December 17, 2020

Oregon Commercial and Industrial Boiler Market Characterization Memo

Developed For

Energy Trust of Oregon
421 SW Oak St. #300
Portland, OR 97204

Developed By

Cadeo Group
107 SE Washington St., Suite 450
Portland, OR 97214

Memorandum

To: Phil Degens, Energy Trust of Oregon
From: Bretnie Eschenbach, Cadeo
Date: December 17, 2020
Re: Oregon Commercial and Industrial Boilers Market Characterization

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Introduction

Cadeo conducted a high-level market characterization of the Oregon boiler market in the fall of 2020. This research sought to characterize the commercial and industrial natural gas boiler market to inform energy savings potential estimates and program opportunities for the Energy Trust of Oregon (Energy Trust).

This memo describes our methodology, the market characterization and efficiency opportunity findings, and our program recommendations and opportunities for future research. A workbook is available upon request that supplements this memo, which contains boiler market characterization data, market analysis, and program opportunity detail.

Our key program and research recommendations from the research include:

1. Creating targeted commercial boiler retrofit programs specific to schools
2. Incentivizing condensing boiler performance as opposed to the condensing boiler itself
3. Tailoring industrial programs to boiler system improvements as opposed to boiler replacement
4. Supporting the Regional Technical Forum's (RTF) measure development and future research
5. Conducting further research into the industrial boiler market to fill data gaps
6. Interviewing boiler technicians, tune-up implementers, and boiler operators to inform program design

Methodology

Cadeo performed three activities to better understand the boiler market and the efficiency opportunities available to the Energy Trust:

1. Conducted a **market characterization** from available data sources to identify the number of commercial and industrial boilers installed in Oregon and where they are located
2. Conducted six **market actor interviews** to better understand the boiler market and identify regional opportunities

3. Performed a broad **efficiency scan** to understand what boiler efficiency opportunities exist and the measures boiler efficiency programs are incenting

The following section describes the methodology the team used to perform these three activities. The full list of sources referenced in this document and consulted for the memo and the supplementary workbook are listed in Appendix A. Source List.

Market Characterization

Our first step in understanding the natural gas boiler market in Oregon included a review the available data sources to develop an estimate of the current installed stock of commercial and industrial boilers. The primary market characterization sources were:

- **The State of Oregon's Database of Active Vessels (Oregon Database)**. The Oregon Database tracks all permitted pressurized vessels in the state of Oregon, including boilers. Using this data source, we characterized all boilers and, where possible, identified those fueled by natural gas. For the purposes of this memo, findings from this source will be limited to natural gas boilers.
- **The 2019 Commercial Building Stock Assessment (CBSA).** The CBSA provided a more detailed snapshot of the commercial boiler stock in the Northwest and filled gaps in the Oregon Database information by including efficiency, capacity, and building type. The team limited the CBSA data to sites in Oregon and estimated the total number of representative boilers by multiplying the number of identical boilers and building sample weight.
- **Additional federal and state energy studies, reports, and data.** We reviewed a number of federal and state publications to supplement the Oregon Database and the 2019 CBSA and gain additional insight into the commercial and industrial boiler markets in Oregon, including:
    - DOE's 2005 Characterization of U.S. Industrial and Commercial Boiler Population
    - The Energy Information Administration (EIA)'s 2018 Oregon State Profile and Energy Estimates
    - The Oregon Public Utility Commission's 2019 Oregon Utility Statistics
    - The DOE Commercial Packaged Boilers Standard's Technical Support Document (TSD)
    - DOE's Compliance Certification Database
    - DOE's ENERGY STAR certification for commercial boilers

We used these data sources to develop high level market characterization calculations, including an estimate of the number of boilers in Oregon by sector, boiler type, fuel type, age, and transport vs non-transport natural gas fuel customer.[1] We also conducted high-level calculations

[1] We define transport customers as natural gas customers that purchase fuel directly from a gas transmission company as opposed to a natural gas utility company, also referred to as brokered and non-brokered customers.

of the energy consumption associated with commercial and industrial natural gas boilers, both for transport and non-transport customers, found in the supplemental workbook.

Market Actor Interviews

In addition to the secondary source review, the team conducted interviews with regional experts on the commercial and industrial boiler market in the Northwest. The team interviewed the three investor-owned natural gas utilities operating in Oregon (Avista, Cascade Gas, and NW Natural), two industry associations specializing in natural gas (Northwest Gas Association [NWGA] and the Gas Technology Institute [GTI]), and a regional market expert on commercial and industrial boilers in the Northwest. The team sought these experts' insights on the following topics:[2]

- **Types of Boilers.** What types of boilers are most common in the commercial sector and industrial sector, respectively? What is the average useful life expectation of a steam boiler versus a hot water boiler? What types of boilers are most common by building type?
- **Boiler Operation.** How are boilers operating in the field? Are there any lessons learned about operational opportunities, either in commercial or industrial boilers?
- **Transport vs Non-Transport Customers.** What portion of natural gas customers are transport customers versus non-transport, and what are the key characteristics of both?
- **Market Trends.** What trends in Oregon are affecting the boiler market? For example: electrification or trends in major Oregon industries.
- **Program Opportunities.** What are the best opportunities to save gas energy is from boilers? How obtainable are those savings, and what are the challenges?

Efficiency Scan

Finally, we performed an efficiency scan to understand the scope of utility commercial and industrial boiler programs, the recommended boiler upgrade and retrofit guidance, and commercial and industrial boiler control strategies. We reviewed the following sources to evaluate the available commercial and industrial boiler measures:

- Consortium for Energy Efficiency (CEE), which provides guidance to utilities on boiler upgrade and efficiency recommendations with definitions
- DOE's Federal Energy Management Program (FEMP), which provides boiler efficiency recommendations and requirements for federal buildings
- Minnesota Consortium for Energy Efficiency (MNCEE), which studied savings associated with five energy efficiency measures and their savings on the sampled buildings

[2] Appendix B includes the full interview guide.

- North Carolina Clean Energy Technology Center's "DSIRE" database, which provides information on current commercial and industrial boiler measures run by utilities in the U.S.

Market Characterization Findings

As described in the Methodology section, we reviewed the Oregon Database, the 2019 CBSA, and federal and state energy data sources to characterize the commercial and industrial natural gas boiler market and identify energy savings potential and opportunities in Oregon. We also conducted six market actor interviews to fill gaps and further characterize the boiler market.

This section describes the key findings from the market characterization,[3] summarized in two categories:

1. Findings related to the overall Oregon boiler market and gas consumption estimates from the Oregon Database, Oregon energy data, and national trends
2. Findings specific to commercial boilers from the 2019 CBSA

Limited data exist specific to the industrial boiler market, so the Market Characterization Findings does not include a section specific to industrial. Instead, we included findings related to the industrial boiler market in the first section addressing the total Oregon boiler market.

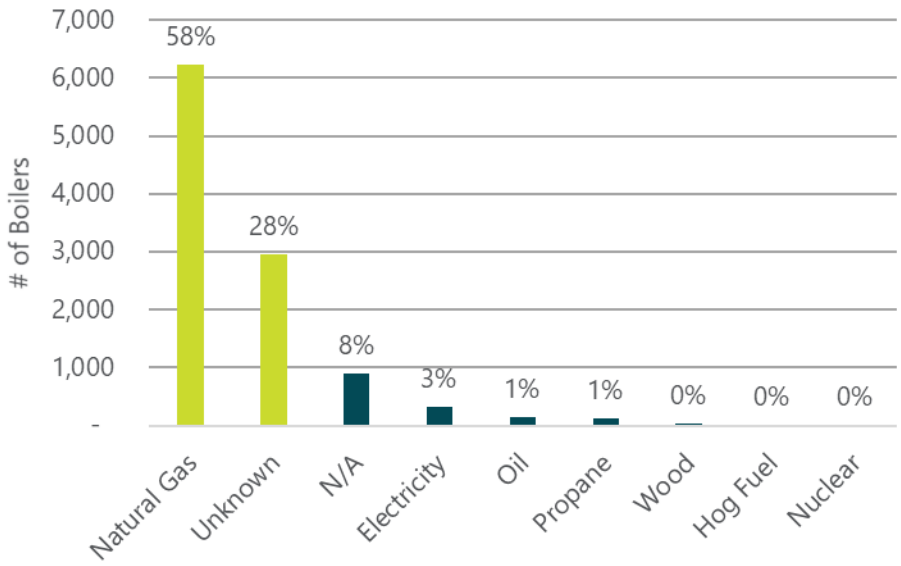
Oregon Boiler Market and Gas Consumption Findings

We first characterized the total boiler market by identifying boilers by fuel type. An estimated 86% of boilers in the Oregon Database are natural gas boilers.[4]

[3] The supplementary workbook, available on request from Phil Degens (phil.degens@energytrust.org) at Energy Trust, contains more detail on these findings.

[4] 28% of the boilers in the Oregon database were labeled as "unknown" fuel type. Since 99% of boilers in the CBSA were natural gas, we assumed all of the "unknown" boilers were natural gas.

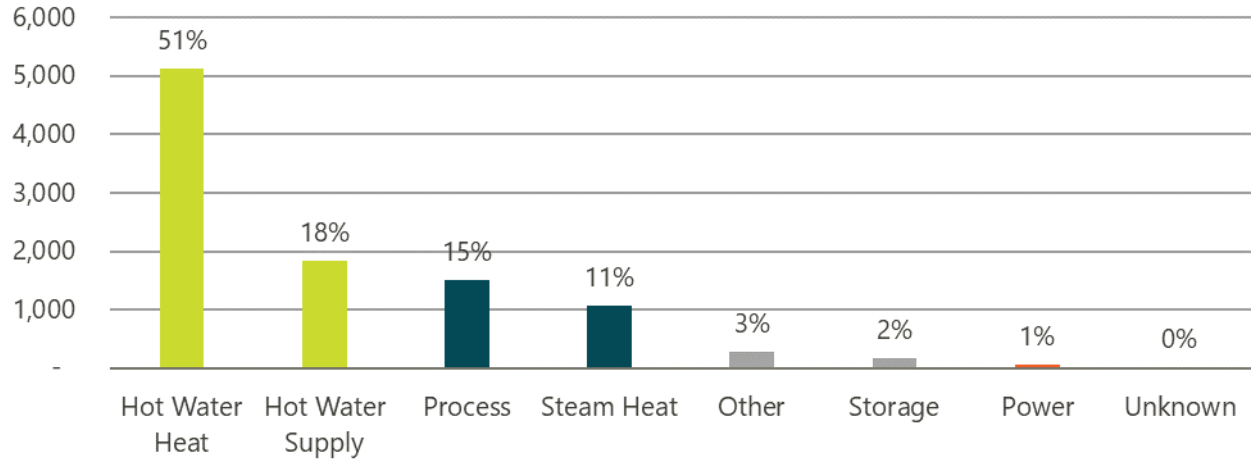
Figure 1: Oregon Boilers by Fuel Type (Oregon Database)



Hot Water vs Steam Boilers

After filtering the Oregon Database for only natural gas boilers, we found 70% of Oregon's commercial and industrial boilers are hot water boilers. Steam boilers account for 26% of Oregon's boilers, and power generation only accounts for 1% of Oregon's boilers.

Figure 2: Oregon Boilers by End Use (Oregon Database)[5]



[5] We assumed Hot Water Heat and Hot Water Supply boilers were hot water boilers, and Process and Steam Heat were steam boilers.

These findings are consistent with DOE's Commercial Packaged Boiler rulemaking documents, which indicate the market share of gas-fired hot water boilers is increasing, while steam boilers and non-gas boilers are decreasing.

The Oregon Database does not identify if a boiler is in a commercial or industrial application, so we assumed hot water boilers appear most often in commercial applications and steam boilers appear most often in industrial applications, although both boiler types are installed in both sectors.

Boiler Vintages

We further explored hot water and steam boilers by age and found that buildings are replacing hot water boilers much more frequently than steam boilers. Of the hot water boilers, 72% were manufactured in the past 20 years, while only 49% of the steam boilers were manufactured in the same time period.

Figure 3: Number of Hot Water Boilers by Vintage

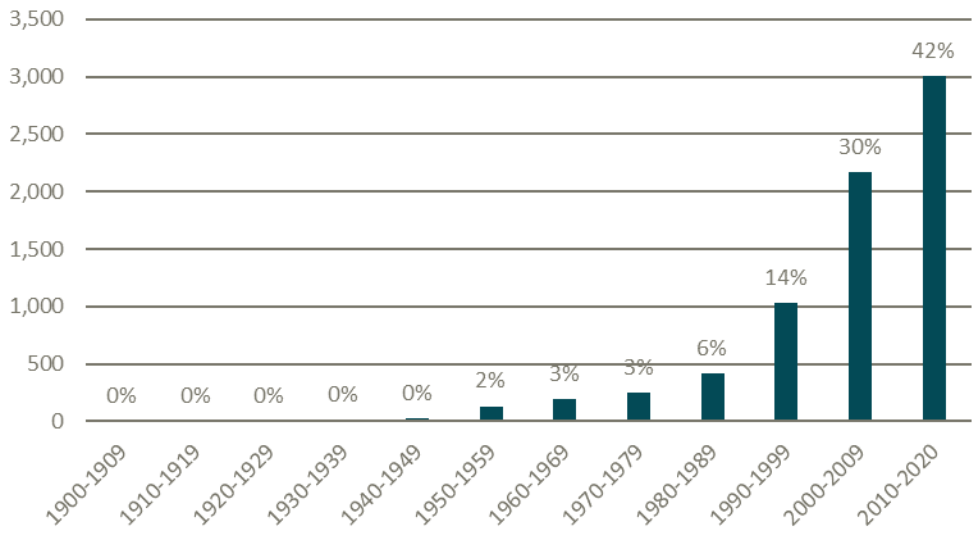


Figure 4: Number of Steam Boilers by Vintage

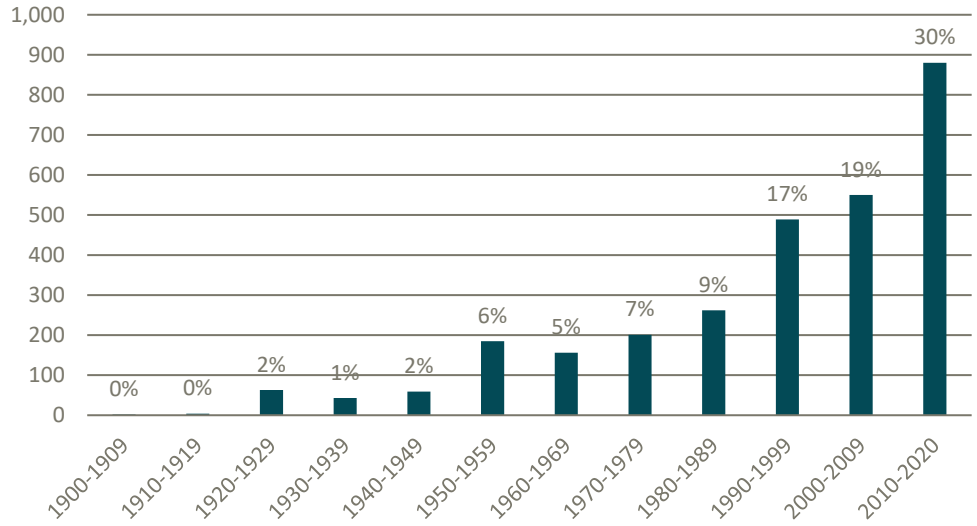
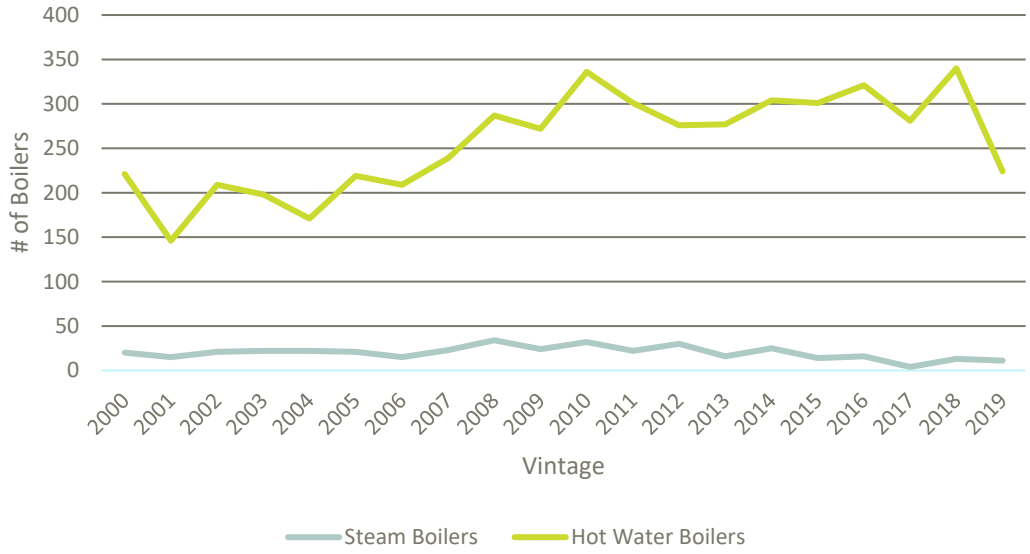


Figure 5: Number of Boilers by Vintage and Type, 2000-2019

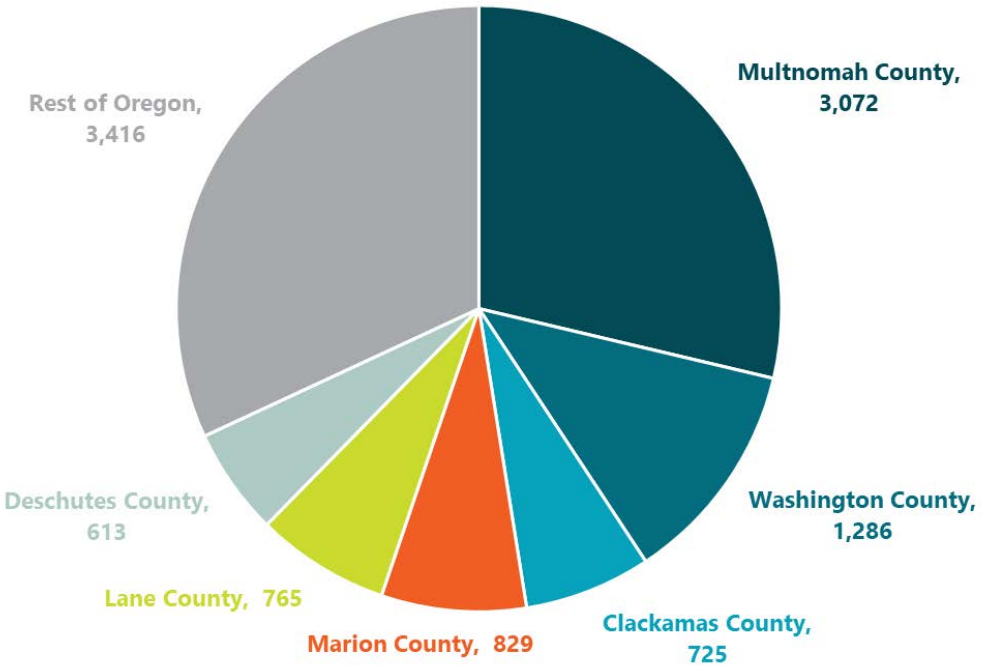


The efficiency industry commonly describes the boiler market as older vintage, with some market experts implying a prevalence of barely-functioning boilers in ancient boiler rooms. The interviewees we spoke with explained that while many commercial and industrial buildings have boilers older than 20 years (a commonly cited expected life), many actually operate well and efficiently. When operators maintain boilers well, the mechanical components can last a very long time. Efficiency programs have discounted or ignored opportunities for boilers beyond their estimated useful life, focusing instead on the purchase of a new boiler. The efficiency industry could realize significant savings by thinking more broadly about savings opportunities from boilers beyond their traditionally defined expected useful life.

Boiler Geographic Location

We also reviewed the boiler locations by zip code and county and found that the Portland metro area (Multnomah, Washington, and Clackamas counties) contains nearly 50% of the installed boilers in Oregon.

Figure 6: Percent of Boilers by County (Oregon Database)



Natural Gas Consumption and Number of Boilers by Customer Type in Oregon

Even though the majority of boilers in Oregon are hot water boilers and likely commercial, the EIA's 2018 Oregon State Profile estimates industrial natural gas consumption accounts for 65% of the commercial and industrial natural gas consumption in Oregon (all gas consumption, not just boilers). Cadeo estimates that 12.4 TBtu of natural gas consumption is associated with commercial gas boilers and 23.2 TBtu is associated with industrial boilers, excluding transport customers that purchase fuel directly (see Table 1 for supporting assumptions). We corroborated these findings with DOE's 2005 boiler market characterization that estimates while industrial boilers only make up 25% of the number of boilers, they make up 80% of energy consumed by boilers in both the commercial and industrial sectors.

Table 1: Estimates of the Number of Boilers in Oregon[6]

Total number of boilers in Oregon		Source of Assumption
10,092	Total Number of Gas Boilers in Oregon[7]	Oregon Database of Active Vessels
7,951	Total Number of Commercial Gas Boilers in Oregon	Boiler & Active Vessel Database, Assumes Hot Water Boilers = Commercial, plus the number of steam boilers in the CBSA
1,580	Total Number of Industrial Gas Boilers in Oregon	Boiler & Active Vessel Database, Assumes Steam Boilers = Industrial, minus the number of steam boilers in the CBSA
26%	Percent of boilers not regularly operating (backup applications)	2019 CBSA
5,884	Number of Active Commercial Gas Boilers in Oregon	Number of Commercial Gas Boilers minus backup boilers
1,169	Number of Active Industrial Gas Boilers in Oregon	Number of Industrial Gas Boilers minus backup boilers
5,825	Number of Active Non-Transport Commercial Gas Boilers in Oregon	NWGA Interview (99% Commercial Non-Transport)
59	Number of Active Transport Commercial Gas Boilers in Oregon	NWGA Interview (1% Commercial Transport)
818	Number of Active Non-Transport Industrial Gas Boilers in Oregon	NWGA Interview (70% Industrial Non-Transport)
351	Number of Active Transport Industrial Gas Boilers in Oregon	NWGA Interview (30% Industrial Transport)

Electrification Trends

Interviewees indicated that while electrification is an emerging topic in the commercial sector, they are not seeing changes to the stock of commercial boilers yet. They noted that there has actually been an *increase* in gas boilers, partially due to boilers transitioning away from other non-electric fuels such as oil.

All interviewees told us the industry expects boilers as a technology to transition to electrification slowly because water heating and steam generation is an energy intensive process at the commercial and industrial scale. Therefore, switching gas boilers to electric boilers can be cost-prohibitive, and this incremental cost increases as the capacity of the boiler increases. The commercial hot water boiler market could electrify sooner because there are other options for

[6] The supplementary workbook includes more detailed analysis of Oregon boilers by boiler type (water tube, fire tube, etc.), vintage, and end use.

[7] Remaining boilers not in commercial or industrial include storage, power, and "unknown" boilers.

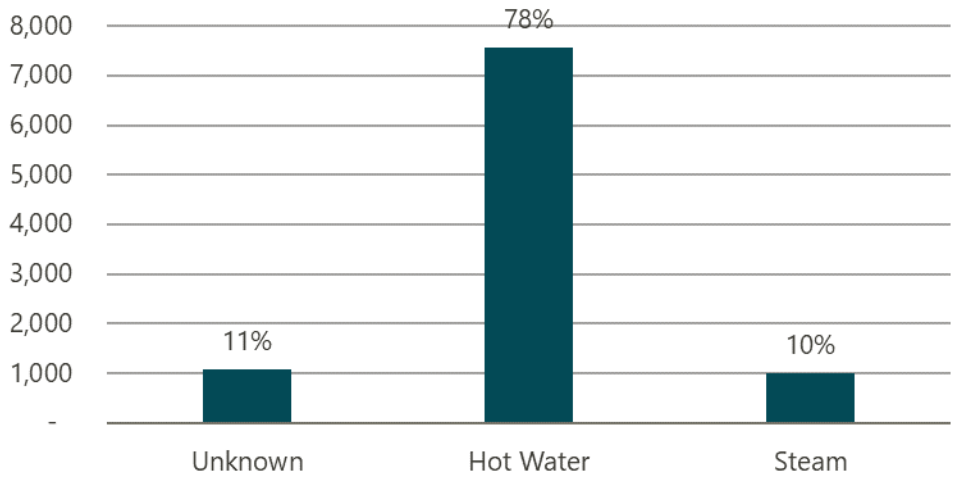
space heating on the commercial scale. The market is unlikely to transition to electric boilers but might shift to non-boiler systems entirely.

The industry expects the industrial boiler market to electrify last because these are mostly steam boilers and larger capacity (more energy intensive) units, and because few viable options for electric alternatives currently exist.

Commercial Boiler Findings

In addition to the Oregon Database, we analyzed the 2019 CBSA boiler data to further characterize the boiler market. While the CBSA is limited to commercial boilers,[8] the database includes more granular data that the Oregon Database does not include, such as efficiency, capacity, and location data. Consistent with previous findings, the CBSA showed that 99% of commercial boilers are natural gas. The CBSA also confirmed that the majority of boilers in commercial applications are hot water boilers and only 10% are steam.

Figure 7: Number and Percent of Boilers by Type (2019 CBSA)

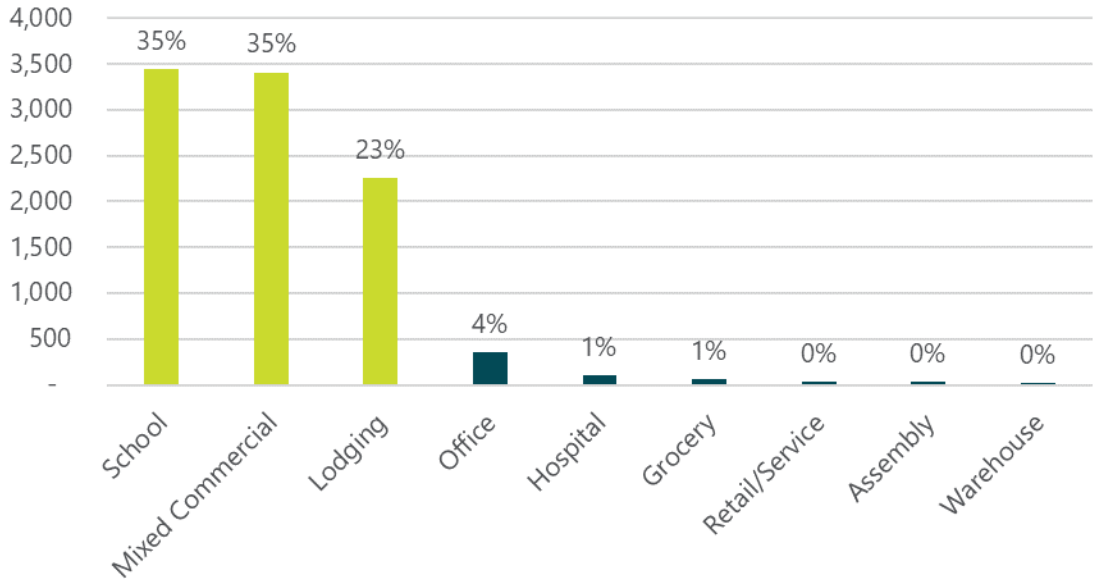


Boilers by Commercial Building Type

We found that of the commercial boilers, 93% are located in three building types: schools, mixed commercial, and lodging.

[8] The CBSA includes all commercial building types, but excludes multifamily buildings, covered in NEEA's Residential Building Stock Assessments.

Figure 8: Number and Percent of Oregon Boilers by Building Type (2019 CBSA)



The CBSA indicates that the majority of steam boilers in commercial buildings (88%) are in schools. The rest are in hospitals, lodging, and retail, but at very small percentages.

Table 2: Boiler Type by Building Type (2019 CBSA)

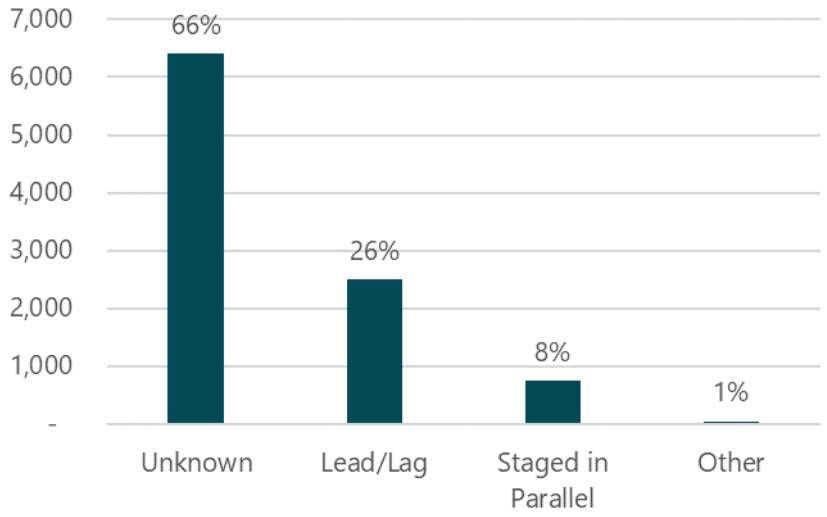
Building Type	Hot Water	Steam	Unknown	Total Building Type
Assembly	1%	-	-	-
Grocery	1%	-	-	1%
Hospital	-	4%	-	-
Lodging	15%	3%	100%	23%
Mixed Commercial	45%	-	-	35%
Office	5%	-	-	4%
Retail/Service	-	4%	-	-
School	34%	88%	-	35%
Warehouse	-	-	-	-
Total	100%	100%	100%	100%

Commercial Boiler Staging

The CBSA also contains data about boiler staging, which we used to build assumptions around the number of boilers serving as backup, and therefore not operating frequently or consuming

much natural gas. Of the commercial boilers, 26% serve in a lead/lag operation, where one boiler continuously operates, and additional boilers only serve peak loads.

Figure 9: Number and Percent of Boilers by Staging (2019 CBSA)

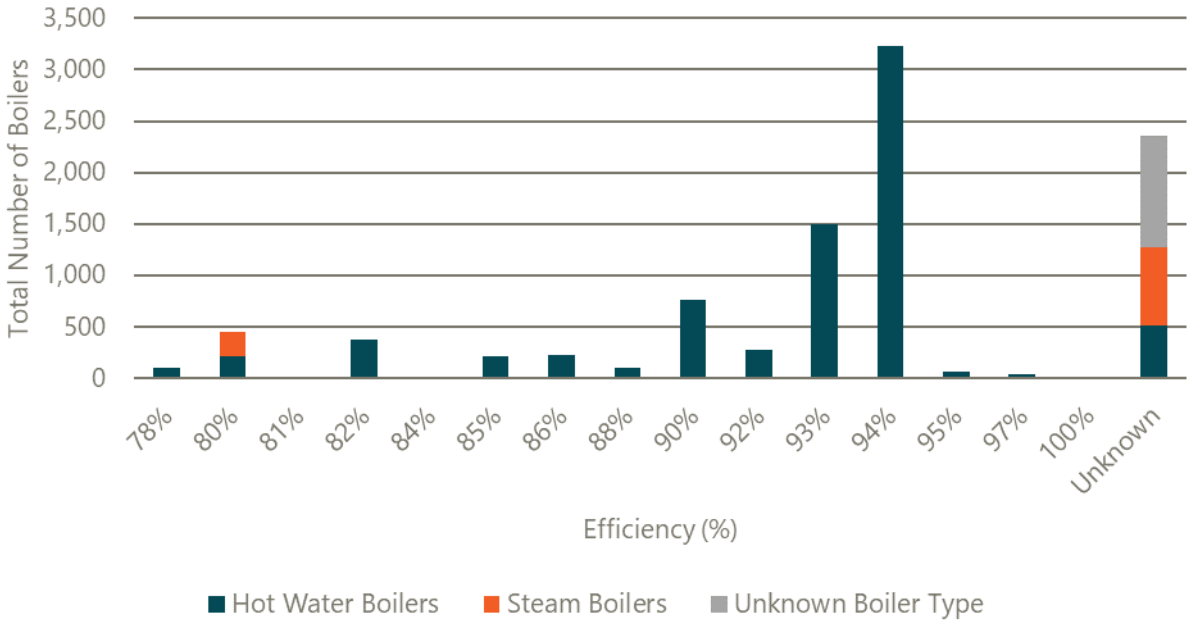


Commercial Condensing Boilers and Efficiency

Much of the focus of national efficiency programs and efficiency opportunities focus on incentivizing customers to purchase a condensing boiler, and the CBSA and other sources indicate the market is moving towards condensing boilers in the stock. A major finding from the 2019 CBSA review was that 63% of Oregon's commercial gas boilers are already condensing or have condensing capability. These findings are consistent with ENERGY STAR's market data that show condensing boiler sales rose from 30% of the commercial market in 2012, to 60% in 2016, and are expected to continue growing.

Even though the market is moving to more efficient condensing boilers in the stock, there may still be opportunities to ensure installed condensing boilers are operating at condensing efficiency levels. DOE publications, the RTF, and interviews with regional market experts estimate as much as 90% of condensing boilers in the market are not reaching condensing conditions due to improper design, installation, and operational practices. Boilers not operating at condensing temperatures means the temperature difference between the water temperature leaving and returning to the unit does not provide enough of a delta for the boiler to condense. When a boiler does not condense, it loses the opportunity to recover a significant amount of heat that instead vents out the stack. This indicates an opportunity to improve the efficiency of these installed condensing commercial boilers by ensuring proper design, installation, and operation practices.

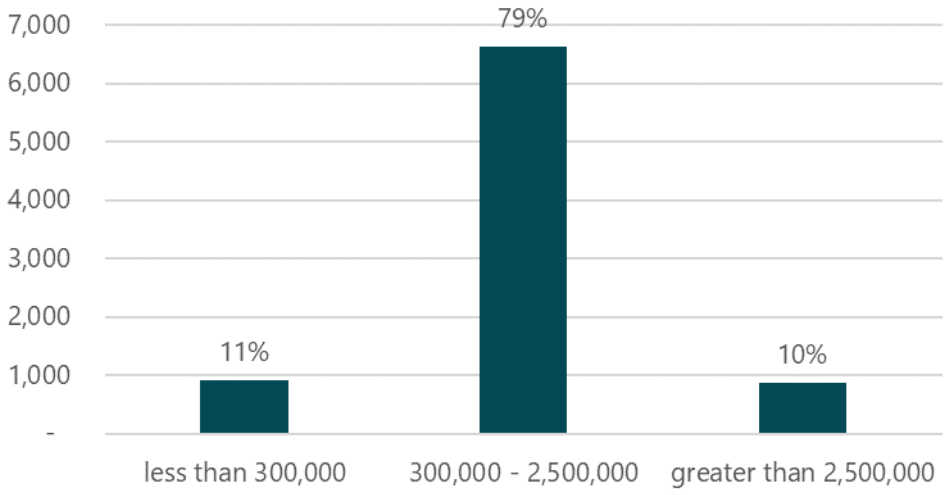
Figure 10: Number of Commercial Boilers by Rated Efficiency and Boiler Type (2019 CBSA)



Commercial Boiler Capacity

The Oregon Database excludes capacity data, but the CBSA indicates the majority of commercial boilers fall under DOE's "small" boiler size, between 300,000 and 2,500,000 Btu. These findings are consistent with DOE's Commercial Packaged Boiler rulemaking documents, which indicate the majority of boilers fall between 300,000 and 2,500,000 Btu. We do not have data on industrial boiler sizes, but we think it safe to assume the majority of those boilers are larger than 2,500,000 Btu.

Figure 11: Number of Commercial Boilers by Capacity (Btu) (2019 CBSA)



Opportunity Findings

After characterizing the commercial and industrial boiler market, we explored the efficiency opportunities available to improve the existing boiler stock. We categorized our findings into four primary categories:

1. Total Boiler Market Opportunities
2. Commercial Boiler Opportunities
3. Industrial Boiler Opportunities
4. Utility Program Measure Opportunities

The following sections describe our findings related to these four categories in more detail.

Total Boiler Market Opportunities

The following findings are applicable to both commercial and industrial boilers in Oregon.

Retrofit Opportunities for Older Boilers

As described previously, boilers beyond their traditional estimated useful life are often working properly and as efficiently as newer boilers. One interviewee told us boilers could run forever if maintained properly, and, therefore, people are more likely to fix an existing boiler than replace it. This is partially due to the difficulty and expense of physically removing a boiler from a space, which one interviewee said can be more than the cost of a new boiler. An alternative approach to removing and replacing older boilers is to replace an older boiler without removing it from the site; depending on the site, newer properly sized boilers can be smaller than old boilers and often can be installed in the same boiler room with the old boiler remaining in place.

Because boilers have a longer useful life than assumed and removal can be challenging, vintage should not prevent programs from pursuing retrofit measures. Future opportunities should not ignore these older boilers; programs may see more success in getting them to run more efficiently rather than encouraging the customer to replace them. For example, while the industry has identified condensing technology as a key energy savings opportunity in boiler systems, burner retrofits and other retrofits can also realize condensing-level savings. According to subject matter experts, older boilers can operate efficiently, but they are commonly oversized or have a failing distribution system (oversized pipes, leaking steam traps). These factors can affect the increase the gas consumption of existing boilers, even when operating at high efficiency ranges.

Interviewees mentioned three approaches for addressing operational or efficiency issues with older boilers:

- Since boilers like to run constantly and evenly, buildings with oversized boilers may look for additional ways to use the extra boiler capacity, such as for domestic hot water. An oversized boiler often runs intermittently in order to meet the building's relatively low heating load during non-peak hours. The boiler could run more efficiently by running

constantly to produce more steam or hot water than the building requires and diverting the additional heat to boost domestic hot water.

- Even if an oversized boiler is able to run at a reduced firing rate (e.g., 2-stage burner), the reduced load case where an oversized boiler would spend the majority of its time likely has a lower efficiency. Retrofitting these boilers with a modulating burner and modern digital controls would allow these boilers to operate more efficiently at part loads where they spend the majority of their time.
- Another option for increasing the efficiency of an old boiler is the retrofit addition of a secondary heat exchanger, or turning a conventional boiler into a condensing boiler. This is a more common practice with industrial steam boilers, but there are also commercially available products for hot water hydronic heating boilers as well.

Improving the Performance of Condensing Boilers

As previously mentioned, findings indicate as much as 90% of condensing boilers in the market are not reaching condensing conditions due to improper design, installation, and operational practices. Even though the market is moving to more efficient condensing boilers naturally, the larger opportunity may be to ensure installed condensing boilers are operating at condensing efficiency levels through better design, installation, and operational practices.

- **Design practices.** Designers commonly oversize boilers by 10% or more, but oversizing increases the likelihood boilers will not reach condensing temperatures. Designing boilers to meet the load is crucial to ensuring condensing boilers achieve their rated efficiency. Designers also often overlook control sequencing, which is integral to a condensing boiler's performance.
- **Installation practices.** Regional market experts and program scan activities introduced three installation practices that can address condensing boiler performance:
    - When a boiler is installed, and especially a condensing boiler, boiler tuning is key to maximizing combustion efficiency. Boiler tuning is also an important periodic maintenance step for condensing boilers.
    - Properly commissioned controls ensure the boiler varies temperature resets to match the increased or reduced load. Since the control settings, such as hot water supply temperature or boiler sequencing, are also key to ensuring condensing operation, proper installation would confirm that a boiler system is operating at the design conditions.
    - The installation phase is critical to ensuring a system operates optimally during both peak loads, but also the most common part load conditions where a boiler most commonly operates. Equipment designers often add a safety factor in their design to ensure the boiler can meet loads during the coldest days of the year. Oversizing can be minimized with modulating burners, digital controls, and outside air temperature reset, which puts more emphasis on commissioning the controls.

- **Operation Practices**. Many condensing boilers do not operate in condensing range, meaning the temperature difference between the water temperature leaving and returning to the unit does not provide enough of a delta for the boiler to condense. When a boiler does not condense, it loses the opportunity to recover a significant amount of heat that instead vents out the stack. The operating efficiency of a boiler will drop by 5% or more when not operating in condensing ranges. Implementing a water temperature reset strategy ensures the supply water temperature will match the load, allowing the temperature difference to operate in conditions optimal for condensing. Any boiler tune-up program should include controls checks when digital controls are present on a condensing system, including ensuring temperature resets are working correctly.

Region Technical Forum's New Boiler Measure

The RTF approved a draft standard protocol that regional utilities can use in commercial boiler programs at the November 2020 RTF meeting.[9] The new protocol includes a calculator to estimate savings from natural gas boiler efficiency measures. The protocol is primarily targeted at commercial hot water boilers due to the data availability to develop the protocol; however, the tool could be expanded for industrial boilers, especially if additional research fills current data gaps.

The calculator estimates savings for the following measures:

- The purchase of a new condensing boiler
- The retrofit of an existing boiler with an upgraded burner
- Burner controls including reset strategies, modulating capabilities, and staging sequences

The RTF has identified areas of future research that would improve or expand the calculator:

- Pre- and post-monitoring or billing analysis to support or update the assumptions in the calculator
    - The key areas of interest are efficiency curves, time spent at each load condition, the load level of boilers at each load condition, and average return water temperature at each load condition
- Boiler model specific data to better represent boiler characteristics that vary between models such as efficiency curves and other performance data
- Better understanding how boilers are operating in the field and the types of controls on existing boilers

[9] https://rtf.nwcouncil.org/meeting/rtf-meeting-november-10-2020, https://nwcouncil.app.box.com/v/ComGasBoilersSPv1-0

The RTF also emphasized the previously mentioned finding that while the prevalence of condensing boilers has increased significantly, many condensing boilers are not operating to their rated performance due to improper design, installation, or operation practices.

Mid-Efficiency Boilers

We heard from several interviewees that they are considering mid-efficiency boiler incentives in the future. Mid-efficiency boilers refer to non-condensing boilers with efficiencies between 83-88%. The efficiency industry is still defining mid-efficiency boilers, but are commonly less expensive than condensing boilers, require less maintenance, and provide an average 85% efficiency. The market is moving towards more affordable mid-efficiency boilers, and interviewees believe there is a savings opportunity associated with these boilers.

Mid-efficiency boilers also offer an alternative to high-efficiency condensing boilers. As already discussed, improperly sized or controlled condensing boilers will spend much of their time in non-condensing operation, which drops their efficiency down to that of a conventional boiler. The most common reason for this is a lack of an outdoor air temperature reset control strategy, which has been identified to improve the operation of a condensing boiler. Condensing boilers without this controls strategy spend most operating time at an efficiency comparable to a mid-efficiency boiler. Therefore, it can be more cost effective to use a mid-efficiency boiler that requires less maintenance and still provides steady efficiency above a baseline conventional boiler.

Commercial Boiler Opportunities

The following findings are specific to the commercial boiler opportunities.

Opportunities for Targeted Building Type Programs

Even though commercial boilers use less natural gas on average than industrial boilers, there are far more of them, and the vast majority of commercial facilities are non-transport customers. NWGA estimated only 1% commercial customers are transport customers. Since schools, lodging, and mixed commercial house 93% of the commercial boilers, future programs should target measures towards these customers and building types. Additionally, 88% of the commercial steam boilers are in schools, so focusing on schools in future programs would capture a large portion of the commercial steam boiler market.

Schools are a unique opportunity because while they have maintenance staff, historically they do not have the bandwidth or training to maintain boiler systems in a way that prioritizes energy efficiency. Training or incentivizing boiler tune-ups and controls initiatives tailored to schools should focus on sequencing, burner staging, digital controls, and temperature resets.

Commercial Condensing Boilers

The commercial boiler market appears to be turning over at a higher rate that the industrial boiler market, and when facilities do purchase new boilers, they appear to be purchasing condensing boilers. Natural gas utilities we interviewed have seen steady growth of condensing

boilers to dominate the market. They have also seen a spike in boiler replacements in recent years, primarily driven by the school market.

While most utility companies and efficiency organizations have focused on promoting the purchase of condensing boilers, we recommend future programs focus on ensuring these condensing boilers follow best design, installation, and operation practices described previously.

Industrial Boiler Opportunities

The following findings are specific to the industrial boiler market.

Industrial Opportunities Outside of Transport Customers

A much higher percentage of industrial natural gas customers are also transport customers compared to commercial customers, largely because transport customers consume more gas and, therefore, tend to be larger sites like production facilities. NWGA estimates 30% of industrial facilities are transport customers as opposed to commercial transport customers which only account for 1% of customers. The industrial boiler market is relatively small (about 1,600 in Oregon). We assume that half of these boilers are either in backup applications or associated with transport customers, leaving 800 industrial boilers to pursue through programs. Our market characterization findings indicate that despite the small number of boilers in the non-transport industrial sector, these boilers are very large and consume natural gas in orders of magnitude larger than commercial boilers, and interviewees agreed that the industrial sector is still worth pursuing but will require a more targeted approach.

Industrial boilers have more variability in application, size, and configuration than commercial boilers, which makes their market a more challenging target for programs. One major theme of the interviews conducted was that industrial boiler programs will need to utilize a customized approach instead of a standardized incentive program. One way to customize this approach, one interviewee said, is to subdivide the industrial sector by steam pressure (which affects the code safety requirements for a site), application, or industry site (e.g., breweries, dairy processing). This helps focus the program opportunity offerings to each subdivision. Our interview findings indicated focusing on smaller, lower pressure, light industrial boilers as a good entry point for the industrial market. The larger, higher pressure, more heavy industrial boilers are more likely to be well maintained by on site engineering and maintenance staff, and therefore have the incentive and ability to monitor and improve efficient boiler operation themselves.

Industrial Retrofit Opportunities

Boiler replacements will be harder to justify in industrial applications due to the high cost and the business impacts of taking a boiler offline from operations. Based on our interview findings, the best industrial opportunities are retrofitting boilers' burners to condensing or modulating and upgrading controls to ensure operational strategies can be employed. Key interviewees identified two opportunities for industrial boiler programs:

- Industrial facilities present good opportunities for boiler tune-up programs to ensure the boilers are operating optimally.
- Industrial boiler systems typically have larger distribution systems, so piping insulation and properly operating steam traps have a larger impact on natural gas than commercial systems.

Since boiler tune-ups and steam traps historically have low program uptake, understanding how to improve these measures for higher uptake with industrial customers may be worth additional research.

Utility Program Measure Opportunities

Our scan of commercial and industrial utility programs found a wide range of measures and program strategies. Both commercial and industrial programs focused heavily on encouraging the purchase of an efficient boiler, primarily condensing boilers. Commercial and industrial programs also offered a range of controls measures through both custom and deemed incentives.[10] Boiler tune-up programs were the most common, but other measures included:

- Steam trap replacement
- Outside air temperature reset strategies
- Modulating burner retrofits
- O2 or cut-out controls
- Turbulators
- Advanced load monitoring
- Pipe insulation

CEE's Commercial Boiler Incentive provides guidance on the most cost-effective efficiency measures. They include purchasing an efficient boiler while emphasizing the importance of installing and operating boilers properly in order to ensure the boiler's performance meets its rated expectations. CEE recommends the following measures as specific areas of focus:

- Boiler tune-ups, focusing on:
    - Inspecting the burner
    - Inspecting and optimizing the flame pattern
    - Inspecting the systems controlling the air to fuel ratio
    - Optimizing CO emissions
    - Measuring CO and O_2 levels before and after the tune-up
- Modulating boiler burners, which allow the boiler to operate efficiently at partial loads
- Boiler and burner sequencing for systems with multiple boilers
- Supply water temperature reset, which is crucial to ensuring condensing boilers operate in condensing ranges

[10] Appendix C includes a full list of boiler control strategy definitions, and the supplementary workbook includes tables of measures incented by utility.

- Boiler right-sizing, since boilers are commonly oversized
- System maintenance, including specific guidance for operators
- Pipe insulation to limit heat loss from the distribution system
- Hybrid boiler systems, which include both condensing and conventional boilers with advanced controls

Both CEE's program and interview findings indicate boiler tune-ups can increase the efficiency of a boiler by 5%, which is on the order of the savings from a condensing boiler. Appendix D includes a full description of these measures.

Program Recommendations and Future Research

The following program recommendations come from Cadeo's assessment of the Oregon boiler market and the efficiency opportunities to improve the performance of Oregon's boiler stock. Cadeo views this research as the first step in exploring this market further, so we have also provided recommendations for future research the Energy Trust can explore to fill data gaps and develop robust, effective boiler programs in the future.

Program Recommendations

Our market characterization and interviews indicate that while some opportunities overlap, the types of boilers (type, vintage, size, etc.) and the opportunities to improve those boilers vary widely between the commercial and industrial sectors, so each require programs and measures specific to each sector. Commercial programs should focus on deemed measures and easy accessibility to reach a large number of customers, while industrial programs should focus on custom measures with targeted outreach to industrial customers.

Targeted Commercial Programs

Since schools, lodging, and mixed commercial house 93% of the commercial boilers, future programs should target measures and program design towards these customers and building types. Additionally, with the majority of the commercial steam boilers in schools, prioritizing schools in future programs would capture a large portion of the commercial steam and hot water boiler market.

Programs targeting schools present a unique opportunity but also challenges. Maintenance staff often have limited bandwidth and technical training, but schools have a high interest in cost-saving measures. We recommend exploring program opportunities with the following priorities:

- Offering free training to maintenance staff on low-cost boiler opportunities and no-cost maintenance practices
- Incentivizing boiler tune-ups and controls incentives tailored to schools, either through free tune-ups or working with implementers to control costs to the participant
    - Controls measures should focus on upgrading to digital controls to allow for sequencing, burner staging, and temperature resets

Incentivize Performance, not Condensing

Since the market appears to already be shifting to condensing boilers, we recommend future programs do not incentivize the purchase of a condensing boiler. Instead, we recommend future programs focus on incentivizing boilers to perform as rated, and not the efficiency rating itself:

- Incentivizing right-sizing of boilers
- Incentivizing commissioning of new boilers
- Incentivizing boiler tune-ups and controls upgrades, focusing on upgrading to digital controls to allow for sequencing, burner staging, and temperature resets

If Energy Trust does pursue a condensing boiler program, we recommend including burner retrofit incentives to target existing boilers unlikely to purchase a new boiler.

Industrial Program Measures

Since most industrial boilers are larger boiler *systems* with multiple boilers, we recommend exploring measures that focus on improving the efficiency of the system:

- Boiler and burner sequencing
- Pipe insulation
- Steam trap replacement
- Hybrid boiler systems
- Boiler tune-ups

Since boiler tune-ups and steam traps historically have low program uptake, understanding how to improve these measures for higher uptake with industrial customers may be worth additional research.

Future Research

This research sought to understand the Oregon boiler market, but further research could improve the current findings and fill data gaps.

Support the RTF's Research Goals

The RTF's recent addition of a commercial boiler measure presents good program opportunities and additional research questions. As the RTF explores possible research, we recommend Energy Trust support that research where feasible with the following priorities:

- Research and data gathering on industrial load shapes to support using the new tool for industrial customers more accurately
- Research on part load efficiency to better understand the savings tradeoffs of operating at lower loads, but also lower efficiencies at part load
- Researching how boilers actually operate in the field, as opposed to rated efficiency, with a focus on common control capabilities

Industrial Boiler Data Gaps

This research provided a high-level overview of the commercial and industrial boiler market, but robust data specifically on the industrial boiler market left this research without a full picture of industrial boilers in Oregon.

If Energy Trust chooses to pursue industrial boiler program measures, we recommend further researching the following industrial boiler gaps:

- Industrial boiler capacities
- Industrial boiler locations, by facility type and application, to understand niche opportunities
- Further understanding which industrial facility types are transport customers and non-transport customers to target programs to appropriate customers

Market Research on Program Opportunities

This research identified several high-level program opportunities. We recommend exploring these opportunities in more depth through:

- Interviewing boiler technicians to better understand the retrofit and tune-up opportunities and inform program design strategies
- Interviewing boiler tune-up implementers to better understand the reasons for low uptake of tune-up measures and what would make future programs better
- Interviewing industrial facility boiler operators to vet any proposed program measures, build understanding of barriers to efficiency and inform possible program strategies

Appendix A. Source List

Title	Author or Publishing Organization	Location (URL, file location, etc.)
State of Oregon Department of Business and Consumer Services Database of Active Vessels	State of Oregon Department of Business and Consumer Services	http://www4.cbs.state.or.us/ex/imd/reports/rpt/index.cfm?ProgID=VSL8901
United States Postal Service Zip Codes	United States Postal Service	https://www.unitedstateszipcodes.org/zip-code-database/
Quarterly Census of Employment and Wages	Bureau of Labor Statistics	https://www.bls.gov/cew/downloadable-data-files.htm
2019 Commercial Building Stock Assessment (CBSA)	NEEA	https://neea.org/data/commercial-building-stock-assessments
Northwest Power and Conservation Council's Seventh and 2021 Plan	Northwest Power and Conservation Council	https://www.nwcouncil.org/2021-power-plan-technical-information-and-data
Characterization of the U.S. Industrial/Commercial Boiler Population	Energy and Environmental Analysis, Inc. on behalf of Oak Ridge National Laboratory (DOE)	https://www.energy.gov/sites/prod/files/2013/11/f4/characterization_industrial_commerical_boiler_population.pdf
2016-12-09 Final Rule Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Packaged Boilers	DOE Energy Efficiency and Renewable Energy Office	https://beta.regulations.gov/document/EERE-2013-BT-STD-0030-0083
DOE Compliance Certification Database (CCMS)	DOE Energy Efficiency and Renewable Energy Office	https://www.regulations.doe.gov/certification-data/CCMS-All.html#q=Product_Group_s%3A*
EPA ENERGY STAR Certification for Commercial Boilers	EPA ENERGY STAR	https://www.energystar.gov/products/heating_cooling/commercial_boilers
Consortium for Energy Efficiency Commercial Boiler Systems Initiative Description	Consortium for Energy Efficiency	https://library.cee1.org/system/files/library/7543/CEE_ComBoilerSystems_InitiativeDescription_2015_FINAL.pdf
Oregon Utility Statistics 2019	Oregon Public Utility Commission	https://www.oregon.gov/puc/forms/Forms%20and%20Reports/2019-Oregon-Utility-Statistics-Book.pdf

Sustaining Utility Natural Gas Efficiency Programs in a Time of Low Gas Prices	ACEEE	https://www.aceee.org/sites/default/files/pdfs/sustaining_utility_natural_gas_efficiency_programs.pdf
State Energy Data System (SEDS)	US Energy Information Administration (EIA)	https://www.eia.gov/state/seds/seds-data-complete.php?sid=OR#Consumption
Consortium for Energy Efficiency Commercial Boiler Systems Initiative Description	Consortium for Energy Efficiency	https://library.cee1.org/system/files/library/7543/CEE_ComBoilerSystems_InitiativeDescription_2015_FINAL.pdf
Purchasing Energy-Efficient Large Commercial Boilers	Department of Energy Office of Energy Efficiency and Renewable Energy	https://www.energy.gov/eere/femp/purchasing-energy-efficient-large-commercial-boilers
Commercial Condensing Boiler Optimization	Minnesota Consortium for Energy Efficiency	https://www.mncee.org/getattachment/Resources/Projects/Condensing-Boiler-Optimization/Commercial-Condensing-Boiler-Optimization-Research-Summary.pdf.aspx
DSIRE	NC Clean Energy Technology Center	https://programs.dsireusa.org/system/program
Technology Snapshots	Gas Technology Institute (GTI)	**Confidential.** Available from GTI by request for Energy Technology Program (ETP) participants

Appendix B. Regional Expert Interview Guide

Types of Boilers

- In our initial research, we found that 70% of boilers in Oregon are hot water versus steam, and most hot water boilers are in commercial applications. On the other hand, we know that steam boilers are found predominately in industrial applications and that industrial boilers consume anywhere from 65-80% of natural gas energy in Oregon.
    - Is that consistent with what you understand about the boiler market?
    - We know where these boilers are and how much energy they consume in commercial, but we do not know as much about industrial. Do you have insights into what industry types industrial boilers are likely to be found in? Energy consumption?
    - **[NW Natural, Cascade, Avista]** Since gas boilers are such a large part of industrial gas loads, do you incorporate boilers into your resource planning? Either program planning or load forecasting? If so, how? (Prompts: big boilers? How cost effective are these measures?)
- In our evaluation of the boilers market, we found that about 70% of steam boilers (industrial) are outside of their useful life. Is that consistent with your understanding of industrial boilers?
    - Do you have insight into where these old boilers are in industrial? In a specific building type?
- We know that 30% of hot water and steam boilers are in schools, and we think this is where most of the commercial opportunities are going to be in terms of savings. Any insights into the opportunities in or challenges around schools?

Boiler Operation

- We have good data on the characteristics of boilers in Oregon, but we do not know a lot about how they are operating in the field. Are there any lessons you have learned about operational opportunities, either in commercial or industrial boilers?
    - Are boilers in the field operating below their rated efficiency level?
        - Why? What are the operational challenges or opportunities to get boilers to operate more efficiently?
        - Same percentage of boilers operating below rated efficiency for commercial and industrial?
    - We have found in our research that many condensing boilers are not reaching condensing, so the savings from the more efficient system are not achieved. Do you have insight into how condensing boilers are operating in the field?
        - What percentage of condensing boilers would you say are not reaching condensing? Can more boilers be run in the condensing range?
        - What is the primary factor preventing condensing boilers from reaching condensing? (Installation? Operation? Something else?)

- We have also found that 26% of commercial gas boilers are "back up", meaning they are off until the primary boiler fails (or additional capacity is needed). Is this the same for industrial boilers? How many industrial boilers would you guess are backup?

Transport vs Non-Transport Customers

- What portion of natural gas customers are transport customers versus non-transport?
    - Do you have an estimate of whether industrial boiler customers are more likely to be transport customers? How many?
    - What are the key characteristics of transport versus non-transport customers? Do specific industries fall into one or the other category?
- We suspect that there are limited opportunities for program energy savings from transport customers given their cheaper gas rates. Is this correct?
    - What are the opportunities for non-transport customers? *[In other words, if you take out the boilers associated with transport customers, are there enough non-transport customer boilers left for program savings to be worth pursuing?]*

Market Trends

- Are there trends in fuel switching, electrification, decarbonization that will impact the boiler market?
    - We assume that industrial gas customers will be the last to electrify, but are you seeing trends that would disagree?
    - Do you think electrification is affecting the commercial gas boiler market?
- Are there trends in major Oregon industries that use gas that will impact the boiler market?
    - For example, specific industries/manufacturing that are changing?

Program Opportunities

- What do you think the best opportunities to save gas energy is from boilers?
    - Is the answer different for industrial boilers and commercial boilers? Hot water vs steam?
    - Is the opportunity for boilers in getting existing boilers to operate more efficiently or to replace an inefficient boiler with a more efficient one?
        - Does that answer change if it is hot water versus steam?
        - Commercial versus industrial?
        - Size or capacity
        - System versus standalone
- Assuming there are savings opportunities, how obtainable are they likely to be?
    - What types of savings are most likely to be obtainable? Will they require specific types of intervention? Are there specific industries or building types that might be worth pursuing first?
    - We think there are good opportunities around boilers in schools. Are there trends in schools that could be leveraged to induce additional savings?
- We know one of the challenges with the boilers market is that so many of the large steam/industrial boilers are well beyond their useful life (more than 20 years old).

Incentivizing these customers will be difficult since replacing these boilers is so expensive and can have large impacts on operations. Are there strategies you think would influence these customers to replace their old boilers?
    - Is there a breaking point (either capacity, type of system, type of customer) where the cost and impact are too large to influence?
- We know that industrial boilers consume anywhere from 65%-80% of the total natural gas energy in Oregon. Knowing this, is the potential for savings in the number of boilers in the market, or in targeting the largest consumers of gas, or both?

Appendix C. Boiler Control Strategies

Boiler Control Strategy	Definition	How the Measure Saves Gas Energy
Steam Trap Replacement	Steam traps prevent steam from leaving a boiler's heat distribution system.	Leaking steam traps allow heat to unnecessarily leave the boiler's heat distribution system. This wastes heat that can be used elsewhere in the system. It also forces more fuel to be burned to compensate for heat losses and lower temperatures throughout the boiler's heat distribution system.
Outside Air Reset	This control correlates the boiler supply water temperature to the outdoor air temperature. As the OAT becomes warmer, the boiler supply water temperature decreases. As the OAT decreases, the boiler supply water temperature increases.	This reduces the amount of system losses because the temperature change between the boiler's heat distribution system and the surroundings is smaller. This also allows for a stepwise increase of capacity of boiler operations
Boiler Tune-up	Boiler Tune up includes the following elements: 1.) Inspect Burner 2.) Inspect and optimize flame pattern 3.) Inspect system controlling air to fuel ratio 4.) Optimize CO emissions 5.) Measure CO and O2 levels before and after tune-up	A boiler tune-up ensures the boiler is operating within its intended regime, and the controls are reviewed, (re)optimized and finalized prior to the boiler starting operation again.
Modulating Burner	A modulating boiler burner allows the burner to match the input down to a percentage of the rated capacity (operate at part load). ENERGY STAR boilers require a minimum turndown ratio of 5:1 meaning the boiler can operate at 20% of its rated capacity, although some boiler	When modulating boilers operate at part-load, less fuel is burned and energy transfer is enhanced to generate greater fuel savings.

	controls allow the burners can modulate up to a 10:1 ratio.	
O2/Cut out Controls	This control monitors and adjusts excess air in the boiler combustion area to maintain an optimal fuel to air ratio. O2 controls aid in compliance with CO standards by monitoring the CO or the O2 in the flue gas which provides feedback to a controller. Cut out controls turn the boiler off at a preset outdoor air temperature.	O2 controls allow the fuel to air ratio to be optimized and prevents the boiler from running in unsafe conditions. O2 controls also prevents fuel waste by ensuring there is sufficient O2 for combustions in the boiler combustion area. The cutout controls prevent the boiler from operating above a certain temperature. This prevents the boiler from running in temperature where no heating, minimal heating, or other more efficient heating systems can be run.
Dampers	Dampers can be used to control the draft and temperature for boilers which heat multiple spaces.	Once a boiler turns off, the auto-close flu traps and stores any escaping heat that can be saved and used for heat recovery later.
Turbulators	This increases the turbulence of the hot combustion gases and the convective heat transfer to the tube surface. The result is improved boiler efficiency. Turbulators are usually installed on the last boiler pass.	Turbulators increase the available amount of heated gas which can be exchanged into the pipes.
Advanced Load Monitoring	This system allows the boiler to "predict" future load through a microprocessor and use past data to determine when the boiler will need to fire, the boiler's loading and when the boiler can be prevented from firing.	Derive energy savings by dynamically managing the boiler differential, where a microprocessor with memory of past boiler cycles prevents the boiler from firing for a period of time, to limit cycling losses during perceived low-load conditions.

Boiler & Burner Sequencing	Boiler sequencing allows systems to run a combination of boilers optimally to meet a building or site's full heating load. This means each of the boilers can also operate with different supply water temps, return water temps, and pressures. The sequencer determines the number of boilers required to meet the system demand by monitoring the steam pressure in the header or the steam flow, and keeps the remaining boilers in a warm standby state, allowing them to be brought up to pressure quickly in the event of an increase in demand.	The use of a boiler sequencing system ensures that boilers are fired in a controlled manner providing cost savings by preventing individual boilers from over firing and cycling on and off unnecessarily.

Appendix D. CEE Boiler Measure Recommendations

CEE Recommendations	Definition	How the Measure Saves Gas Energy
Boiler Tune-up	A boiler tune-up requires a technician to visit the boiler to improve and/or adjust the boiler's operational controls. The CEE initiative has a Boiler Tune-up checklist to verify the controls are working properly: 1.) Inspect Burner 2.) Inspect and optimize flame pattern 3.) Inspect system controlling air to fuel ratio 4.) Optimize CO emissions 5.) Measure CO and O2 levels before and after tune-up	Tune-ups reduce gas consumption by ensuring the boiler is operating at optimal temperature ranges and air-to-fuel mixes.
Modulating Boiler Burner	Modulating Boiler Controls allow the boiler to operate at partial rated loads (20% of capacity, 50% of capacity, etc.) rather than on/off or cycling.	Modulation allows the boiler to fire at a rate lower than the rated capacity. This saves energy because the boiler does not have to fire at full capacity and can run more efficiently at part loads.
Boiler & Burner Sequencing	Boiler sequencing allows systems to run a combination of boilers optimally to meet a building or site's full heating load. This means each of the boilers can also operate with different supply water temps, return water temps, and pressures. The sequencer determines the number of boilers required to meet the system demand by monitoring the steam pressure in the header or the steam flow, and keeps the remaining boilers in a warm standby state, allowing them to be	The use of a boiler sequencing system ensures that boilers are fired in a controlled manner providing gas savings by preventing individual boilers from over firing and cycling on and off unnecessarily.

	brought up to pressure quickly in the event of an increase in demand.	
Supply Water Temp Reset	Supply water temperature reset strategies reduce the amount of system losses because the temperature change between the boiler's heat distribution system and the surroundings is smaller. This also allows for a stepwise increase of capacity while the boiler is operating. A good rule of thumb is the return water temp should not fall below 140 F. Only 1 control package per system is required.	Temperature reset strategies save gas energy by lowering the supply water temperature when demand is lower.
Boiler Right-sizing	Boilers are commonly oversized, which consumes more gas energy because the boiler will run less efficiently at part-load conditions. Right-sizing boilers requires performing load calculations to size the boiler to match typical conditions.	Right sizing the boiler saves gas energy by reducing boiler cycling and operating the boiler at more efficient load conditions.
System Maintenance	Maintaining a boiler properly includes conducting scheduled checks, replacing parts on a cyclical basis, and identifying issues before they become problems. Boiler operators can conduct annual or biennial routine work following the ASHRAE Standard 180.	Regular maintenance prevents the boiler from running in unsafe conditions and extends the Effective Useful Life (EUL) of the boiler.
Multiple Boiler Sequencing Control	If a building has multiple boilers, it is important to sequence the boilers for when and how boilers fire to match the load as closely as possible.	This prevents boilers from operating at low part load efficiencies and allows the most efficient boiler or boiler combination to operate.
Linkageless Controls	This control allows the user to control the fuel to air ratio of each burner independently rather than setting all burners to the same fuel to air ratio. This control should only be installed on boilers which have modulating controls.	This allows individual boilers to operate with different fuel to air ratios, reducing wasted fuel.

Pipe Insulation	The facility manager or other staff should insulate heat distribution pipes throughout the building/site.	This reduces the amount of heat lost to the surrounding while steam/hot water is being transported to the point of use.
Installing a Hybrid Boiler System	Hybrid boilers systems incorporate condensing and conventional boilers into an integrated system used to heat spaces. This is most effective for high temperature heating applications. This should be installed with: 1.) Modulating Boilers and linkageless controls on all new boilers and a turndown of 4:1 for all boilers with 85-89.9% Thermal efficiency and a turndown of 5:1 for all boilers with >90% thermal efficiency 2.) Supply water temp reset according to manufacturer instructions 3.) Full system connection to boiler sequencing controls, including existing boilers	This system will save energy based on control strategies explanations above.
Installing a Fully Condensing Multiple Boiler System	This system replaces all boilers with condensing boilers. This should be installed with: 1.) Modulating Boilers and linkageless controls with a turndown of 5:1 for all boilers 2.) Supply water temp reset according to manufacturer instructions 3.) Full system connection to boiler sequencing controls, including existing boilers 4.) Return water temp of <130 F to ensure boilers operate in the condensing regime year-round condensing	This system will save energy based on control strategies explanations above.