flash steam when released at atmospheric pressure. A heat recovery system can resolve both problems.

The product literature available on the website of manufacturer A states the standard industry practice of automatic TDS control. The discharge of water from the boiler can be done in two ways. See Figures 17 and 18.

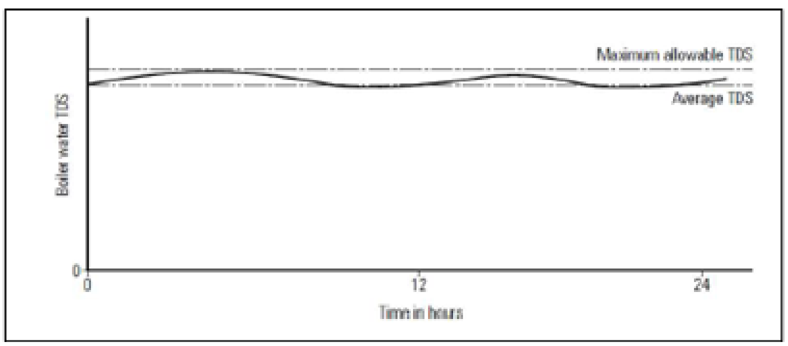
a) Intermittent flow: Water is blown down through a discharge valve with periodic openings for a short period of time. In this case, TDS level is close to the recommended value only for brief periods of time.

Figure 17: Boiler blowdown- Intermittent [15]



b) Continuous flow: Water is blown down through a continuous discharge with low water flow. In this case, the TDS level values are close to the ideal value during most of the boiler operation time. Such a type of system is a good candidate for installing a heat recovery system. U.S. DOE Tip Sheet on Boiler Blowdown recommends a conversion of an intermittent blowdown system to a continuous one coupled with heat recovery [x].

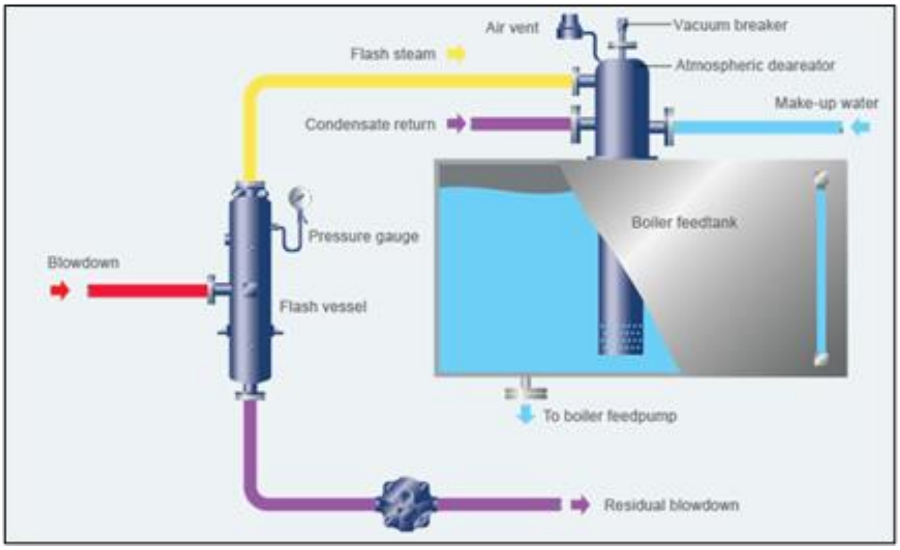
Figure 18: Boiler blowdown- Continuous [15]



Energy recovery from flash steam:

A flash vessel can be used to recover energy from flash steam. It provides a space where the steam velocity is low enough to allow the separation of hot water and flash steam. This flash steam is used to increase the temperature of boiler feed water. Figure 19 demonstrates a functional diagram of manufacturer A's flash energy recovery system.

Figure 19: Energy recovery using a flash vessel [15]



This energy recovery system will require a flash vessel, a steam trap to drain the vessel, a vacuum breaker to release the vacuum generated during the times when the boiler does not need to blow down and other steam distribution equipment.

Figure 20: Energy recovery using a flash vessel and a cold break tank [15]

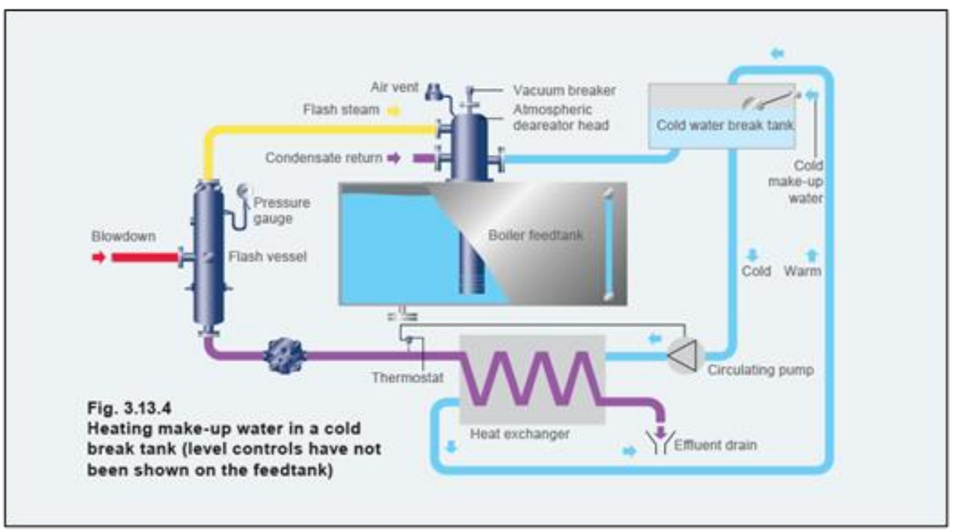


Figure 20 demonstrates the energy recovery using a flash vessel and a make-up water tank (also called cold-water break tank). One of the major applications of this type of flash recovery is a site where there is not a simultaneous flow of incoming cold make-up water and residual blowdown. Here a cold break tank is used as a heat sink and a thermostat is used to control a small circulating pump. The discharge of hot water from the boiler is directed to a flash vessel. A portion of the discharged water will re-evaporate in the form of flash steam due to low pressure inside the vessel. This flash steam is injected into the deaerator head or boiler feed tank to recover heat and water. The remaining liquid in the flash vessel is directed to a plate heat exchanger where it transfers heat to the incoming boiler feed water. Such a system recovers up to 90% of the thermal energy from the discharge and reduces the cost of chemical treatment with water recovery from flash steam.

A general rule of thumb shared by manufacturer A indicates that for a 10% blowdown rate, about 1.7% fuel savings can be accrued by installing the above energy recovery system.

3. Flash Recovery Energy Management Equipment (FREME)

FREME i.e., Flash Recovery Energy Management Equipment system is a heat recovery system that delivers energy savings by recovering waste heat from a condensate return from the steam distribution system. This recovered energy is used to pre-heat the boiler feed water.

Many heat recovery systems fail to recover all the energy content in the returned condensate because of the limitations on increasing the feedwater temperature due to a potential problem of cavitation which can damage the feed water pumps. However, FREME is installed on the higher-pressure side of the boiler feed water pumps. This helps to resolve the potential problems around the cavitation of feed water pumps and allows more energy to be recovered.

Figure 21 depicts the functional diagram of a typical FREME system (manufacturer A). This system consists of two plate heat exchangers. One water to water type which transfers heat from the hot water condensate to the boiler feed water. In the second pass, the heat from flash steam is also transferred to the feed water.

As per the general rule of thumb shared by manufacturer A, for every 6^{0} F rise in boiler feedwater temperature, 1% fuel savings can be achieved. In a typical application, this FREME system increases the boiler efficiency by about 5.5% which leads to a reduction in total energy costs by 26%. Figure 22 highlights the energy saving potential of FREME in a typical application. Applications include brewing, distilling, food and beverages, laundries, pulp and paper, pharmaceuticals, and hospitals. Additional benefits include elimination of external venting of flash steam and significant savings on feedwater chemicals.

Figure 21: FREME System (manufacturer A) [16]

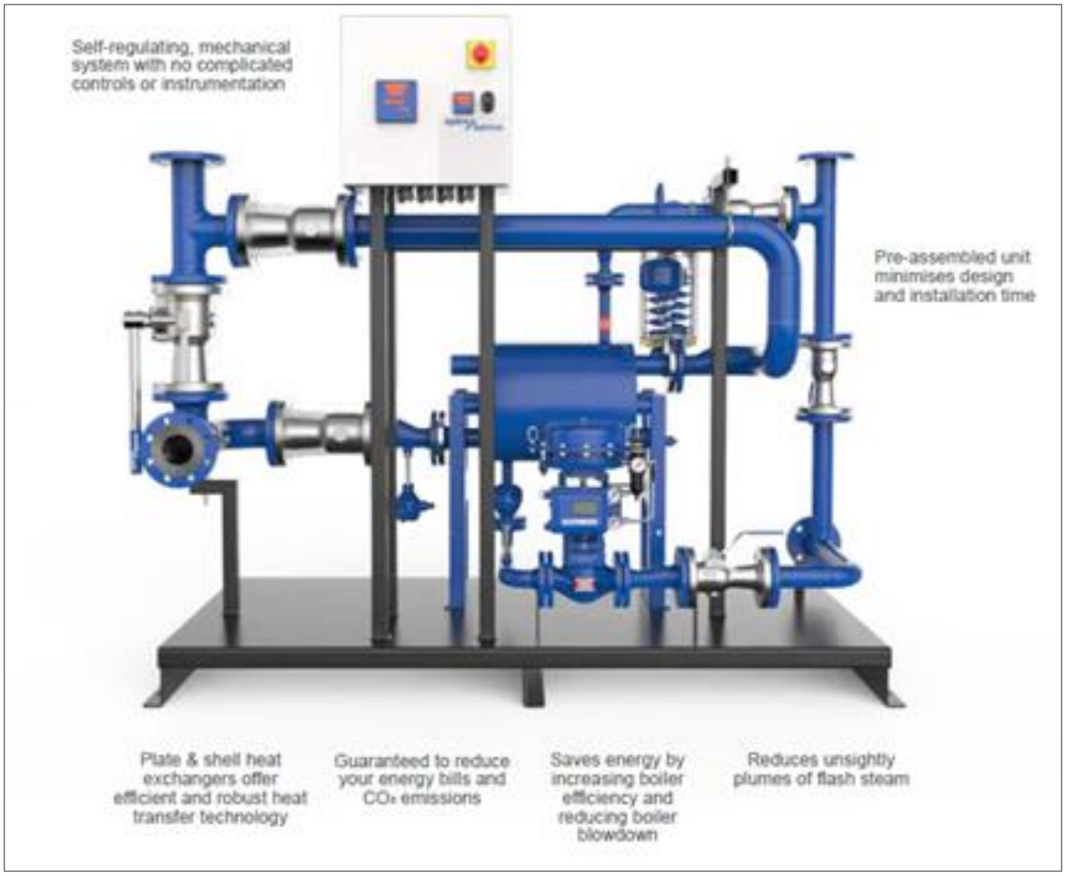
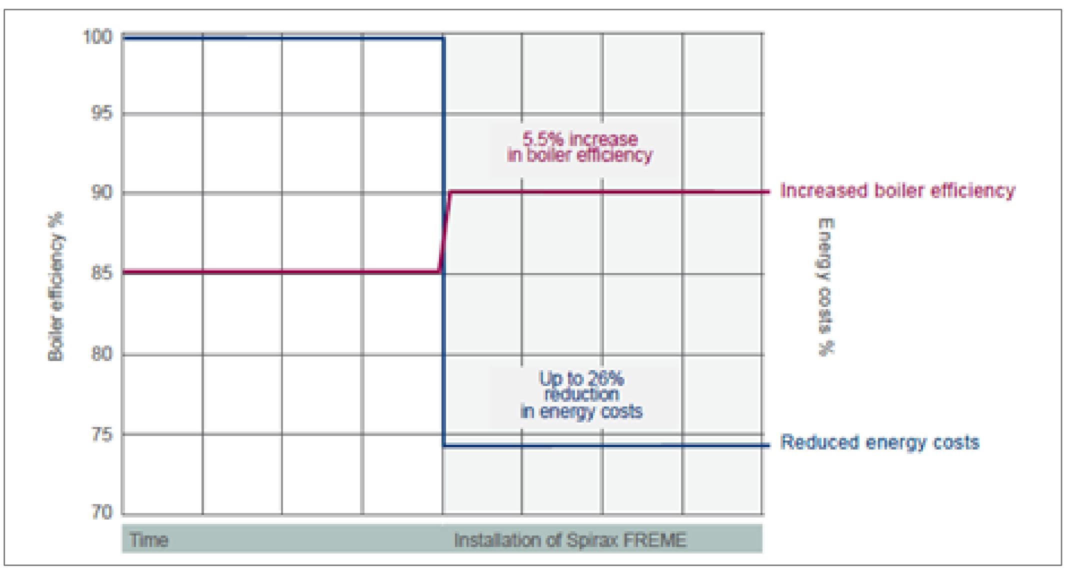


Figure 22: Benefits of installing manufacturer A's FREME System [16]



4. Boiler Economizers and Alternative Configurations

This section summarizes the applications and advantages of installing alternative configurations of boiler economizers and associated accessories.

a) Installing two element water level control system

The standard single element boiler water level control system, with a proportional control, provides better control on most boiler installations. With this type of control system, the water level is higher at low steaming rates and lower at higher steaming rates. This is also called a falling level control characteristic.

However, a single element control has some limitations when there are very sudden load changes. In case of a sudden load change, the pressure inside the boiler further reduces and a proportion of the boiler water flashes to steam. The flashing of boiler water and the increased heat input as the burner output goes to maximum, means that the water will contain more steam bubbles. Also, its density will be further reduced. Due to reduced pressure inside the boiler, the steam is drawn off at a greater velocity. This can create a swell of steam bubble and water mixture, resulting in apparent rise in water level. The water level controller detects this as an increase in water level and closes the feedwater valve. When there is a peak steam demand, no water is added to the boiler. Thus, at the peak load when the flue gas temperatures are on the higher side, there is no or less heat recovery from the economizers due to reduced feed water flow to the boiler.

A two-element control reverses the falling level control characteristic to ensure the water level is made to rise at high steaming rates or peak loads. This control system ensures that quantity of water in the boiler stays constant at all the loads. The system works by using the signal from a steam flow meter installed to increase the water level controller set point. An additional controller needs to be installed to integrate the signals from steam flow meter and water level controller for this measure implementation.

In this way, a two-element water level control synchronizes the heat source (flue gas) and heat sink (boiler feed water) i.e., feed water enters the economizer at peak loads when the heat content of flue gas is on the higher side. This enhances the efficiency of flue gas stack economizer. As per general rules of thumb shared by manufacturer A, this type of control system increases the efficiency of boiler system by 1-2%. See Figures 23 and 24.

Figure 23: Two element water level control [17]

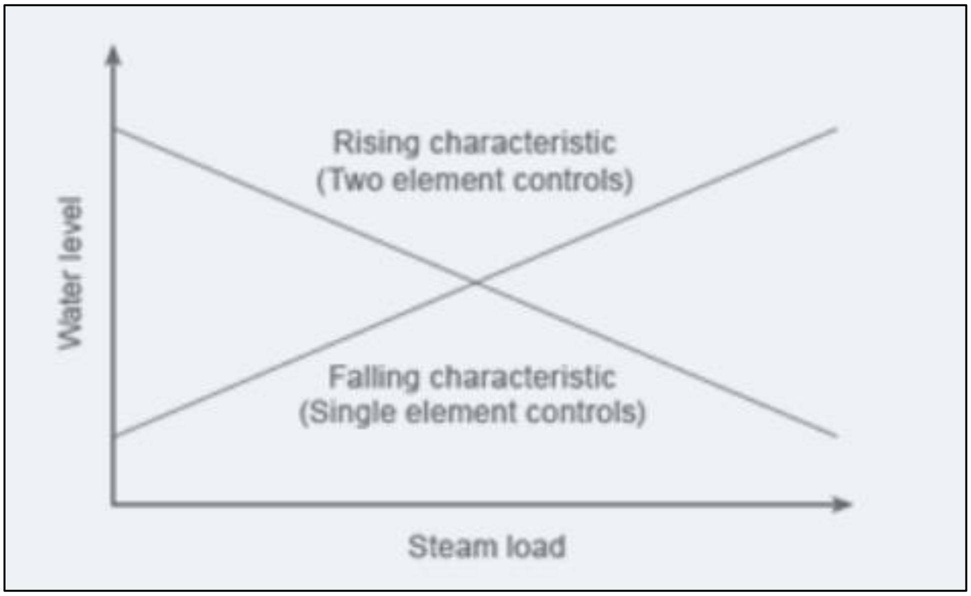
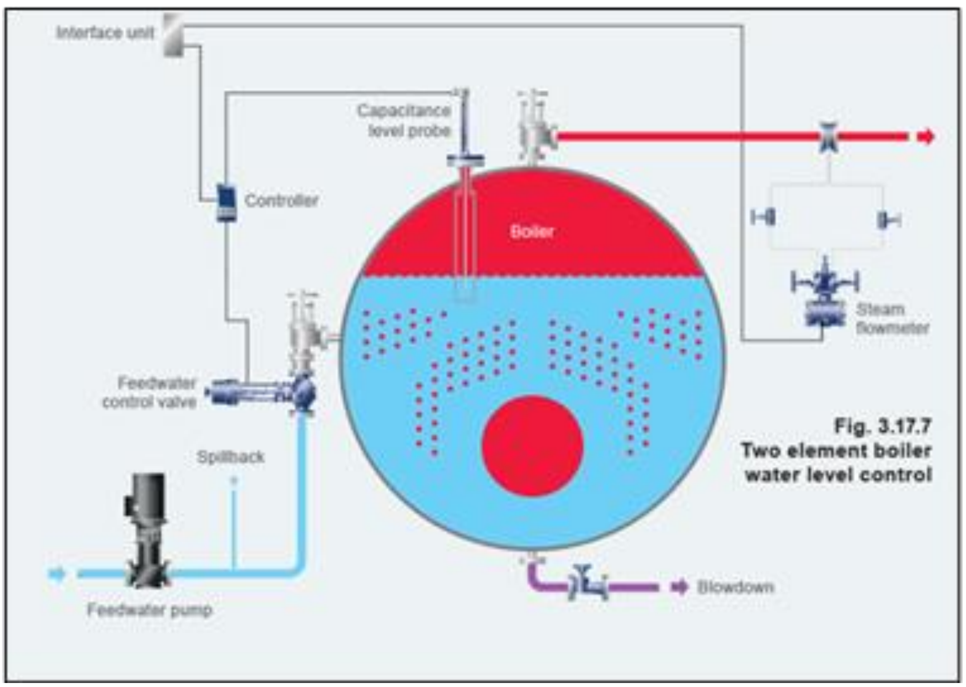


Figure 24: Two element water level control (manufacturer A) [17]



b) Two stage heat recovery, coupling several boilers to one economizer unit

Brand B, manufactured by manufacturer C operates as an efficiency improvement device for hot water boilers. This unit can be paired with one or more non-condensing boilers. The heating surface is designed for both sensible and latent heat exchange. For most industrial applications, multiple boilers can be installed with a common heat recovery unit.

Additionally, the installed cost of one unit is approximately one-third of that of a new condensing boiler.

A two-stage condensing economizer achieves the greatest gains in boiler efficiency. Two stage technology allows for multiple water heat sinks to extract more energy from the exhaust flue gases. More condensation takes place in the second stage. These economizers can provide efficiency gains in the ranges between 5-12%.

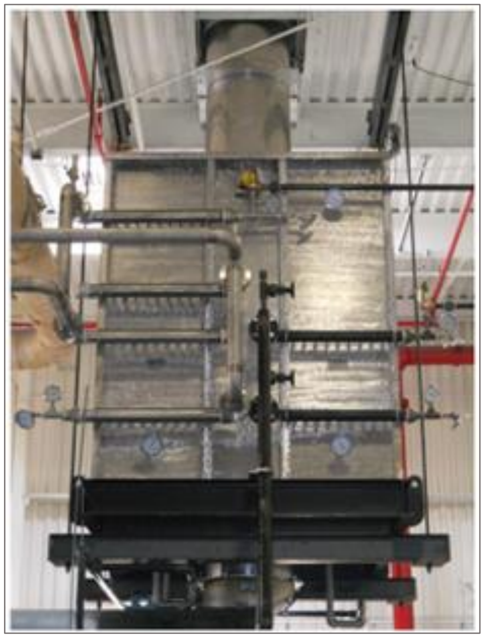
There are two types of arrangements possible:

i. Stacked arrangement- This is the lowest cost method of making a two-stage economizer. A two staged condensing economizer is installed on the boiler. See Figure 25.

ii. Side by side arrangement- The side-by-side configuration of an economizer has an internal three pass design which provides an optimum arrangement for two stage economizers. See Figure 26.

Figure 25: Economizer- Two stage stacked (manufacturer C) [18]

Figure 26: Economizer- Side by side design (manufacturer C) [18]



c) Transport Membrane Condenser (TMC) Technology

This technology employs an innovative method of capturing waste heat and water vapor from boiler exhaust gases. A patented Transport Membrane Condenser (TMC), by manufacturer D, recovers both sensible and latent heat to achieve fuel-to-steam efficiency as high as 92-94% [19]. Refer Figure 27.

Porous membrane ceramic tube bundles are placed in the boilers' exhaust. The hot flue gas passes outside of the tubes while cold water runs through the tubes under a slight negative pressure. The cold water causes flue gas condensation to occur on the outside of the tubes, and the condensed pure water transports through the tube wall and combines with the water stream on the inside of the tubes. This technology increases the supply temperature to the boiler and recovers waste energy to reduce fuel consumption.

TMC technology works effectively for boilers up to a maximum size of 300 HP. The effectiveness of heat recovery decreases as the diameter of the boiler tube increases. High installation costs and high estimated payback periods could be an important barrier in implementation of this technology for boiler systems.

Figure 27: Ultramizer TMC Technology (manufacturer D) [19]

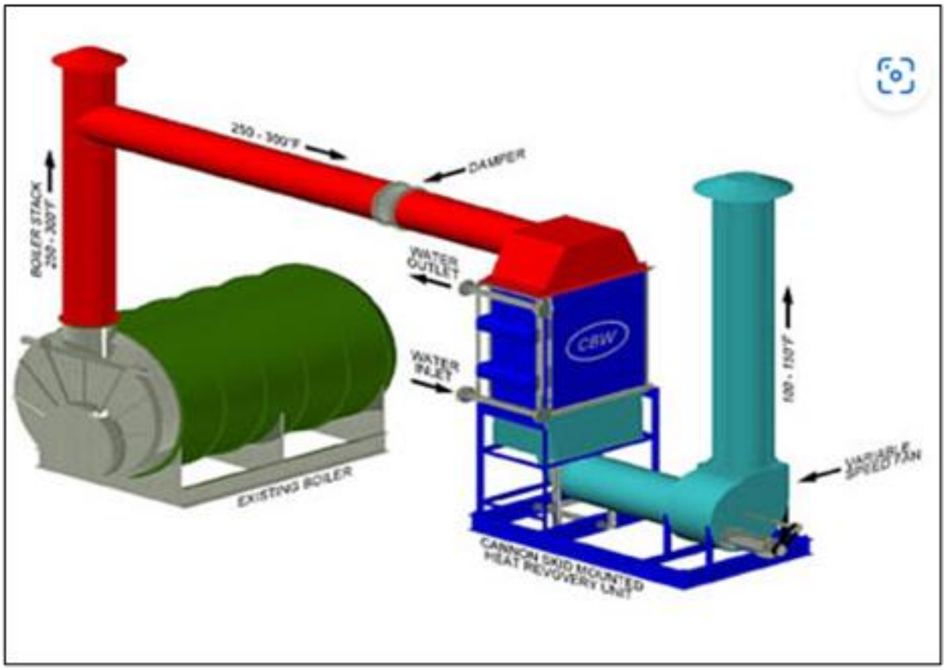
e) On-demand Condensing Economizer

Many sites have a site with space constraints where an economizer unit just won't fit onto customer's existing boiler. Some sites may prefer heat recovery units with better control on exit temperatures of flue gas and water. In such cases, an On-demand Condensing Economizer manufactured by manufacturer E would work the best.

Such a type of on-demand economizer (manufactured by manufacturer E) operates only when the system needs hot water, and the economizer unit can also be installed up to a 100 ft. distance from the boiler. The system runs the fan and pump only when heat is available and hot water is needed.

This automated type of on-demand economizer system may boost the boiler efficiency to over 90%. Also, this eliminates backpressure or condensation concerns. The incremental cost of this system is on the high side due to the additional cost of an induced draft fan in the system instead of the economizer working on back pressure of flue gases. In this type of a system, multiple small sized boilers can be coupled to a single condensing economizer. Figure 28 demonstrates a schematic diagram of on-demand condensing economizer system.

Figure 28: Schematic of On-demand Condensing Economizer System [20]



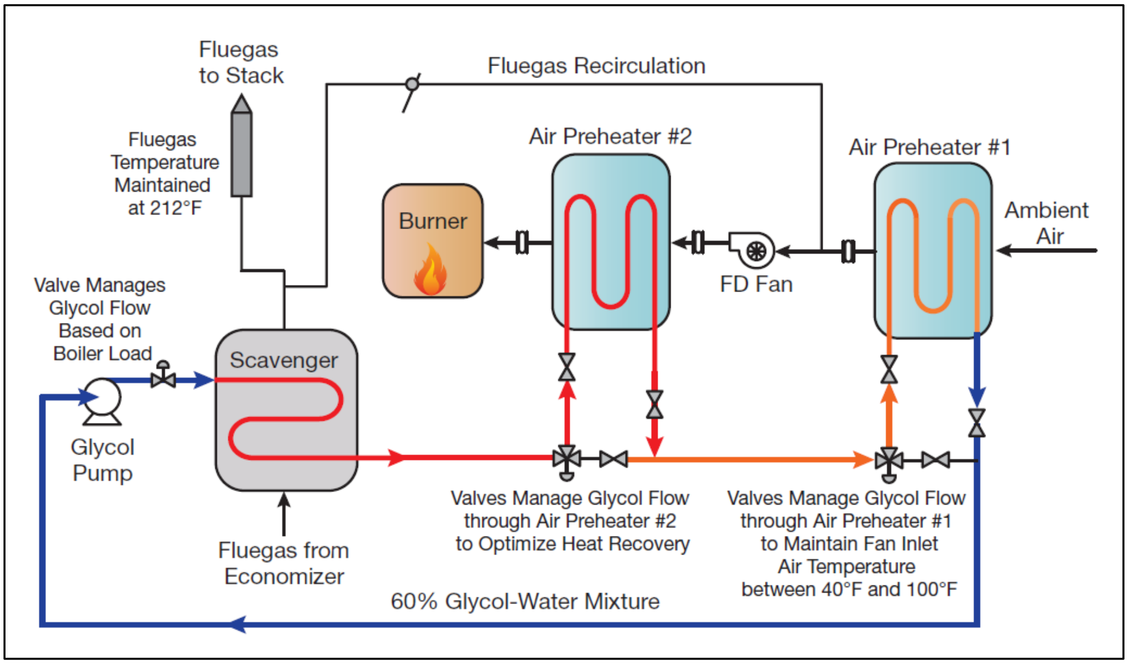
f) Glycol Scavenging Systems

A glycol scavenging system is a combustion air preheater that uses glycol as a heat transfer medium. In this type of a system, heat is transferred from the flue gas to the incoming combustion air. This system consists of a glycol scavenger to transfer the heat from flue gas to the glycol, a glycol pump skid to provide circulation and air preheater to transfer the heat from glycol to the combustion air. Refer to Figure 29 for a functional diagram of glycol scavenging system.

The first preheater heats the cold ambient air and maintains at a minimum temperature of 50^{O}F; eliminating the possibility of condensation during winter months. The second air preheater is located downstream of the fan that can heat the combustion air above 140^{O}F, which reduces the fuel consumption of the burner. As per the rules of thumb share by manufacturer F, this type of heat recovery system increases the boiler system efficiency by 2-3%.

A glycol-based heat recovery system can be used with any boiler system that includes a forced draft fan of a size larger than 200 HP. Adding this type of system to smaller sized boilers will require significant modifications to fan design and inlet ducting to the burner. Despite the advantage of better efficiency metrics delivery from the boiler, preheating the combustion air results in greater levels of NOx emissions.

Figure 29: Schematic of Glycol Scavenging System [21]



5. Remote Boiler Controller

Manufacturer G

This is a summary of a smart remote boiler controller manufactured by manufacturer G. A cloud platform monitors and creates optimizing analytics for facilities. The boiler equipment can be viewed on a secure webpage and alerts, or updates can be sent to mobile phones. The results can be seen on an easy-to-use dashboard in real time. This system provides more information about preventive maintenance and performance of boiler systems [22]. The available case studies and product literature do not correlate these benefits with direct energy efficiency gains of the system.

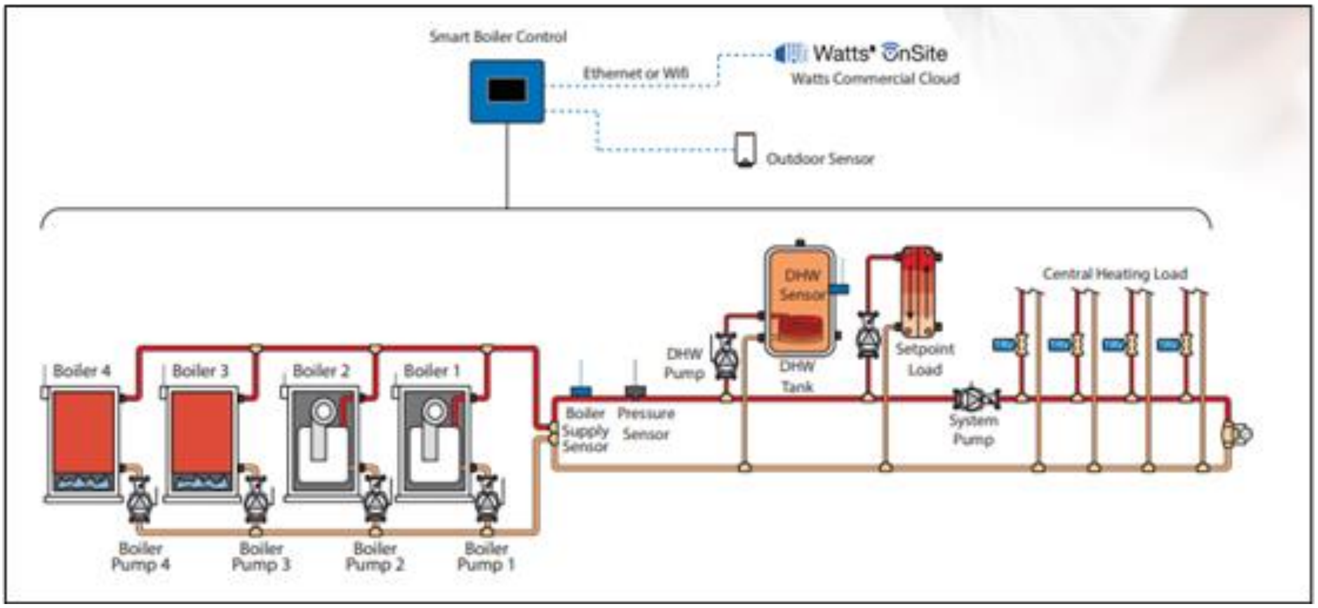
Manufacturer H

This is a summary of a smart remote boiler controller manufactured by manufacturer H. This provides an easy-to-use single solution for remote boiler monitoring. This allows the facility manager to control up to 16 boilers with expansion panels. Additionally, this can be integrated with the Building Management System for both new construction and retrofits.

This system sends alerts via text, email, and push notifications to help maintain boiler efficiency, operability, and performance real time. The operating settings of boilers and their sequencing can be changed remotely. This can result in operational, maintenance costs, repairs, and labor savings.

This remote boiler controller system avoids shutting down of hot water boilers and assigns priority to high efficiency boilers first, leading to possible energy savings at low loads. Figure 30 demonstrates a sample mechanical diagram for a smart remote boiler control system manufactured by H.

Figure 30: Mechanical Diagram of Remote Boiler Controller (Manufacturer H) [22]



6. Advancements in burner related technology, oxygen trimming and parallel positioning

Oxygen trim is a feature that maintains excess air at a desired level in a combustion system. This continually measures and maintains an optimum air-to-fuel ratio in a combustion zone. This helps to stabilize the combustion zone due to changes in temperature, atmospheric pressure, relative humidity and normal wear and tear.

Parallel positioning combustion control systems optimize burner fuel-to-air ratio by using high resolution actuators for fuel and air. These systems are an alternative to conventional complex linkage systems and facilitate the control of quantities of air and fuel delivered to the burner head independently.

Additional energy savings can be accrued when oxygen trim and VFD blower fan functionality are implemented. Figure 31 indicates a schematic of a parallel positioning system with additions of oxygen trim, Flue Gas Recirculation (FGR) and variable speed blower fan control. The rules of thumb (shared by manufacturer F) indicate that typical stand-alone parallel positioning systems increase boiler efficiency by 2-3%. Adding a blower fan VFD or oxygen trim system can further increase boiler efficiency by an additional 2-3%.

Following are the benefits of parallel positioning:

a. Better air-fuel ratio results in higher turndown up to 10:1. Higher turndown means less cycling that results in reduced fuel consumption.

b. Less hysteresis loss compared to a linkage control system. A parallel positioning system provides opportunities to improve performance with a servo motor for every point including air, oil, and gas.

c. Linkage less control and repeatability- Linkage systems require the burner to be setup with higher excess air levels because of changes in atmospheric pressure, temperature and normal wear and tear. Parallel positioning facilitates lower excess air levels because of repeatability, which increases the boiler efficiency.

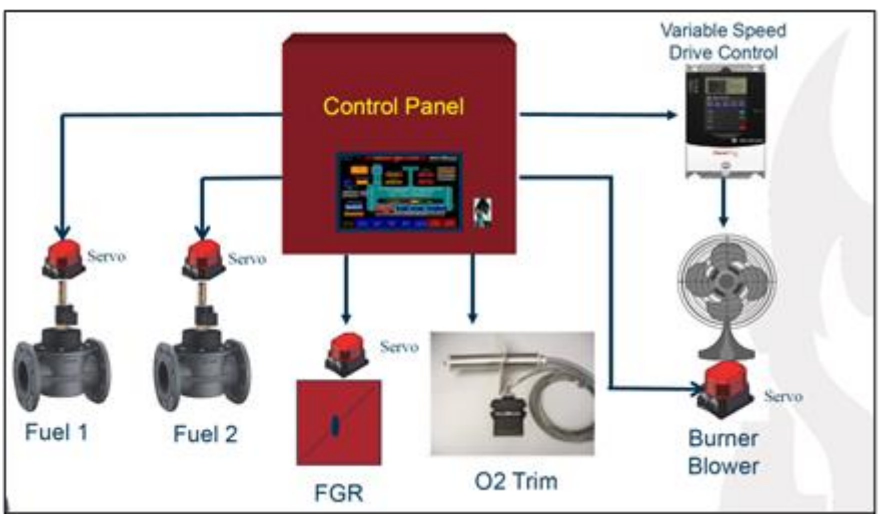
d. User interface of the control system has built in communication capabilities.

Following are the benefits of adding oxygen trim system in boiler combustion:

a. Better O_2 consistency in flue gas and better combustion

b. Fuel-air corrections in conjunction with ambient air temperature changes

Figure 31: Schematic of Parallel Positioning System (Manufactured by F)



Adding a VFD for controlling the combustion air facilitates better control of excess air over the entire firing range. The other benefits include- reduced wear and tear, increased turndown capabilities and noise reduction at mid-to-low speeds.

New Products and Emerging Technologies in Boilers

a) Concept of Dual Returns

See Figure 32 for a plot on Energy Efficiency vs Return water temperature and Figure 33 for a schematic of a combination plant with dual returns.

Figure 32: Thermal Efficiency vs Return water temperature (Manufacturer I) [23]

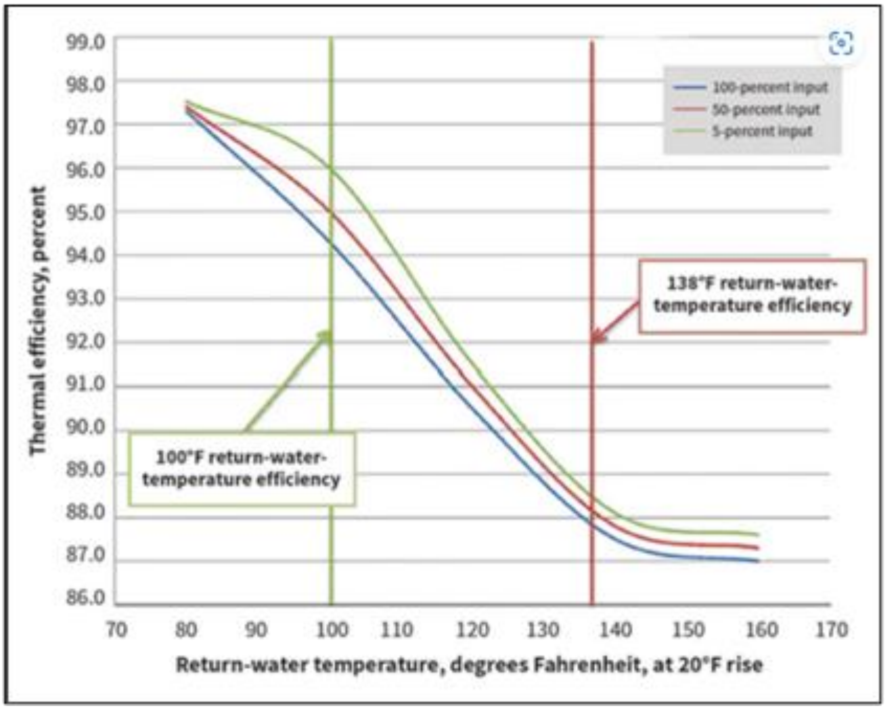
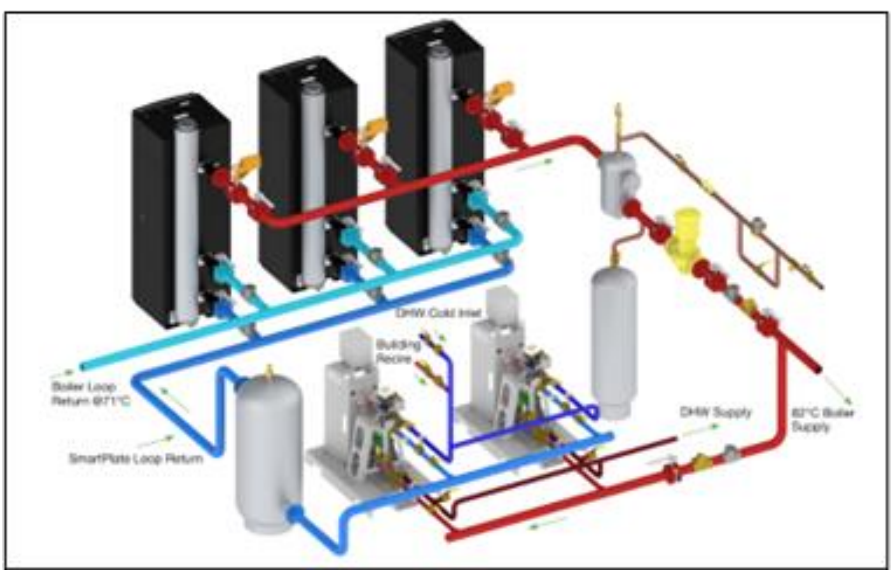


Figure 33: Combination plant with dual returns (Manufacturer I) [23]



Dual returns overcome the limitations of traditional condensing boilers with single returns. In hydronic systems with different loops (such as space heating and domestic hot water), the returns are blended. This compromises the actual performance of condensing boiler system. This is because the condensing zone of the heat exchanger is smaller and less efficient.

In a dual return system, fire tubes are used to connect a high temperature return (greater than 140^{o}F) to an upper inlet section and a low temperature return (less than 130^{o}F) to a lower inlet section. This results in a larger condensing zone that enhances boiler efficiency. Figure 45 demonstrates the impact of return water temperature on the thermal efficiency of the system.

Typical applications include- a system having both high temperature space heating and domestic hot water or pool heating needs. A high efficiency boiler with dual returns allows to take advantage of diverse load demands specific to a site. The systems incorporating dual returns provide installation flexibility as well. There are no minimum return temperature limitations, as with some conventional single return systems and multiple flow configurations are possible. Check valves must be installed at both return connections to prevent crossflow between the returns.

This manufacturer (I) has a product portfolio of SmartPlate water-water heat exchangers for combination systems to complement the performance of condensing boilers. These heat exchangers incorporate a stainless steel, brazed plate double wall style heat exchanger in a counter flow design. Additionally, these heat exchangers are designed for low supply temperatures to maximize system efficiency. Additionally, the efficiency gain for a combination boiler system with dual returns and an indirect heat exchanger would be between 3% to 5.5% on average.

b) Hydrogen blends in boilers

Hydrogen, as the primary or blending fuel, has had increased awareness as a method to reduce greenhouse emissions. The interactions and brief interviews with boiler manufacturers during AHRI Expo 2023 showed an inclination towards characterizing the boilers with respect to hydrogen blend percentage. The burners, manufactured by manufacturer J, can burn natural gas with a 30% hydrogen blend. All industrial boilers, manufactured by H, can also burn hydrogen up to 30%.

Hydrogen blending with natural gas in boilers is a great alternative [24]. At 10% hydrogen, CO_2 reduction is approximately 3.4% less. At 30% of hydrogen, CO_2 reduction is approximately 12% less. However, the article doesn't talk about the impact of hydrogen blends on NO_x emissions and boiler efficiency. A review of literature reveals a huge range of possible changes in NO_x emissions from hydrogen-natural gas blends. Some literature data indicates an increase in NOx emissions as hydrogen composition is increased [25]. Additionally, blending has no clear impact on energy efficiency of the system is noted based on the manufacturer interviews; however, note that Hydrogen has a low 325 Btu per cubic foot value, approximately one-third of a natural gas. Also, the flame speed of hydrogen is 10 times that of natural gas at standard pressures and temperatures [24]. Therefore, burner heads or diffusers will need to be redesigned to work with higher percentage blends of the lighter and faster burning fuel for pure hydrogen combustion. However, the manufacturer interviews indicated that such major equipment upgrades may not be necessary for blending hydrogen into natural gas. Further energy efficiency testing is recommended by researchers to determine the impact of hydrogen blending in a boiler.

Measure Table

The inputs from the literature review and boiler manufacturer interviews were used to draft a proposed measure table. The measure table comprises of the following information in a tabular format: measure description, Measure Application Type (MAT), estimated energy savings, applications, cost effectiveness and measure costs (if available). Refer to Appendix D: Measure Table for detailed information.

Potential measures derived from the U.S. DOE Tip Sheets and literature review:

Table 11: Measure Table: Literature Review

	Measure Description
1	Combustion air positive shutoff using automated flue damper
2	Combustion fan VFD
3	Combustion air preheater
4	Parallel positioning controls
5	Dynamic staged entrainment burner technology for Commercial Boilers/Burner Retrofit
6	O2 Trimming
7	Flue Gas Recirculation (FGR)
8	Blowdown Heat Recovery
9	Condensing economizer
10	Installing turbulators in boiler tubes (for fire tube boilers)

Potential measures derived from the boiler manufacturer interviews:

Table 12: Measure Table: Manufacturer Interviews

	Measure Description
1	On-demand economizer
2	Transport Membrane Condenser Technology
3	Rainmaker economizer (for hot water boilers)
4	Multi-stage economizers with side-by-side design (for hot water boilers)
5	Exhaust Vent Condenser
6	Energy recovery using a flash vessel
7	Flash Recovery Energy Management Equipment
8	Installing two element water level control
9	Remote boiler controller
10	Dual returns and smart plate heat exchanger
11	Glycol Scavenging Systems

The above measures were compared and weighed based on metrics such as potential energy saving estimates, measure cost, impact on NOx emissions etc.

The following measures or technologies are good candidates for near term hits for the deemed measure packages:

1. Combustion air positive shutoff using automated flue damper: This measure is cost effective for boiler size larger than 2.5 MMBTU/h [26]. Refer to Appendix D: Measure Table for detailed notes.
2. Combustion fan VFD: This measure is cost effective for combustion air fans with motors 10 HP or larger [26]. Refer to Appendix D: Measure Table for detailed notes.
3. Parallel positioning controls, O2 Trimming: This measure is cost effective for boilers of size 4.5 MMBTU/h or larger. Refer to Appendix D: Measure Table for detailed notes.
4. Installing turbulators in boiler tubes (for fire tube boilers): This measure is a low cost and easy to install design improvement of the boiler tubes.

Following measures or technologies are promising and recommended for field and/or lab testing and further analysis:

1. On-demand economizer
2. Transport Membrane Condenser Technology
3. Rainmaker economizer (for hot water boilers)

4. Multi-stage economizers with side-by-side design (for hot water boilers)
5. Exhaust Vent Condenser
6. Energy recovery using a flash vessel
7. Flash Recovery Energy Management Equipment
8. Installing two element water level control
9. Dual returns and smart plate heat exchanger

Notes:

1. Measures 1-4 have a potential large market for industrial boilers. Whereas measures 5-7 and 9 have a potential large market in hospitals and other commercial boilers applications.
2. Publicly available and standardized third-party performance data is lacking for the above technologies which also makes energy savings and/or cost effectiveness analysis challenging. Field and/or lab testing on all the commercially available products is recommended to obtain performance curve data, measure cost data, energy cost savings and installation configurations.

The following measures or technologies are not currently viable for measure package development and are not recommended for further analysis:

1. Combustion air preheater: Preheating of combustion air increases the burner flame temperatures resulting in greater levels of NOx emissions.
2. Flue Gas Recirculation (FGR): It reduces NOx emissions but has no direct impact on increasing energy efficiency of the boiler system.
3. Remote boiler controller: No direct impact on increasing the energy efficiency of the boiler system (except where existing boilers with varying part load efficiency can be operated with the most efficient one as baseload).
4. Glycol Scavenging Systems: Preheating of combustion air increases the burner flame temperatures resulting in greater levels of NOx emissions.

Potential Barriers in Measure Implementation

Following are the potential barriers in implementation of measures related to boiler add-ons:

- **Space constraint:** Some of the industrial boilers might have limited space to install the condensing economizer near the boiler. Some of the boiler manufacturers discussed that customers may be inclined towards installing the economizer at a distance from the boiler, if the site has any space constraints. Also, multiple boilers can also be paired to one flue gas stack economizer unit.

- **Variability in size of boilers:** The energy saving potential, technical feasibility and cost effectiveness of an add-on measure is also dependent on the size of boilers. For example, one of the manufacturers indicated that TMC technology might be effective only for smaller size of boilers. This is because as the tube diameter increases, the overall heat transfer in the ceramic heat exchanger decreases. The variability in size and applications of boilers is also an important parameter in selecting and installing condensing economizer.
- **Ease of installation and measure costs:** Several manufacturers discussed the importance of ease of installation in increasing the uptake of AOE measures for boilers. These measures require less labor and capital costs in infrastructure upgrades and are more likely to get implemented compared to the large capital ones which have higher installation and higher material costs.
- **Impact on NOx emissions:** A potential barrier or limitation of installing boiler add-on is its negative impact on reducing NOx emissions. For example, combustion air preheating increases boiler efficiency but also results in increased NOx emissions.

Results

Historical IOU participation data analysis demonstrates that more than 90% of the claims submitted during the years 2019-21 were for deemed measures. Many existing deemed boiler related measure claims focus on the entire boiler retrofit, except for the year 2019. This highlights that there is a significant opportunity for measure package development related to boiler add-ons.

Estimated Boiler Count for California state is summarized in the following table. The basis of information is previous case studies and publicly available data for boiler licensing.

Table 13: Boiler inventory categorization in California

	Sector	Number of Estimated Boilers
1	Multifamily	22,631
2	Industrial	3,170
3	Commercial	3,483
4	Others	151

Customer surveys (virtual screening and in-person site) were conducted to collect valuable information about the installed boilers and implemented energy efficiency measures. The survey also aimed to collect data regarding type of boiler, primary end usage and customer pain points in installing add-on related measures (if any). About 46 customers responded to the online survey with a low response rate and total of 5 site visits were completed. The measures such as Advanced burner technology, Flue Gas Recirculation (FGR) and VFDs on combustion fans were found to be more prevalent compared to other measures.

Boiler manufacturers and distributors were interviewed to understand emerging technologies and new products in boilers and accessories. About 25 boiler manufacturers and distributors were interviewed during November 2022 – April 2023 period. The inputs from the literature review and boiler manufacturer interviews were used to draft a measure table. The measure table comprises of the following information in a tabular format: measure description, Measure Application Type (MAT), estimated energy savings, applications, cost effectiveness and measure costs (if available). About 11 measures were derived from these interviews and further studied. Refer to Table 14 for the measure descriptions. A summary of the findings for each emerging technology was presented which includes the mechanism behind the technology, applications, advantages, limitations and estimated high-level energy savings.

Table 14: Measure Table (Manufacturer Interviews)

	Measure Description
1	On-demand economizer
2	Transport Membrane Condenser (TMC) Technology
3	Rainmaker economizer (for hot water boilers)
4	Multi-stage economizers with side-by-side design (for hot water boilers)
5	Exhaust Vent Condenser
6	Energy recovery using a flash vessel
7	Flash Recovery Energy Management Equipment
8	Installing two element water level control
9	Remote boiler controller
10	Dual returns and smart plate heat exchanger
11	Glycol Scavenging Systems

Potential implementation barriers of measures related to boiler add-ons include space constraint, variability in size of boilers, installation limitations, high upfront costs, and general adverse environment for implementing gas technologies.

Conclusions and Future Recommendations

Several technologies and commercially available new products in the boiler accessories segment are discussed in this project report. The selection of a particular solution for any packaged boiler depends on the size of boiler, scope of process, and application. The estimates provided here give a reasonable indication of the potential energy savings that can be achieved. Some of the market barriers are also discussed based on the inputs from customer surveys and boiler manufacturer interviews.

Publicly available and standardized third-party performance data is lacking for many technologies which also makes energy savings or cost effectiveness analysis challenging. The following technologies or products are promising and commercially available and field or lab testing is recommended.

1. On-demand economizer
2. Transport Membrane Condenser (TMC) Technology
3. Rainmaker economizer (for hot water boilers)
4. Multi-stage economizers with side-by-side design (for hot water boilers)
5. Exhaust Vent Condenser
6. Energy recovery using a flash vessel
7. Flash Recovery Energy Management Equipment
8. Installing two element water level control
9. Dual returns and smart plate heat exchanger

The GET Program could provide input to measure package development for the identified technologies or new products.

1. Combustion air positive shutoff
2. Combustion fan VFD
3. Parallel positioning controls, O2 Trimming
4. Installing turbulators in boiler tubes (for fire tube boilers)

The following measures are not viable for measure package development and not recommended for further analysis. This is due to no or less impact on energy savings and negative impact on reducing NOx emissions.

1. Combustion air preheater
2. Flue Gas Recirculation (FGR)
3. Remote boiler controller
4. Glycol Scavenging Systems

Note: The efficiencies of these add-on measures are not additive if there is a technology overlap.

Appendix A: Customer Survey Instrument

The following Figures A.1-5 demonstrate the snapshots of the online customer survey instrument:

Figure A.1: Survey Instrument-Snapshot of online survey form

California Statewide Gas Emerging Technologies (GET) Program Boiler Survey

The California Statewide Gas Emerging Technologies (GET) Program boiler survey will be used to create important industry benchmarks and help shape future innovation.

This invitation-only questionnaire covers four short sections, each taking less than two minutes to complete.

As a thank you for your time, we would like to offer you a $15 Amazon gift card for your completed survey. For those interested, there is also an opportunity to indicate if you'd like to participate in more in-depth interviews with additional compensation.

Figure A.2: Survey Instrument- Snapshot of online survey form

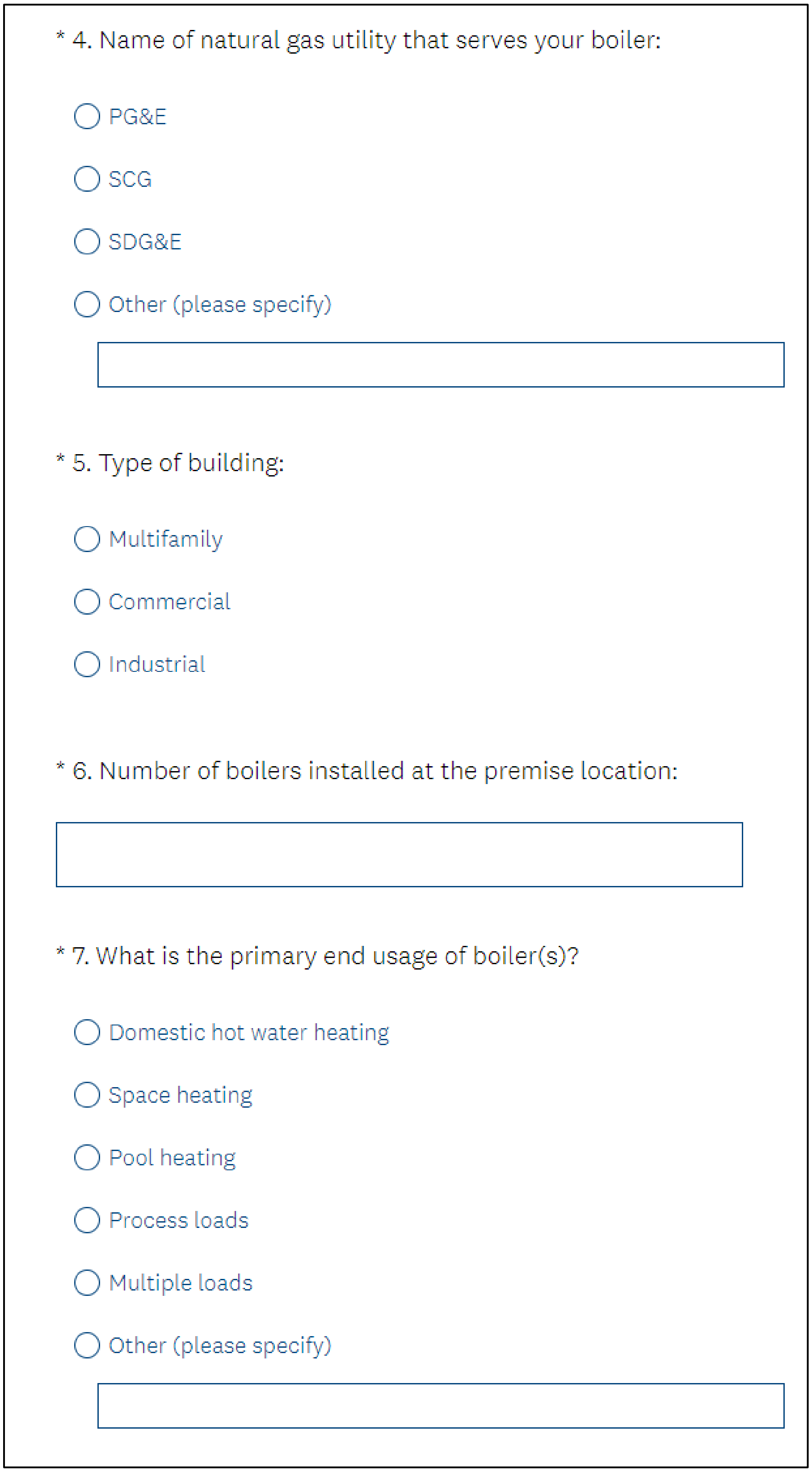
* 1. Name

* 2. Email

* 3. Do you have a natural gas-fired boiler at the site?

- Yes
- No

Figure A.3: Survey Instrument- Snapshot of online survey form



* 4. Name of natural gas utility that serves your boiler:

- PG&E
- SCG
- SDG&E
- Other (please specify)

* 5. Type of building:

- Multifamily
- Commercial
- Industrial

* 6. Number of boilers installed at the premise location:

* 7. What is the primary end usage of boiler(s)?

- Domestic hot water heating
- Space heating
- Pool heating
- Process loads
- Multiple loads
- Other (please specify)

Figure A.4: Survey Instrument- Snapshot of online survey form

* 8. Year of installation of boilers:

- ◯ Before 2000/2000-2010
- ◯ After 2010

* 9. Type of boilers(s)

- ◯ Fire tube
- ◯ Water tube
- ◯ Other (please specify)

* 10. Which of the following accessories OR strategies have you installed/implemented on the boilers?

- ☐ Flue Gas Recirculation (FGR)
- ☐ O2 Trimming
- ☐ Non-condensing or condensing economizer
- ☐ VFDs on combustion fans
- ☐ Advanced burner technologies (such as dynamic staged entrainment, low NOx burners)
- ☐ Automated flue dampers
- ☐ DHW Temperature modulation control
- ☐ DHW Demand control strategy
- ☐ Parallel positioning controls
- ☐ Combustion air preheater
- ☐ Blowdown heat recovery

Figure A.5: Survey Instrument- Snapshot of online survey form

11. Have you installed gas-fired infrared (IR) heaters/burners at your premise? If so, could you list the manufacturer, model, and/or low intensity/high intensity?

* 12. Do you provide ICF permission to send you a $15 Amazon e-gift card upon completion of this survey?

- ◯ Yes
- ◯ No

* 13. Would you be open to a hosting 1–2-hour site visit at your facility to allow the collection of more detailed information? (Note: You would be eligible for a $100 Amazon gift card) If yes, please provide the best contact information.

- ◯ No
- ◯ Yes

* 14. Would you like more information on available energy efficiency programs?

- ◯ Yes
- ◯ No

The following Figures A.6-9 demonstrate the snapshots of on-site survey instrument:

Figure A.6: Site survey instrument- snapshot

Building level information		
Type of building		
Number of buildings at complex		
Number of boiler(s) installed		
Number of reduntant or back up boiler(s)		
Year of building construction		
Representative year of manufacture of boiler(s)		
Any major renovations in the near past? (Y/N)		
Prior participation in EE programs? (Y/N)		
Other notes		

Figure A.7: Site survey instrument- snapshot

Boiler Specifications		
Type of boiler (Fire tube/water tube, hot water/steam)		
Year of installation of boiler		
End usage (DHW/Space heating/Combined usage)		
Loads served		
Boiler make details		
Boiler model and serial number		
Condensing/Non-condensing boiler?		
Rated efficiency (%)		
Combustion efficiency, if available (%)		
Input capacity in kBtu/h		
Output capacity in kBtu/h		
Boiler maintenance schedule (notes)		
Boiler repair history		
Other notes		

Figure A.8: Site survey instrument- snapshot

Boiler Characteristics		
Boiler economizer present? (Y/N)		
Type of economizer- condensing/non-condensing (Y/N)		
Automated flue damper present? (Y/N)		
VFDs on combustion fans? (Y/N)		
DHW Temperature setpoint details		
DHW Temperature control strategy notes		
Measure(s) installed		
Installation dates		
Notes about measure cost and savings		

Figure A.9: Site survey instrument- snapshot

Burner Specifications & Flue Gases		
Burner make details		
Burner model		
Notes regarding combustion control strategy		
Oxygen trimming present?		
Flue gas recirculation present?		

Appendix B: Survey Responses

Overall, 4,407 individuals were contacted on their email up to 5 times during the period from December 2022 to February 2023. This list included customers from all the sectors: Residential, Multifamily, Industrial and Commercial. An automated system was setup for sending out survey links through a survey platform as well as from the program email address. This customer outreach was coupled with $15 gift cards for each completed survey response.

Refer to Figures B.1-4 for the snapshots of customer survey responses.

Figure B.1: Summary of survey responses (Q. 1 - 4)

California Statewide Gas Emerging Technologies (GET) Program Boiler Survey		
Q1. Name		
Answered	**46**	
Skipped	**0**	
Q2. Email		
Answered	**46**	
Skipped	**0**	
Q3. Do you have a natural gas-fired boiler at the site?		
Answer Choices	Responses	
Yes	80.43%	37
No	19.57%	9
	Answered	**46**
	Skipped	**0**
Q4. Name of natural gas utility that serves your boiler:		
Answer Choices	Responses	
PG&E	23.08%	9
SCG	53.85%	21
SDG&E	5.13%	2
Other (please specify)	17.95%	7
	Answered	**39**
	Skipped	**7**

Figure B.2: Summary of survey responses (Q. 5 – 8)

Q5. Type of building:		
Answer Choices	Responses	
Multifamily	17.95%	7
Commercial	46.15%	18
Industrial	35.90%	14
	Answered	**39**
	Skipped	**7**

Q6. Number of boilers installed at the premise location:	
Answered	**39**
Skipped	**7**

Q7. What is the primary end usage of boiler(s)?		
Answer Choices	Responses	
Domestic hot water heating	30.77%	12
Space heating	20.51%	8
Pool heating	2.56%	1
Process loads	20.51%	8
Multiple loads	7.69%	3
Other (please specify)	17.95%	7
	Answered	**39**
	Skipped	**7**

Q8. Year of installation of boilers:		
Answer Choices	Responses	
Before 2000/2000-2010	54.84%	17
After 2010	45.16%	14
	Answered	**31**
	Skipped	**15**

Figure B.3: Summary of survey responses (Q. 9 – 12)

Q9. Type of boilers(s)		
Answer Choices	Responses	
Fire tube	45.16%	14
Water tube	29.03%	9
Other (please specify)	25.81%	8
	Answered	**31**
	Skipped	**15**

Q10. Which of the following accessories OR strategies have you installed/implemented on the boilers?		
Answer Choices	Responses	
Flue Gas Recirculation (FGR)	29.03%	9
O2 Trimming	19.35%	6
Non-condensing or condensing economizer	25.81%	8
VFDs on combustion fans	25.81%	8
Advanced burner technologies (such as dynamic staged entrainm	38.71%	12
Automated flue dampers	19.35%	6
DHW Temperature modulation control	16.13%	5
DHW Demand control strategy	3.23%	1
Parallel positioning controls	6.45%	2
Combustion air preheater	3.23%	1
Blowdown heat recovery	16.13%	5
	Answered	**31**
	Skipped	**15**

Q11. If Yes to Non-condensing or condensing economizer		
Answer Choices	Responses	
Installed new	100.00%	4
Retrofitted	0.00%	0
	Answered	**4**
	Skipped	**42**

Q12. Have you installed gas-fired infrared (IR) heaters/burners at your premise? If so, could you list the manufacturer, model, and/or low intensity/high intensity?	
Answered	**23**
Skipped	**23**

Figure B.4: Summary of survey responses (Q. 13 - 15)

Q13. Do you provide ICF permission to send you a $15 Amazon e-gift card upon completion of this survey?

Answer Choices	Responses	
Yes	81.48%	22
No	18.52%	5
	Answered	**27**
	Skipped	**19**

Q14. Would you be open to a hosting 1–2-hour site visit at your facility to allow the collection of more detailed information? If yes, please provide the best contact information.

Answer Choices	Responses	
No	66.67%	18
Yes	33.33%	9
	Answered	**27**
	Skipped	**19**

Q15. Would you like more information on available energy efficiency programs?

Answer Choices	Responses	
Yes	51.85%	14
No	48.15%	13
	Answered	**27**
	Skipped	**19**

Appendix C: Site Survey Responses

Table C.1: Summary of site surveys (Sites 1 and 2)

	Site #1	Site #2
Type of building	Commercial- Mixed Use	Commercial
Number of buildings at complex	1	2
SQ FT Area of Building	680|000	184|000
Number of boiler(s) installed	4	7
Number of reduntant or back up boiler(s)	NA	NA
Year of building construction	1977-78	1984
Representative year of manufacture of boiler(s)		
Any major renovations in the near past? (Y/N)	Y	
Prior participation in EE programs? (Y/N)		Y, Lighting and VFD measures
Other notes		
Utility Bills		
Boiler Specifications		
Type of boiler (Fire tube/water tube, hot water/steam)	Fire tube, hot water	Fire tube, hot water
Year of installation of boiler		3 in 1985, 4 in 2000-2005
End usage (DHW/Space heating/Combined usage)	Space heating	Space heating, DHW, Pool heating
Loads served		
Boiler make details	RBI, Raypak Boilers	
Boiler model and serial number		
Condensing/Non-condensing boiler?	1 Condensing Boiler	
Rated efficiency (%)		
Combustion efficiency, if available (%)	84%, 84%, 85%, 88% respectively	
Input capacity in kBtu/h	750	
Output capacity in kBtu/h	One 660, Three 5231 rated (125 HP)	Two 1158, Three 500 MBH
Boiler maintenance schedule (notes)		
Boiler repair history		Boiler retubing in Feb. 2023
Other notes	Lead-lag sequencing based on loop temperature	

Table C.2: Summary of site surveys (Sites 1 and 2)

	Site #1	Site #2
Boiler Characteristics		
Boiler economizer present? (Y/N)	N, one new condensing boiler	N
Type of economizer- condensing/non-condensing (Y/N)		
Automated flue damper present? (Y/N)	Y	N
VFDs on combustion fans? (Y/N)	Y	N
DHW Temperature setpoint details	180 F BMS setpoint	155 F setpoint for space heating, 84 F setpoint for pools
DHW Temperature control strategy notes		
Measure(s) installed	Burner upgrades, FGR, Automated Flue Dampers, VFDs on Combustion Fans	O2 Trimming, DHW temperature modulation
Installation dates	2012	
Notes	Driver for installing burner upgrades was AQMD requirement in 2012	Broken insulation observed
Burner Specifications & Flue Gases		
Burner make details	Power Flame	
Burner model	LNIC2-G-20A	
Notes regarding combustion control strategy		Low Nox burners in RBI packaged units
Oxygen trimming present?	Y, in packaged PowerFlame Low Nox Burners	
Flue gas recirculation present?	Y	

Table C.3: Summary of site surveys (Sites 3, 4 and 5)

	Building level information		
	Site #3	Site #4	Site #5
Type of building	Commercial- Office Building	Multifamily	Multifamily
Number of buildings at complex	1	89 units/3 stories	1
SQ FT Area of Building	120|000		
Number of boiler(s) installed	3	1	1
Number of reduntant or back up boiler(s)	NA		
Year of building construction	1973	1971	
Representative year of manufacture of boiler(s)			
Any major renovations in the near past? (Y/N)	Y, Change from low pressure steam to hot water non-condensing boilers		
Prior participation in EE programs? (Y/N)			
Other notes			
Utility Bills			
	Boiler Specifications		
Type of boiler (Fire tube/water tube, hot water/steam)	Hydronic hot water	Fire tube, hot water	Fire tube, hot water
Year of installation of boiler	2013		
End usage (DHW/Space heating/Combined usage)	Space heating, DHW		DHW
Loads served			
Boiler make details	Camus Hydronic Boilers	Raypak HI Delta Boiler	Raypak Boiler
Boiler model and serial number			
Condensing/Non-condensing boiler?			
Rated efficiency (%)			96%
Combustion efficiency, if available (%)	85% as per combustion test reports		
Input capacity in kBtu/h	All 3.4 MMBtu/h		999|000
Output capacity in kBtu/h	All 4 MMBtu/h		959|040
Boiler maintenance schedule (notes)			
Boiler repair history			
Other notes	All boilers run on the same % load; one leading and other two lagging		

Table C.4: Summary of site surveys (Sites 3, 4 and 5)

	Site #3	Site #4	Site #5
	Boiler Characteristics		
Boiler economizer present? (Y/N)			N
Type of economizer- condensing/non-condensing (Y/N)			
Automated flue damper present? (Y/N)	N		N
VFDs on combustion fans? (Y/N)			N
DHW Temperature setpoint details	120 F setpoint on weekends 180 F on weekdays		
DHW Temperature control strategy notes			
Measure(s) installed			
Installation dates			
Notes	1) The building is pre-heated on the weekends. 2) Non-condensing boilers retrofit due to high investment cost on condensing retrofit and reliability concerns on peak days.	The building manager had limited info about the boilers and present conditions.	
	Burner Specifications & Flue Gases		
Burner make details	Packaged Camus Hydronic Boiler		
Burner model			
Notes regarding combustion control strategy			
Oxygen trimming present?			N
Flue gas recirculation present?			N

Appendix D: Measure Table

Figure D.1: Snapshot of Measure Table (Measures 1 – 6 enlisted from literature review)

Measure #	Measure	Measure Application Type	Type of Building (if any)	Measure Costs	Savings			Payback/Cost Effectiveness	EUL
					Therms and kWh Savings	Cost Savings	Efficiency		
1	Combustion air positive shutoff using flue damper	NC, AOE	All	$1,500 for 2.5 MMBtu/h unit	Annual savings = 229 therms	PV (Energy savings) = $3,460 PV (Maintenance) = $112 PV (Energy savings) = $3,460		Benefit/cost ratio = 2.1 LCC = $1,848	15 years
2	Combustion fan VFD	TBD	All	$4,249 for 10 HP motor	Annual savings = 6,943 kWh	PV (Energy savings) = $6,333 PV (Maintenance) = $597	Increase in efficiency by 2-3%	Benefit/cost ratio = 1.3 LCC = $1,487	15 years
3	Parallel positioning controls	TBD	All	$9,000 for 5 MMBtu/h unit	Annual savings = 1,054 therms	PV (Energy savings) = $15,984 PV (Maintenance) = $4,775	Increase in boiler efficiency by 2-3%	Benefit/cost ratio = 1.2 LCC = $2,209	15 years
4	Dynamic staged entrainment burner technology for Commercial Boilers	TBD	All		Annual savings for 250 BHP boiler Gas- 736 MMBtu Electricity- 11,432 kWh		2% efficiency increase compared to boilers with FGR/HEA/SCR		
5	Domestic hot water temperature controller	AOE	MF & Commercial Boilers	MF: $288 for 5 units, $28 for 40 units C: $87 for 25 units, $15 for 250 units	1,526 therms/year			Range from the permutations file- eTRM TRC ratio varying from 0.08 to 3.99 TSB varying from 7.47 to 104.94	5 years
6	Domestic hot water temperature controller with continuous monitoring	AOE	MF & Commercial Boilers				Same magnitude of gas savings as above		5 years

Figure D.2: Snapshot of Measure Table (Measures 1 – 6 enlisted from literature review)

Measure #	Measure	Avoided Emissions	Notes	Existing MP (Y/N)	Reference WP/study
1	Combustion air positive shutoff using flue damper	C02- 2,702,500 lbs, NOx - 2,327 lbs, SOx - 1,575 lbs	2. This measure saves 30% of total standby losses; which are 2% of rated fuel input	N	CASE: 2013 California Building Energy Efficiency Standards www.efiling.energy.ca.gov
2	Combustion fan VFD	C02- 10,114,431 lbs, NOx - 2,762 lbs, SOx - 16,562 lbs	1. The baseline motor load is assumed at 100%; Load factor = 0.7 2. VFD fan motor load calculated using fan affinity laws; fan speed using correlation (correlation equation for blower speed and firing rate)	N	CASE: 2013 California Building Energy Efficiency Standards www.efiling.energy.ca.gov
3	Parallel positioning controls	C02- 36,144,500 lbs, NOx - 31,116 lbs, SOx - 21,058 lbs	1. Parallel positioning controls optimize the combustion excess air to improve efficiency 2. Establish air damper positions as a function of fuel valve positon for all firing rates	N	CASE: 2013 California Building Energy Efficiency Standards www.efiling.energy.ca.gov
4	Dynamic staged entrainment burner technology for Commercial Boilers	CO2- 48 tons, NOx- 8 lbs	1. This technology was developed by GTI to achieve NOx emissions < 9 vppm without compromising on energy efficiency 2. Estimated 9% fuel consumption savings compared to the baseline boiler, Operational reliability at lower firing rates	N	CEC-500-2021-045: Demonstration of a Novel Ultra-Low Oxides of Nitrogen Boiler for Commercial Buildings
5	Domestic hot water temperature controller		1. The temperature modulating boiler controller is AOE for central water heating system. 2. This AOE minimizes supply and return water temperatures and piping heat losses. 3. This controller lowers the storage water/boiler temperature according to DHW usage.	Y	SWWH016 eTRM CA Energy Efficiency Source Data
6	Domestic hot water temperature controller with continuous monitoring		1. The continuous monitoring improves the realization rate of the DHW Controller implementation. 2. This also helps in fault detection and diagnostics	Y	

Figure D.3: Snapshot of Measure Table (Measures 7 – 12 enlisted from literature review)

Measure #	Measure	Measure Application Type	Type of Building (if any)	Measure Costs	Savings			Payback/Cost Effectiveness	EUL
7	Central boiler dual setpoint temperature controller	AOE	Multifamily boilers	$1000 Controller costs $20/unit installation cost				Range from the permutations file- eTRM TRC ratio varying from 0.39 to 0.78 TSB varying from 27.97 to 55.91	
8	Condensing boiler economizer	AOE, NC	Commercial & Industrial Steam Boilers	$1.05/kBtuh for single stage			Baseline Efficiency: 79%		RUL = 6.7 years
				$1.03/kBtuh for double stage			Proposed Efficiency Feedwater Economizer: 81.4% Condensing Economizer: 87.2%	Range from the permutations file- eTRM TRC ratio varying from 3.37 to 9.53 TSB varying from 3.37 to 21.63	EUL = 15 years
9	O2 Trimming	TBD					Increase in boiler efficiency by 2-3%		
10	Combustion air pre-heater	AOE					Increase in boiler efficiency by 2-3%		
11	Blowdown heat recovery	TBD	All steam boilers		MMBTU/hr savings is a function of steam pressure and % blowdown rate				
12	Flue gas re-circulation (FGR)	TBD							

Figure D.4: Snapshot of Measure Table (Measures 7 – 12 enlisted from literature review)

Measure #	Measure	Avoided Emissions	Notes	Existing MP (Y/N)	Reference WP/study
7	Central boiler dual setpoint temperature controller		1. Controlling supply water temperature reset based on outside air temperature 2. Applicable to hot water systems < 500,000 Btu/h and for buildings built before 2005	Y	SWWH024/02/
8	Condensing boiler economizer		1. The saving potential is based on the existing stack temperature, volume of make-up water and hours of operation.	Y	www.caetrm.com/measure/SWPR007/01/
				N	
9	O2 Trimming			N	
10	Combustion air pre-heater			N	
11	Blowdown heat recovery			N	https://www.energy.gov/sites/prod/files/2014/05/f16/steam10_boiler_blowdown.pdf
12	Flue gas re-circulation (FGR)			N	

Figure D.5: Snapshot of Measure Table (Measures 13 – 23 enlisted from manufacturer interviews)

Measure #	Measure	Measure Application Type	Type of Building (if any)	Measure Costs	Savings			Payback/Cost Effectiveness	EUL
13	On-demand economizer	AOE	Commercial, Industrial boilers				Boiler efficiency over 90%		
14	Ultramizer Technology						Fuel-to-steam efficiency between 92-94%		
15	Rainmaker economizer (for hot water boilers)						Increase in boiler efficiency between 5-12%		
16	Multi-stage economizers with side by side design (for hot water boilers)								
17	Exhaust Vent Condenser		All steam boilers		1% fuel savings and 1% water savings				
18	Energy recovery using a flash vessel		All steam boilers		1.7% fuel savings for 10% blowdown rate				
19	Frash Recovery Energy Management Equipment		All steam boilers			26% energy cost savings	Increase in boiler efficiency by 5.5%		
20	Installing two element water level control		All steam boilers				Increase in boiler efficiency by 1-2%		
21	Remote boiler controller		All boilers		Operational, maintenance costs, repairs and labor savings				
22	Dual returns and smart plate heat exchanger	TBD	All boilers				Increase in boiler efficiency by 3-5.5%		
23	Glycol Scavenging Systems						Increase in boiler efficiency by 2-3%		

Figure D.6: Snapshot of Measure Table (Measures 13 – 23 enlisted from manufacturer interviews)

Measure #	Measure	Avoided Emissions	Notes	Existing MP (Y/N)	Reference WP/study
13	On-demand economizer			N	
14	Ultramizer Technology			N	www.utd-co.org/wp-content/uploads/2021/12/UTD_Annual_Report_Research_Project_Summaries_2020-21.pdf
15	Rainmaker economizer (for hot water boilers)			N	
16	Multi-stage economizers with side by side design (for hot water boile			N	
17	Exhaust Vent Condenser			N	
18	Energy recovery using a flash vessel			N	
19	Frash Recovery Energy Management Equipment			N	
20	Installing two element water level control			N	
21	Remote boiler controller			N	
22	Dual returns and smart plate heat exchanger			N	
23	Glycol Scavenging Systems		Typically for larger sized boiler systems (> 200 HP)	N	www.aiche.org/cep

Figure D.7: Snapshot of Measure Table (Measures 24 and 25 enlisted from U.S. DOE Tip Sheets)

Measure #	Measure	Measure Application Type	Type of Building (if any)	Measure Costs	Savings		
24	Installing turbulators in boiler tubes (for fire tube boilers)	AOE	All fire tube boilers	$15 for each turbulator			Increase in boiler efficiency by 2-3%
25	Burner retrofit	AOE	All boilers		1% efficiency rise- 6,250 MMBTU/yr 2% efficiency rise- 12,345 MMBTU/yr 3% efficiency rise- 18,290 MMBTU/yr		

Figure D.8: Snapshot of Measure Table (Measures 24 and 25 enlisted from U.S. DOE Tip Sheets)

Measure #	Measure	Avoided Emissions	Notes	Existing MP (Y/N)	Reference WP/study
24	Installing turbulators in boiler tubes (for fire tube boilers)			N	www.energy.gov/sites/prod/files/2014/05/f16/steam25_firetube_boilers.pdf
25	Burner retrofit			N	www.energy.gov/sites/prod/files/2014/05/f16/steam24_burners.pdf

References

[1] C. Schoeneberger, J. Zhang, C. McMillan et al. (2022), Electrification potential of U.S. industrial boilers and assessment of the GHG emissions impact, Advances in Applied Energy 5 (2022) 100089, https://doi.org/10.1016/j.adapen.2022.100089.

[2] Final Report by Cadmus (2019), California Statewide Multifamily Boiler Market Assessment, Prepared for SoCalGas, CALMAC ID: SCG0225.01.

[3] https://www.epa.gov/ghgreporting/data-sets (Last visited in August 2022).

[4] Final Report by Cadeo (2020), Oregon Commercial and Industrial Boiler Market Characterization Memo, Developed for Energy Trust of Oregon.

[5] Conservation Applied Research and Development Final Report (2018), Quality Installation and Retro-commissioning of High-Efficiency Condensing Boilers, Prepared for Minnesota Department of Commerce, Division of Energy Resources.

[6] Public Records Requests Processed by AQMDs in California.

[7] https://www.energy.gov/sites/prod/files/2014/05/f16/steam13_vent_condenser.pdf.

[8] https://www.energy.gov/sites/prod/files/2014/05/f16/steam10_boiler_blowdown.pdf.

[9] https://www.energy.gov/sites/prod/files/2014/05/f16/steam24_burners.pdf.

[10] https://www.energy.gov/sites/prod/files/2014/05/f16/steam26a_condensing.pdf.

[11] www.energy.gov/sites/prod/files/2014/05/f16/steam25_firetube_boilers.pdf.

[12] https://cedars.sound-data.com (Last visited in October 2022).

[13] https://www.caetrm.com/ (Last visited in October 2022).

[14] www.spiraxsarco.com/learn-about-steam/the-boiler-house/controlling-tds-in-the-boiler-water#article-top.

[15] https://www.spiraxsarco.com/learn-about-steam/the-boiler-house/heat-recovery-from-boiler-blowdown-tds-control-only#article-top .

[16] https://content.spiraxsarco.com//media/spiraxsarco/international/documents/au/sb/freme-sb-p575-01-au.ashx?rev=9c132691dc8e49249c81d6b87163dd18.

[17] https://www.spiraxsarco.com/learn-about-steam/the-boiler-house/automatic-level-control-systems#article-top.

[18] http://heatsponge.com/

[19] https://mn.gov/commerce-stat/pdfs/ultramizer-heat-and-water-recovery-system.pdf.

[20] https://cannonboilerworks.com/wp-content/uploads/On-Demand-brochure.pdf.

[21] Daniel Skiles (2014), Improve the Performance of Your Boiler System, American Institute of Chemical Engineers (AIChE).

[22] https://www.preferred-mfg.com/products/controls/the-preferred-cloud-platform.html.

[23] www.aerco.com/combination.

[24] https://digital.bnpmedia.com/publication/?i=722587&oly_enc_id=4946C7834912C7Y?oly_enc_id=4946C7834912C7Y

[25] Madeleine L. Wright et.al. (2022), Emissions of NOx from blending of hydrogen and natural gas in space heating boilers. https://doi.org/10.1525/elementa.2021.00114.

[26] CASE: 2013 California Building Energy Efficiency Standards www.efiling.energy.ca.gov.