High Efficiency Commercial Boiler Systems Initiative Description

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May 16, 2011
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1 Background

Commercial boiler systems use 1,040 trillion Btus (British thermal units) of natural gas annually, of which 709 trillion Btus are used to heat 32 percent, or 20 billion square feet, of commercial floor space.¹ This represents 51 percent of total natural gas expenditures for non-mall commercial buildings. Based on this, it is clear that boiler systems represent a major energy end use in the commercial sector.

In many end use areas—for residential, commercial, and industrial customers—the Consortium for Energy Efficiency (CEE) has achieved huge energy savings and market impact by suggesting approaches to energy efficiency programs. By voluntarily adopting CEE’s program recommendations, efficiency programs achieve greater energy savings through consistent approaches that provide consistent signals to the market across state and national boundaries. Currently, there are close to 40 CEE members running programs to address commercial boiler system efficiency. Of these 40 programs, the approaches vary widely from straightforward prescriptive measures for residentially sized boilers in small commercial applications to more complex programs with incentives varying by boiler size. Some programs simply address the boiler itself, while others address the entire system by incorporating measures for controls, other auxiliaries, or tune-up programs. To help efficiency programs capture the large savings potential in commercial boiler systems, the CEE High Efficiency Commercial Boiler Systems Initiative (the “Initiative”) provides program recommendations to address system efficiencies and help ensure that expected savings are achieved.

1.1 Purpose of Document

The Initiative serves to help efficiency program administrators understand the wide range of savings opportunities in commercial boiler systems and identify appropriate best paths forward in capturing savings based on a given application or system design. To help programs build and deliver leveraged, informed, and cost effective commercial boiler programs, CEE has developed this comprehensive approach to address the complex set of technical issues and opportunities, market forces and barriers, and business drivers at work. This Initiative focuses on mass market commercial boiler systems, looking at (1) new construction, (2) boiler replacement and system retrofit, and (3) systems optimization. The Initiative also provides guidance on outreaching to the supply chain and addressing various system measures, including rightsizing, quality operations and maintenance, and system controls.

The purpose of this document is to provide guidance to efficiency program administrators. It is not intended to provide guidance to others in the supply chain. As the Initiative evolves, CEE may develop additional resources to help program administrators apply the guidance within their programs and reach out to supply chain actors.

The following sections detail the technology, market, and approaches to achieving savings in this market. Section 2 outlines the scope of the Initiative. Section 3 provides background on the market and technology. Section 4 details the Initiative approach. Sections 5 and 6 address member participation requirements and CEE’s role in promotion of the Initiative, respectively.

1.2 Initiative Objectives

Commercial boiler systems are technically complex and the energy solutions span across various technologies and installation practices. Understanding the relationship between the system design and various energy solutions is important to help maximize energy savings over time. Therefore, providing well-informed and leveraged energy efficiency solutions is a challenge. To better help members address energy savings opportunities in commercial boiler systems, the objectives of this Initiative include:

- Increase the number of new commercial boiler systems operating in the condensing range
- Increase the number of existing commercial boiler systems that are optimized to operate at the highest efficiencies allowable for the given system throughout the year
- Increase the number of quality installed and maintained high efficiency commercial boiler systems
- Educate building owners, design engineers, and contractors on what constitutes high efficiency in a given system and options for maintaining high efficiencies throughout the life of the boiler
- Educate contractors on the importance of and how to conduct quality installations and maintenance for high efficiency commercial boiler systems
- Encourage creation of an enhanced efficiency metric for commercial boiler systems—in place of the current steady state boiler metrics—that better captures the infield operating efficiency of the boiler system throughout the year

2 Scope and Product Definition

2.1 Equipment Definitions

The U.S. Department of Energy (DOE) defines “commercial packaged boilers” to be “a type of packaged low pressure boiler that is industrial equipment with a capacity, (rated maximum input) of 300,000 Btu per hour (Btu/h) or more which, to any significant extent, is distributed in commerce: (1) For heating or space conditioning applications in buildings; or (2) For service water heating in buildings but does not meet the definition of ‘hot water supply boiler’ in [part 431 of 10 CFR].”

One main distinction of hot water supply boilers is that they are suitable for

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2 The Energy Policy and Conservation Act (EPCA) defines a “packaged boiler” as a “boiler that is shipped complete with heating equipment, mechanical draft equipment, and automatic controls; usually shipped in one or more sections.” (42 U.S.C. 6311(11)B). DOE further refined this definition to exclude a boiler that is “custom designed and field constructed” and allows for boilers shipped in more than one section and that “the sections may be produced by more than one manufacturer, and may be originated or shipped at different times and from more than one location.” (10 CFR 431.102)

3 10 CFR 431.82
heating potable water. The term ‘domestic water heating’ also refers to hot water supply boilers and will be used for the remainder of this document.

Commercial packaged boilers are constructed to comply with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Heating Boilers Section IV. Once the boiler meets the code, it receives the ASME Code Symbol, which in the case of space heating boilers is the “H” stamp.

The Energy Policy and Conservation Act (EPCA) separates boilers into two classes based on the type of fuel: gas-fired commercial packaged boilers and oil-fired commercial packaged boilers. In January 2009, DOE adopted new energy standards for commercial packaged boilers based on the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2007, which bases its classes on fuel type, size, output and draft type. The new DOE standards will take effect March 2, 2012. The Federal Energy Management Program (FEMP) has its own definitions, breaking boilers into eight classes based on fuel type, size and output. Both ASHRAE and FEMP define “small” commercial boilers as those between 300,000 Btu/h and 2.5 million Btu/h and “large” commercial as larger than 2.5 million Btu/h. Below, Table 1 summarizes the various boiler equipment classes and respective energy conservation standard for each of these parties.

Table 1: Current Federal and Industry Commercial Boiler Classes and Standards

<table>
<thead>
<tr>
<th>Boiler Class</th>
<th>EPCA</th>
<th>FEMP</th>
<th>ASHRAE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small gas-fired hot water</td>
<td>80% TE</td>
<td>80% TE</td>
<td></td>
</tr>
<tr>
<td>Small gas-fired steam all except natural draft</td>
<td>79% TE</td>
<td>79% TE</td>
<td></td>
</tr>
<tr>
<td>Small gas-fired steam natural draft</td>
<td>77% TE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large gas-fired hot water</td>
<td>80% TE</td>
<td>80% TE</td>
<td></td>
</tr>
<tr>
<td>Large gas-fired steam all except natural draft</td>
<td>79% TE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large gas-fired steam natural draft</td>
<td>77% TE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small oil-fired hot water</td>
<td>83% TE</td>
<td>83% TE</td>
<td></td>
</tr>
<tr>
<td>Small oil-fired steam</td>
<td>83% TE</td>
<td>83% TE</td>
<td></td>
</tr>
<tr>
<td>Large oil-fired hot water</td>
<td>83% TE</td>
<td>84% CE</td>
<td></td>
</tr>
<tr>
<td>Large oil-fired steam</td>
<td>83% TE</td>
<td>81% TE</td>
<td></td>
</tr>
</tbody>
</table>

* Note: These ASHRAE standards will become the new DOE energy standards effective March 2, 2012.

4 10 CFR 431.102


In August 2010, Natural Resources of Canada released proposed energy efficiency minimums for commercial gas and oil-fired boilers to amend the current regulations. This proposal establishes minimums that are fairly consistent to the ASHRAE minimums; however, it is important to note that these are not yet finalized. Table 2 outlines these proposed minimums.

### Table 2: Proposed Canadian Federal Minimums for Commercial Boilers

<table>
<thead>
<tr>
<th>Boiler Class</th>
<th>2012</th>
<th>2015 (R)</th>
<th>2015 (NC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small gas-fired hot water (no standing pilot)</td>
<td>80% TE</td>
<td>84% TE</td>
<td>90% TE</td>
</tr>
<tr>
<td>Small gas-fired steam (no standing pilot)</td>
<td>77% TE</td>
<td>79% TE</td>
<td>---</td>
</tr>
<tr>
<td>Large gas-fired hot water (no standing pilot)</td>
<td>82% CE</td>
<td>86% CE</td>
<td>90% CE</td>
</tr>
<tr>
<td>Large gas-fired steam (no standing pilot)</td>
<td>77% TE</td>
<td>79% TE</td>
<td>---</td>
</tr>
<tr>
<td>Small oil-fired hot water</td>
<td>82% TE</td>
<td>85% TE</td>
<td>---</td>
</tr>
<tr>
<td>Small oil-fired steam</td>
<td>81% TE</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Large oil-fired hot water</td>
<td>84% CE</td>
<td>87% CE</td>
<td>---</td>
</tr>
<tr>
<td>Large oil-fired steam</td>
<td>81% TE</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

R – Replacement market only  
NC – New construction market only

### 2.2 Efficiency Definitions

The ANSI-Z21.13/CSA 4.9 Standard for Gas-Fired Low Pressure Steam and Hot Water Boilers is the recognized standard across the US and Canada to determine steady state efficiency. The US also recognizes, the BTS-2000 Testing Standard for Commercial Space Heating Boilers. Both test methods determine two different efficiency metrics used for defining commercial boiler performance. These are:

- **Combustion Efficiency (CE):** Measures the ability of the boiler to burn fuel and equals 100 percent minus the percentage of fuel energy lost in the exhaust gases (i.e. flue loss).

- **Thermal Efficiency (TE):** Measures the ratio of the heat energy output to the heat energy input, exclusive of jacket losses, and can be considered combustion efficiency minus jacket losses.

Currently, there is not a consistent industry standard for measuring performance. As noted in Table 1 above, with the adoption of the ASHRAE 90.1-2007 standard TE has become the more common metric; however, some classes continue to reference CE. There is no direct mathematical correlation between the two metrics, which creates great challenges for efficiency programs.

Being metrics that measure only steady state efficiency, neither CE nor TE adequately measure the system efficiency since commercial boilers typically operate at part loads. Additionally, the required inlet and outlet water temperatures (which impact boiler performance) do not necessarily replicate actual infield temperatures. For example, for non condensing boilers the BTS-2000 requires inlet water temperatures between 35 to 80 degrees Fahrenheit (F) and outlet water temperatures of 180 degrees F plus or minus 2 degrees F.\(^9\) For condensing boilers, the


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required inlet and outlet water temperatures are 80 degrees F plus or minus 5 degrees F and 180 degrees F plus or minus 2 degrees F, respectively.\textsuperscript{10}

ASHRAE is working to develop a national test standard to address seasonal efficiency in commercial steam and hot water systems that is expected to better represent infield conditions. The objective is similar to AFUE, or annual fuel utilization efficiency, used to characterize residential boilers—boilers that are less than 300,000 Btu/h. A seasonal metric for commercial systems would allow efficiency programs and building owners to better understand the potential operating efficiency of a given system. Until such a metric is available, this Initiative provides a specification based on TE, which is considered to be the more robust metric since it also includes jacket losses. CEE believes that while imperfect, this metric tested to the above standards provides a comparable basis for selecting high efficiency boilers. The Initiative also provides guidance on approximating CE equivalents to the specification.

2.3 Initiative Scope

This Initiative addresses hot water, commercial packaged boiler systems between 300,000 to 4 million Btu/h capacity. This size range is intended to capture the bulk of the mass market for commercial boiler systems. The Initiative emphasizes the capacity of the system, rather than the boiler itself, as residential boilers may be staged in commercial applications such that the overall system capacity is 300,000 Btu/h or greater. Currently, the scope does not include systems used for process heating or domestic hot water boilers used for potable water. This Initiative does not address steam systems; however, the Initiative approach encourages programs to message to—and potentially support—upgrading from steam to hot water systems (Section 4.2.2). In addition to the boiler itself, this Initiative addresses controls and other systems accessories that can aid in optimizing the system efficiency.

3 Technology and Market Background

The following section provides a technical and market background for commercial boilers within the size range of this Initiative. Specific information on residential boiler technologies and the market is available in CEE’s High Efficiency Residential Gas Heating Initiative Description. While this section focuses on the boiler itself, CEE recognizes that addressing the system as a whole is key to optimizing the efficiency of the boiler. To this end, the Initiative Approach outlined in Section 4 focuses on optimizing the system efficiency.

3.1 The Commercial Packaged Boiler

A commercial packaged boiler is a pressure vessel consisting of a tank or water tubes, heat exchangers, fuel burners, exhaust vents and controls.\textsuperscript{11} Packaged boilers commonly fall into the category of either watertube or firetube. In watertube boilers, the water passes through the tubes

\textsuperscript{10} Ibid.

and the exhaust gases remain in the shell side. Firetube boilers, on the other hand are constructed to have the exhaust gases pass through the tubes with the water on the shell side. A third potential configuration is the cast iron sectional boiler where the water is contained within cast iron sections. All three configurations are used in commercial space heating applications. This section provides more detail on the different efficiency levels of a commercial packaged boiler.

### 3.1.1 Commercial Boiler Efficiency

The boiler itself has three natural breakpoints for efficiency: low efficiency (80 percent), mid efficiency (83 to 88 percent), and condensing (88 percent and above). All boilers operate under the same thermodynamic principles, and a theoretical maximum efficiency can be calculated for a given system design—although, it should be noted that this calculated maximum may not be representative of the actual operating efficiency. These laws of thermodynamics translate to the efficiency of a commercial boiler being highly dependent on the return water temperature of the system. As shown in Figure 1, high efficiencies are attained when the return water temperatures drop below 130 degrees F and the boiler operates in condensing mode.

**Figure 1: Impact of Return Water Temperature on Efficiency**

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13 Ibid.


15 Ibid.
Factors that can impact the efficiency of a boiler include: flue gas temperature, stack losses, heating medium temperatures, radiation and convection losses, excess air, ambient air temperature, and turndown (see Appendix B for Definitions). The Initiative Approach (Section 4) addresses each of these aspects of commercial boiler system efficiency. The next sections provide more detail about conventional boilers, mid efficiency boilers, condensing boilers, and hybrid boiler systems.

### 3.1.2 Conventional Boilers
Conventional boilers—which dominate the market due to their relatively low cost of production—typically have atmospheric draft burners and cast iron heat exchangers. The flue gases for conventional boilers are maintained at a sufficiently high temperature to allow them to exit the system using natural convection. This in turn results in the boiler operating at low efficiencies, as significant heat is lost through the flue. The efficiency of a conventional boiler, which ranges between 80 and 83 percent, can be improved by incorporating auxiliary equipment and controls. Doing so, however, could cause the flue gas temperatures to drop below the dew point and begin operating in condensing mode. Since the condensate is acidic, it will corrode the heat exchanger and damage the flue in a typical conventional boiler.

### 3.1.3 Mid Efficiency Boilers
Within the conventional boiler market, there is some movement towards mid efficiency boilers (83 to 88 percent efficient). A mid efficiency boiler uses forced draft or induced draft power burners, instead of atmospheric draft, to push or pull gases through the firebox and heat exchanger. Because they have relatively high efficiencies and relatively low flue gas temperatures, these boilers often are constructed with stainless steel, or other corrosion-resistant materials, to tolerate condensation in the boiler should it occur during a transition period, such as in start-up. It is important to note, however, that some mid efficiency boilers can continue to use standard venting materials—or Category 1 non-positive, non-condensing venting—if their efficiencies are below 84 percent.

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19 Ibid.
20 Ibid.
21 Industry Interview.
23 Ibid.
24 Industry Interview.
3.1.4 Condensing Boilers

Condensing boilers can operate at efficiencies above 88 percent, although there are only a handful of condensing boilers below 90 percent efficient. Condensing boilers operate at such high efficiencies by capturing some of the latent heat resulting from the phase change of the water vapor in the exhaust gases. As demonstrated in Figure 1 above, this requires return water temperatures less than 130 degrees F, which causes the flue gases to condense. The resultant condensate is acidic and requires corrosion-resistant materials, such as stainless steel, to be used for all heat exchanger and flue surfaces. Additionally, the venting and condensate drainage must include corrosion-resistant materials. An alternative option for condensate is to incorporate a neutralization kit that will increase the pH of the condensate, allowing it to be safely disposed of down copper drains.

In addition, condensing boilers typically include a power burner or pulse combustion with precisely controlled hot surface or spark ignition. Most commercial boilers include modulating burners to avoid losses caused by cycling at part loads. Many also include built-in or optional supply water temperature reset devices to control for capacity. Additionally, many condensing boilers contain advanced control systems and can be staged with other boilers to meet the heating needs of the application. Together these advanced controls allow for condensing boilers to operate at high efficiency under part load conditions when return water temperatures are usually low.

When the return water temperature of the system is higher than 130 degrees F, a condensing boiler will operate like a mid efficiency boiler. Under such operation, the system will not achieve the expected savings. This, coupled with the cost differential of a condensing system, generally means that a condensing boiler is not cost effective in a system where it will not condense. Therefore, when specifying condensing boilers, it is important to understand the building heat loads, seasonal operation, and the required return water temperature of the system.

3.1.5 Mixed Technology Boiler Systems

A mixed technology boiler system—also known as a hybrid boiler system—combines both condensing and conventional boilers into a single system, taking advantage of the benefits of each type of boiler. Central to these systems is a controls system that helps to optimize the efficiency of the systems. In a typical configuration, condensing boilers are sized to provide

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27 Ibid.


29 Please note that the Patented Hybrid Boiler Control™, manufactured by Thermodynamic Process Control (TPC), utilizes a proprietary, patented control process that includes Intelligent Load Sharing™, Flow Intelligent™ programming, and a Flexible Distributed Platform (TPC-FL-FDP™). TPC has informed CEE that: it is not currently contemplating infringement litigation for 2011; it anticipates receiving additional patents in 2011; and that it will begin to investigate potential infringers in 2012. CEE suggests that Administrators monitor potential price and availability impacts in the boiler controls market in view of patent uncertainties.
heating loads for outside temperatures down to 32 to 35 degrees F.  

For many climates, this accounts for the vast majority of the heating season and the shoulder seasons. As the outside temperatures drop further and heating loads increase, conventional boilers can be used to meet the increased demand. This design helps to ensure that return water temperatures are above 140 degrees F while the conventional boiler is in operation to avoid condensation and corrosion of the boiler.

Especially for larger system capacities, including conventional boilers in such a system can help bring down the initial installation cost of the project. Coupled with increased energy savings over a conventional boiler only system, mixed technology boiler systems may be a cost effective option to maximize energy savings.

3.1.6 Boiler Emissions – Nitrogen Oxides

In addition to producing carbon dioxide and water vapor, the combustion process also releases nitrogen oxides (NO\textsubscript{x}), carbon monoxide, and other particulates into the air. NO\textsubscript{x} consists of two forms of nitrogen oxides—nitric oxide (NO) and nitrogen dioxide (NO\textsubscript{2})—that are generated by gas boilers and are together referred to as total oxides of nitrogen or NO\textsubscript{x}. The U.S. Environmental Protection Agency (EPA) requires states and cities to adopt and implement measures to reduce greenhouse gasses and solid particulate matters in the air, such as NO\textsubscript{x}. To this end, some air quality districts, such as the South Coast Air Quality Management District (SCAQMD) in California has established NO\textsubscript{x} emission regulations. The SCAQMD NO\textsubscript{x} regulations as related to boilers that meet the scope of this Initiative are outlined in Table 3.

<table>
<thead>
<tr>
<th>Capacity (Btu/h input)</th>
<th>NO\textsubscript{x} Limit</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 400,000</td>
<td>20 ppm</td>
<td>Jan 1, 2012</td>
</tr>
<tr>
<td>&gt; 400,000 and ≤ 2 million</td>
<td>20 ppm</td>
<td>Jan 1, 2010</td>
</tr>
<tr>
<td>&gt; 2 million and &lt; 5 million</td>
<td>12 ppm</td>
<td>Jan 1, 2014 (Atmospheric Units Only)</td>
</tr>
<tr>
<td>&gt; 2 million and &lt; 5 million</td>
<td>9 ppm</td>
<td>Jan 1, 2012 (Excluding Units at Schools and Universities)</td>
</tr>
<tr>
<td>&gt; 2 million and &lt; 5 million</td>
<td>9 ppm</td>
<td>Jan 1, 2014 (Units at Schools and Universities)</td>
</tr>
</tbody>
</table>

30 Cleaver Brooks Fact Sheet: “Maximizing Heating System Gains with Hybrid Boiler Plants”.

31 Ibid.


These regulations apply to all boilers in the SCAQMD, including existing ones. Other regions have already adopted similar regulations, and it is expected that this will continue into other regions. This may create situations of forced replacement, which in turn creates implications for efficiency programs.

### 3.2 Commercial Boiler Market

Estimates for the size of the commercial boiler market vary drastically. Based on one industry interview, the total commercial boiler market (gas and oil) was estimated to be between 40 and 85 thousand units and rapidly moving toward higher efficiency. Another source estimates that there are approximately 120 thousand commercial boilers in the United States. Of this, approximately 79 thousand are gas-fired units under 10 million Btu/h.\(^{35}\) This source indicates that approximately two-thirds of commercial boilers are used for space heating applications, with domestic hot water accounting for most of the rest.\(^{36}\)

Finally, using DOE Commercial Buildings Energy Consumption Survey (CBECS) data, there are approximately 397 thousand commercial buildings that have natural gas boilers for space heating.\(^{37}\) This data does not capture the percentage of commercially sized units verse residentially sized ones. Based on the DOE CBECS data, the largest markets for commercial boilers are in the Northeast and Midwest, with offices and education facilities being the predominant building types.\(^{38}\)

Table 4 below shows fuel consumption and expenditures for buildings with boilers.

**Table 4: Fuel Consumption and Expenditures for Buildings with Boilers by U.S. Census Region\(^{39}\)**

<table>
<thead>
<tr>
<th>U.S. Census Region</th>
<th>Total US</th>
<th>Northeast</th>
<th>Midwest</th>
<th>South</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of Major Fuel Expenditures (million $)</td>
<td>$31,052</td>
<td>$9,785</td>
<td>$7,454</td>
<td>$7,486</td>
<td>$6,327</td>
</tr>
<tr>
<td>Natural Gas Expenditures (million $)</td>
<td>$7,418</td>
<td>$2,222</td>
<td>$2,457</td>
<td>$1,582</td>
<td>$1,156</td>
</tr>
<tr>
<td>Sum of Major Fuel Consumption (trillion Btu)</td>
<td>2,244</td>
<td>661</td>
<td>656</td>
<td>559</td>
<td>368</td>
</tr>
<tr>
<td>Total Natural Gas Consumption (billion cubic feet)</td>
<td>1,009</td>
<td>270</td>
<td>365</td>
<td>207</td>
<td>166</td>
</tr>
<tr>
<td>All Buildings NG Consumption (billion cubic feet)</td>
<td>1,870</td>
<td>416</td>
<td>683</td>
<td>460</td>
<td>311</td>
</tr>
<tr>
<td>Percentage of Total Buildings NG Consumption Represented by Buildings with Boilers</td>
<td>54%</td>
<td>65%*</td>
<td>53%</td>
<td>45%</td>
<td>53%</td>
</tr>
</tbody>
</table>

---

35 Energy and Environmental Analysis, Inc., May 2005. “Characterization of the U.S. Industrial Commercial Boiler Population”. Section 3: Estimates 93,000 boilers with less than 10 million Btu/h input, of which 85% are fired with natural gas. Note, this estimate is likely understated, as this report relies almost entirely on data from existing ABMA data at the time.

36 Ibid. Note: A small fraction of boilers are used in food service. These are not currently included in the Initiative.


38 Ibid.

39 Ibid.
High Efficiency Commercial Boiler Systems Initiative Description

*Note: This percentage for the Northeast does not accurately represent New England. The percentage of All Buildings natural gas consumption represented by Buildings with Boilers is 78 percent.

3.2.1 Market Structure

In new construction, the typical distribution channel (see channel 3 in Figure 2) for a commercial boiler includes five primary players: manufacturer, manufacturer representative or wholesaler, contractor, design engineer, and owner. In the typical distribution, an owner will work with a design engineer to plan and specify the boiler system. The design engineer or contractor will then consult with a specifier list which provides information about the models that meet the specifications, and contact the manufacturer or wholesaler to purchase the desired model. Manufacturers perceive being on the specifier list to be critical to their business.

As Figure 2 demonstrates, there are several other ways in which an owner can procure a new boiler. Manufacturers suggested that even though a majority of sales were for the replacement market, it was rare for an owner to work directly with the manufacturer representative or wholesaler for a direct replacement (channel 1). Rather, in the replacement market, the building owner often works directly with the contractor to design-build the boiler systems (channel 4).

Figure 2: Commercial Boiler Distribution Channel

![Diagram of commercial boiler distribution channel]

3.2.2 Manufacturers

According to data from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Directory of Certified Product Performance and the American Boiler Manufacturers Association (ABMA) membership list, there are 29 commercial boiler manufacturers. This estimate omits manufacturers that do not submit their boilers to AHRI or that are not members of ABMA. Of

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40 Quantum Consulting, 2003 and Industry Interviews.

41 Ibid.

42 Ibid.
the manufacturers listed in the AHRI Directory, 20 of the 22 supply commercial boilers within the 300,000 to 4 million Btu/h range.\textsuperscript{43}

Unlike other HVAC (heating, ventilation, and air-conditioning) industries, the hydronics industry does not have published market share information. Major manufacturers of commercial boilers between 300,000 and 4 million Btu/h are: A.O. Smith Water Products, Bosch Thermotechnology, Burnham, Buderus, Lochinvar, Raypak, RBI Water Heaters (a division of Mestek), Weil-McLean, and Viessmann.\textsuperscript{44} Appendix C provides a complete list of commercial boiler manufacturers.

### 3.2.3 Boiler Replacement Pathways

There are two common paths for boiler replacement: the boiler is at the end of its useful life or the replacement conducted as part of an energy upgrade. For those at the end of their useful life, often the costs of boiler maintenance begin to outweigh the cost of replacement.\textsuperscript{45} This decision, however, is driven by available funds. While funds may be available for regular maintenance of the boiler system, sufficient funds for the capital cost of replacing the boiler may not be available.\textsuperscript{46} For conventional, cast iron boilers that have significantly long lifetimes (see Section 3.2.5 below), weighing this funding decision may result in a boiler lasting several decades before replacement.

For boiler systems undergoing early replacement during an energy upgrade, often an energy expert assesses and recommends a variety of options for potential upgrade. Of these recommendations, boilers may be one; however, this often depends on the method of assessment—for example, simple paybacks or internal rates of return.\textsuperscript{47} While high efficiency boilers offer significant energy savings, the capital costs can be large and may impact the ultimate decision for replacement. Typically, early replacement of boilers may be incentivized by high fuel prices, efficiency program rebates, and tax incentives.\textsuperscript{48} As noted in Section 3.1.6, forced replacement due to regulation is a third pathway for boiler replacement.

### 3.2.4 Boiler Sales and Market Penetration

Recent estimates of commercial boiler sales indicate that 36,000 units were shipped in 2007. Of these, approximately 10,000 were gas-fired hot water boilers—although it should be noted that some are larger than the size range covered in this Initiative—with the remaining being steam


\textsuperscript{44} Ibid and Industry Interviews.

\textsuperscript{45} Industry Interview.

\textsuperscript{46} Ibid.

\textsuperscript{47} Ibid.

\textsuperscript{48} Industry Interview.
and oil-fired boilers. Of these shipments, DOE estimates that 90 percent are from AHRI manufacturers.

Despite the lack of shipment data by efficiency level, it appears that the commercial boiler market is moving towards high efficiency technologies. Specifically, the sale of condensing boilers appears to have increased dramatically in the past decade. In 1999, CEE estimated condensing boilers to be 2 percent of the total boiler market. In 2006, condensing boilers reportedly made up 20 to 25 percent of the commercial market. Based on interviews with manufacturers, it appears that rapid growth in condensing sales is expected to continue. It is assumed that at least part of the growth in condensing boiler sales can be contributed to multiple boiler systems and the existing stock reaching the end of its useful life.

This industry and technological shift has exceeded installer education, testing procedures, and safety standards. Based on one industry interview, this trend is expected to continue as more Japanese and UK technologies enter the market. The technological shift has meant that boiler technology improvements have gone from a 50 year life cycle to a 10 year life cycle.

3.2.5 Equipment Lifetime

Commercial boilers have the longest lifetime of all major commercial HVAC equipment, with estimated lifetimes between 24 and 35 years. Many conventional cast iron boilers can live well beyond these estimated lifetimes. Given this long measure life, there are relatively few opportunities for boiler efficiency upgrades. This makes it especially important to promote high efficiency boiler systems when a new construction or retrofit opportunity exists. Additionally, quality installation and maintenance are even more critical to achieve lifetime energy savings. Table 5 below shows the median lifetime for a variety of commercial HVAC equipment.

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50 Ibid.


53 Industry Interviews.

54 Industry Interviews.

3.3 Market and Technical Barriers

This section outlines major market and technical barriers that exist in moving the market towards higher efficiency commercial boiler systems. CEE developed the Initiative approach provided in Section 4 to address these barriers.

3.3.1 Technical Requirements for Condensing Boilers

Condensing boilers have different installation requirements than conventional boilers, including system design considerations for return water temperatures, venting, and condensate drainage. This may be a particular barrier for retrofit applications where the existing system cannot adequately handle a condensing boiler. For example, operational requirements of a condensing system require a Category IV vent stack that operates at positive pressure and can handle the acidic nature of the exhaust gas. To comply with this, the venting materials may need to be upgraded to more costly materials such as stainless steel. Because of this, venting via the existing stack may not be an option and alternatives may prove challenging to incorporate. Addressing these technical considerations in retrofit applications may not be cost effective.

Additionally, the rapid introduction of new boiler technologies is perceived by industry to be outpacing installer training. This includes the incorporation of appropriate control schemes for a given system. Often control schemes for conventional boiler systems are incorrectly generalized and may be applied to condensing boiler systems.\(^{57}\) This may result in less optimal operation of the boiler system, reducing the overall efficiency and potentially shortening the life of the boiler and increasing the annual maintenance costs. With no defined best practices for control schemes for condensing systems, selecting an appropriate control scheme is left up to the design engineer and installer.

3.3.2 First Cost

High efficiency boilers cost more because they require corrosion-resistant materials (for condensing), greater insulation, and more sophisticated controls. In addition, these units often have premiums associated with perceived value in the marketplace. While many of these factors can raise the incremental cost, some condensing systems may not require boiler pumps, which

\(^{56}\) Ibid.

\(^{57}\) Industry Interview.
can help bring the costs down somewhat.\textsuperscript{58} Regardless, the overall net incremental cost is still significant, both for a move to mid efficiency and condensing systems.

According to estimates from the DOE, the move from a small standard efficiency boiler to a mid efficiency boiler is approximately $4,000, or a 40 percent increase from the cost of a standard efficiency unit.\textsuperscript{59} A sample of manufacturer data suggests that this estimate is fairly accurate. Based on that data, the move from a standard efficiency unit to a mid efficiency one has an incremental cost of approximately $3,000 per million Btu/h.\textsuperscript{60}

Estimates for a move to condensing boiler systems, however, vary dramatically. According to various industry experts, the price of a condensing commercial boiler alone may be 50 percent more to more than double that of a conventional, standard efficiency unit.\textsuperscript{61} One industry expert estimates the real premium of being $24,000 per million Btu/h for a condensing unit compared to $10,000 per million Btu/h for conventional, or an incremental cost of $14,000 per million Btu/h.\textsuperscript{62} A sample of manufacturer data indicates that this estimate is reasonable; however, the range is very broad from approximately $10,000 to $40,000 per million Btu/h.\textsuperscript{63}

Competition among manufacturers may reduce the incremental cost associated with premiums over time; however, the numerous technologies in the market require specialized knowledge for proper installation, which may keep incremental costs high. In retrofit applications, the cost of upgrading the system itself may also be a barrier to improving the overall system efficiency. This is of specific concern when attempting to upgrade a system for a condensing boiler, as in some instances these costs might be prohibitive and will limit the efficiency options for that building.

### 3.3.3 Split Incentive

Half of non-government-owned commercial boilers are in buildings that are not owner occupied.\textsuperscript{64} Owner-occupied buildings are nearly twice as likely to have an upgrade as those occupied by tenants. In cases where the energy bills are the responsibility of the tenants, there is a split incentive to improving HVAC equipment. Owners are usually responsible for the upfront costs, but do not receive the benefit of savings on the energy bills. The tenants will benefit from the savings, but have little incentive to commit to the high upfront costs with paybacks and

\textsuperscript{58} Ibid.


\textsuperscript{60} Industry Interviews.


\textsuperscript{63} Industry Interviews.

lifetimes that will likely exceed their leases. The high incremental cost of moving to a condensing boiler may magnify this challenge with split incentive.

3.3.4 Lack of a Sufficient Test Procedure

As indicated in Section 2.2, commercial boilers are currently rated in terms of steady state efficiency, which is considered to be an inadequate metric as boilers typically operate at part loads. This is particularly true due to advances in modulating burners and boiler staging that yield more savings, but are not currently captured in the ANSI-Z21.13 or BTS-2000 test standards. Without a test procedure that adequately captures part load operations throughout the year, programs are unable to accurately estimate infield efficiency of the system. This may negatively impact the payback period for higher efficiency systems designed to take advantage of part load operation, which, in turn, may make it more difficult to make the financial case to building owners for the investment in efficiency.

3.3.5 System Design Requirements

Energy savings from commercial boilers can be improved not only by increasing the efficiency of the unit itself, but also by considering the whole system including auxiliaries, quality installation, and proper maintenance. Table 6 below identifies several potential areas of energy loss throughout a boiler system. The efficiency of transferring heat from a boiler into the system—and in just the right amount and at just the right time—is a truer measure of high performance than just the rating on the boiler.

Table 6: Boiler System Losses

<table>
<thead>
<tr>
<th>Potential Area for Energy Loss</th>
<th>Estimated Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burner</td>
<td>1-5%</td>
</tr>
<tr>
<td>Boiler</td>
<td>--</td>
</tr>
<tr>
<td>Flue Gas Loss</td>
<td>5-15%</td>
</tr>
<tr>
<td>Convection &amp; Radiation</td>
<td>5%</td>
</tr>
<tr>
<td>Latent Heat</td>
<td>10%</td>
</tr>
<tr>
<td>Burner Control Method</td>
<td>5-30%</td>
</tr>
<tr>
<td>Distribution System</td>
<td>25-30%</td>
</tr>
<tr>
<td>Piping Leaks</td>
<td>15-20%</td>
</tr>
<tr>
<td>Standby Radiant Loop Loss</td>
<td>10%</td>
</tr>
<tr>
<td>Operations and Maintenance</td>
<td>10-15%</td>
</tr>
</tbody>
</table>

This also means that the entire system can impact the efficiency of a boiler. For example, if a system is designed such that return water temperatures are too high to allow the boiler to condense, then savings will remain on the table and the end user may not recoup the initial

investment in the higher cost of the condensing boiler. Therefore, the unit cannot be addressed in a vacuum, but rather the entire system must be understood when considering an upgrade of a commercial boiler.

Two common technologies that can achieve significant savings and increase the system efficiency are modulating burners and supply water reset control functionality. Modulating burners provide improved control over the combustion of flue gases, allowing the burner to reduce the firing rate when there is lower demand. Modulation is typically defined by the turndown ratio, which is an indication of the burner’s minimum firing capability compared to the maximum firing rate. For example, a 5:1 turndown means that you can operate your boiler at continuous turn down until 1/5 of the nameplate rating. Modulation can achieve up to 3 percent in fuel savings. Most condensing boilers on the market already contain modulating burners. While the Initiative approach outlined below (Section 4) addresses complete boiler replacement, efficiency programs may also see savings through burner retrofits by replacing the existing burner with a multi-stage or modulating burner. This in itself can achieve significant savings and help to optimize the system.

CEE has defined the term supply water temperature reset control functionality to be a means of reducing the temperature of the water to the lowest temperature required to meet the system demand. With this definition, CEE is not defining a specific technical path, but rather the functionality desired. Through this ability to adjust the water temperature, the system has a better match between the boiler output and the actual space heating needs, which in turn reduces the cycling of the boiler and radiant heat loses. Supply water temperature reset control functionality can increase the efficiency of the system by 5 percent. Most condensing boilers on the market include this functionality, either as a built-in or optional component.

3.4 Potential Energy Savings

In 2003, natural gas boiler systems heated 397 thousand commercial buildings, representing 25 percent or 16.4 billion square feet of commercial floor space.66 Another estimate indicates that 12.9 billion square feet of commercial floor space use natural gas commercial boiler systems.67 In 2003, CBECS reported that commercial boilers consumed 709 trillion Btus of natural gas annually. However, other estimates range from 0.23 Quads (230 trillion Btu)68 to 1.35 Quads

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Different methodologies, and not a shift in boiler energy consumption, appear to explain this discrepancy.

This section examines potential national energy savings assuming the full transformation of the existing stock to higher efficiency and condensing technology. According to estimates from the DOE, the existing boiler stock in 2003 operated at 76 percent TE. Since thermal efficiency is not considered to accurately reflect infield efficiency (as noted in Section 2.2), this estimate is likely higher than the actual infield efficiency of the existing boiler stock. To look at the savings potential of the efficiency of the boiler itself, use the following equation:

\[
\frac{\text{New Efficiency} - \text{Existing Efficiency}}{\text{Existing Efficiency}} \times \text{Fuel Input} = \text{Potential Energy Saved}
\]

This back-of-the-envelope calculation was used here to approximate 100 percent market transformation energy savings based on improvements to the unit itself.

### Table 7: National Annual Energy Savings Potential

<table>
<thead>
<tr>
<th></th>
<th>DOE National Consumption Estimate</th>
<th>CBECS National Consumption Estimate</th>
<th>EEA National Consumption Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boiler Consumption</strong>(^1) (TBtu*)</td>
<td>230</td>
<td>709</td>
<td>1,353</td>
</tr>
<tr>
<td><strong>Potential Energy Savings (Low)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Savings (%)</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td>Energy Savings (TBtu)</td>
<td>27.6</td>
<td>85.1</td>
<td>162.4</td>
</tr>
<tr>
<td><strong>Potential Energy Savings (Med)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Savings (%)</td>
<td>18%</td>
<td>18%</td>
<td>18%</td>
</tr>
<tr>
<td>Energy Savings (TBtu)</td>
<td>41.4</td>
<td>127.6</td>
<td>243.5</td>
</tr>
<tr>
<td><strong>Potential Energy Savings (High)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Savings (%)</td>
<td>26%</td>
<td>26%</td>
<td>26%</td>
</tr>
<tr>
<td>Energy Savings (TBtu)</td>
<td>59.8</td>
<td>184.3</td>
<td>351.8</td>
</tr>
</tbody>
</table>

*TBtu = 1 trillion Btu

Table 7 above simply provides estimates for annual energy savings. These estimates do not take into account the long lifetimes of the equipment. Should a system be properly maintained and


\(^{71}\) The first estimate is based on “Energy Consumption Characteristics of Commercial Building HVAC Systems Volume III: Energy Savings Potential” and should be used when comparing with the estimated national savings presented in CEE’s “Market Characterization for Gas-fired Rooftop Units.” The second and third column is the 95% confidence range for the 1995 CBECS data which is the last time CBECS reported fuel consumption by heating technology.
tuned throughout the lifetime of the equipment (24 to 35 years as indicated in Table 5), these savings become increasingly significant.

3.5 Non-Energy Benefits of High Efficiency Boiler Systems

In addition to the energy savings benefits of a high efficiency boiler system, there are several non-energy benefits to consider. These include:

- Increased safety resulting from lower operating temperatures. The lower the operating temperature, the less hazardous a leak in the system would be to people working in the plant.\(^{72}\)

- A smaller footprint, which allows more usable space in a commercial building, especially in new construction. The smaller footprint is beneficial in retrofit applications as it may allow the boiler to fit through the door easier or for the old boiler to be left in place, further reducing the costs.

- Many high efficiency boilers have lower NO\(_x\) burners, several of which meet the SCAQMD requirements for boilers less than 2 million Btu/h (outlined in Section 3.1.6).

- Incorporation of modulation, which not only improves efficiencies, but also reduces the cycling of the boiler on and off. This results in less wear on the gas valves and other components.

- Often being complete packaged systems with advanced controls, reducing the need for contractors to piece together a variety of components. These packaged systems are often modular as well, allowing for easier replacement of specific components that may have required replacement of the entire boiler in less efficient models. Additionally, many of the advanced control systems are compatible with building energy management systems.

- The appeal of an energy efficiency technology, which is becoming increasingly significant as individuals emphasize the importance of environmentally friendly technologies and sustainable practices. This may be used as a marketing tool for attracting tenants in commercial buildings.

4 Initiative Approach

In order to address the market and technology barriers above, this Initiative focuses on achieving savings through a system approach. The approach provides an Equipment and Functionality Specification for program managers defining cost effective efficiency levels for boilers and related functionality requirements for optimizing the boiler regardless of the system design. To ensure a system focus, the initiative also provides guidance on additional measures for optimized systems. Section 5 outlines the importance of certain measures as being mandated for “initiative participation,” while others are optional. Through voluntary adoption of this Initiative by efficiency programs and additional stakeholder engagement through the CEE forum, CEE aims to meet the Initiative objectives outlined in Section 1.2.

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4.1 Required Initiative Participation Components

4.1.1 Equipment and Functionality Specification for Commercial Boilers

This section provides an Equipment and Functionality Specification for programs to address boiler efficiency. CEE developed the tiers to define both high efficiency boilers (Tier 1) and provide necessary flexibility for programs that achieve savings with mid efficiency boilers (Tier 0) based on regional differences in building stock, climate, cost effectiveness, and other considerations. To meet either the Tier 0 or Tier 1 equipment specification requirements, the boiler must be tested to either the ANSI Z21-13 or BTS-2000 standards to ensure a basis of comparison. In addition to boiler efficiency levels, this specification provides functionality and application requirements to help ensure system optimization regardless of application.

Widespread voluntary adoption of the Equipment and Functionality Specification by programs provides a consistent signal to the market defining high efficiency commercial boiler systems.

<table>
<thead>
<tr>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 0</td>
</tr>
<tr>
<td>Equipment 85% TE</td>
</tr>
<tr>
<td>Modulating Burner (minimum 4:1 turndown)</td>
</tr>
<tr>
<td>Supply Water Temperature Reset Control Functionality</td>
</tr>
<tr>
<td>Retrofit Projects Only</td>
</tr>
<tr>
<td>Tier 1</td>
</tr>
<tr>
<td>Equipment 90% TE</td>
</tr>
<tr>
<td>Modulating Burner (minimum 4:1 turndown)</td>
</tr>
<tr>
<td>Supply Water Temperature Reset Control Functionality</td>
</tr>
<tr>
<td>System has the ability to achieve low return water temperatures (&lt; 130 degree F) causing the boiler to produce condensate</td>
</tr>
</tbody>
</table>

As indicated by the specification above, this Initiative encourages manufacturers to test to TE and programs to incorporate TE whenever possible. For members that must use CE, efficiency programs should consider adding 2.2 percent to the above specification to account for average jacket losses. Since not all boilers exhibit the same jacket losses, this is intended to be an approximation used by programs as an additional resource when developing cost effective CE performance levels. This is not intended to be a prescriptive requirement of this Initiative.

In addition to efficiency, boiler emissions, such as NO\(_x\), are another consideration for high efficiency systems. While currently only a few areas regulate emissions for boilers, this may become a trend across other regions in the future. To create greater consistency in defining a low emissions boiler, CEE developed the optional specification for low NO\(_x\) emissions, detailed in Table 9. NO\(_x\) emissions includes sum of nitrogen oxide and nitrogen dioxide in flue gas collectively.

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73 This guidance is based on an analysis of reported CE and TE data for commercial boiler models in the AHRI Directory. CEE used only models that reported both CE and TE, removing any models where CE was equal to or less than TE, to determine the average percent difference. This estimate is in line with average jacket loss estimates.
### Table 9: Optional Specification for NO\textsubscript{x} Emissions

<table>
<thead>
<tr>
<th>Tier</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 300,000 and ≤ 2 million Btu/h</td>
<td>≤ 20 parts per million</td>
</tr>
<tr>
<td>&gt; 2 million and &lt; 4 million Btu/h</td>
<td>≤ 9 parts per million</td>
</tr>
</tbody>
</table>

### 4.1.2 Quality Installation and Boiler Rightsizing

This Initiative aims to increase the markets demand for quality installed and rightsized boiler systems, which will help to ensure that the systems are operating at optimal efficiencies. Programs should require contractor compliance with manufacturer instructions and all federal and local standards for boiler system installation safety. This includes ensuring that contractors incorporate appropriate venting materials and design into a given system. Additionally, programs should consider providing measures—ranging from messaging to incentives—to encourage energy efficiency installations of commercial boiler systems.

To address high efficiency quality installation, a good resource for programs is the *American National Standards Institute / Air Conditioning Contractors of America Standard 5: HVAC Quality Installations Specification* (ANSI/ACCA 5 QI 2010). This standard is a comprehensive document providing consistent guidelines for HVAC installations—including commercial boilers—that can be incorporated into energy efficiency programs. Other CEE Initiatives have adopted the 2007 version of this standard as the CEE QI specification for those initiatives. The 2010 standard includes additional support for hydronic systems and may be more useful for commercial boiler programs. CEE will continue to work with ACCA—bringing in other stakeholders as necessary—to ensure that this standard continues to be the best resource for contractors in defining quality installations. Gas efficiency programs may want to vet this standard for potential adoption as a requirement of this Initiative.

One specific aspect of quality installation is boiler rightsizing. Generally, a non-modulating boiler operates at its maximum efficiency when producing the rated heating output. This results from reductions in the cycling and jacket losses of a boiler. Therefore, in order to achieve the savings associated with a specific performance level, it is essential that a boiler is sized correctly to meet the demands of a specific application. Additionally, an optimally sized boiler will reduce the maintenance costs, as the reduced cycling generally causes less wear on the boiler. To ensure that a boiler is sized appropriate for a given application, programs should consider providing incentives for rightsized boiler systems and require heat load calculations, including Manual N calculations, when providing such incentives. The voluntary incorporation of rightsizing measures into programs will emphasize the importance of correctly sizing a boiler to optimize the system efficiency and encourage contractors to move away from the current practice of like for like replacement.

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75 Ibid.
4.1.3 Quality Operations and Maintenance

Quality operations and maintenance are two key aspects of ensuring safe operation and capturing savings in high efficiency boiler systems. Programs should require contractor compliance with all manufacturer instructions and federal and local codes for boiler system operations and maintenance safety. Additionally, programs should, at a minimum, message to the importance of quality operations and maintenance.

In exploring additional measures beyond messaging, programs should consider maintenance or tune-up programs. There is a key distinction between these two activities. Maintenance items are ongoing, routine actions that are conducted over the life of the product to keep the system in good working order—generally conducted every year or two. One resource that some member programs use to address maintenance is the ASHRAE/ACCA Standard 180: Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems. On the other hand, tune-ups go beyond traditional maintenance and focus on getting the equipment back to its original performance. To this end, resources such as the ANSI/ACCA 5 QI 2010 might be a better resource when working to get the equipment back to its original performance. Neither of these standards are a requirement under this Initiative, but gas members may want to vet these standards with that consideration in mind. In addition to these resources, CEE will work with programs and industry to identify key practices for proper operations, maintenance, and tune-ups in support of member programs.

4.2 Optional Components: Guidance for Efficiency Programs

This section provides additional guidance to efficiency programs on addressing commercial boiler systems and working towards optimal efficiencies throughout the year. Program administrators should consider incorporating some of the following aspects into their mass market or custom programs.

4.2.1 Boiler Sequencing

Program administrators should provide guidance on staged boiler systems and develop programs that encourage the use of multiple boilers to meet the required heat load. For condensing and hybrid systems, boiler sequencing is often an effective means of meeting the building’s heat load and optimizing the boiler system. Higher overall efficiency, simpler control, generally lower capital cost, and greater reliability are among the major advantages that staged systems offer compared with the conventional arrangement of one or two large boilers. As outdoor temperatures fluctuate throughout the heating season, optimally staging multiple condensing boilers allows for the boilers to run at, or at the very least closer to, their best efficiency point—which for condensing boilers occurs at the lowest firing rate and the coldest entering water temperature (see Figure 1). Essentially, when the heating demand is low for a building, only the boiler (or boilers) required to meet the demand will fire. Once the heating demand increases, additional boilers will fire to meet the increase in demand.

Additionally, boiler staging may be controlled from internal, external, or remote set points by means of a boiler management system for sequential boiler firing with outlet temperature feedback. The capability of the system to maintain tight temperature control, modulate firing rate with load, and operate in the condensing mode eliminates the need for hot water storage, temperature blending valves, and primary-secondary pumping systems. Furthermore, the risk of
a major heating system failure is greatly reduced with several small boilers, since the loss of a single small boiler will have minimal or no effect on overall comfort conditions.

In many cases, lower cost, residentially sized boilers may be used as part of a multi-boiler arrangement with the lead boiler sized to meet the minimum load condition and each additional boiler sized to meet the incremental heating loads. Program administrators should apply the guidance specification above to residential boilers in commercial applications. For additional guidance, CEE has developed performance specifications for residential boilers, which are available as part of the CEE High Efficiency Residential Gas Space Heating Initiative.

4.2.1.1 Mixed Technology Systems

In recognition of the potential savings opportunities and the challenges of moving all retrofit projects to condensing, CEE recognizes that mixed technology systems may provide a cost effective option. Expected savings will vary based on the specific configuration. In supporting these systems, members should incorporate the following guidance requirements into their programs:

- Incorporation of both CEE Tier 0 and Tier 1 boilers into a single system, with no boilers rated below these stated levels
- Modulating burners on all boilers (minimum 4:1 turndown)
- Supply water temperature reset control functionality on system
- Incorporation of boiler sequencing controls
- Required heat load calculations
- System designed to achieve low return water temperature (less than 130 degree F) causing the boiler to produce condensate for portions of the year (during the shoulder seasons at a minimum)
- Should be applied to replacement and retrofit projects only

4.2.1.2 Fully Condensing Systems

In the long term, efficiency programs should look at solutions that shift the market towards fully condensing systems. Expected savings will vary based on the specific configuration. In supporting fully condensing systems, members should incorporate the following guidance requirements into their programs:

- Incorporation of only Tier 1 boilers into a single system
- Modulation on all boilers (minimum 4:1 turndown)
- Supply water temperature reset control functionality on system
- Incorporation of boiler sequencing controls
- Required heat load calculations
- System designed to achieve low return water temperature (less than 130 degree F) causing the boiler to produce condensate year around
Should be applied to new construction and major renovation projects only

4.2.2 Upgrading to Higher Efficiency Systems

In working towards high efficiency commercial boiler systems, programs should consider the benefits of upgrading systems to higher tiers. For the purposes of this Initiative, this includes upgrading from steam systems to hot water and upgrading from conventional to condensing systems. While the latter is addressed somewhat in the guidance specification above, programs should consider providing additional support or messaging to encourage the upgrading of the whole boiler system. Through the development of consistent guidance and messaging on system upgrade requirements, efficiency programs will be better positioned to work with design engineers and building owners on the options for efficiency upgrades in a given facility.

4.2.3 Piping Insulation

As indicated in Table 6, standby and radiant circulation loop loss can range between 5 and 10 percent. Insulation of the piping can help to reduce these radiation losses. As a general rule of thumb, all surfaces above 120 degrees F should be insulated. Efficiency programs should consider providing additional measures for ensuring sufficient piping insulation. By incorporating insulation measures into the commercial boiler portfolio, efficiency programs will send the signal to building owners and contractors that insulation is a key component of optimizing maintaining a high efficiency system. Table 10 below provides the minimum piping insulation thickness for a range of operating temperatures and pipe size.

Table 10: ASHRAE 90.1-1999 Minimum Pipe Insulation Thickness

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<tr>
<th>Operating Temp (°F)</th>
<th>Pipe Size (inches)</th>
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<td>1.0</td>
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4.2.4 Early Replacement Programs

Due to the significantly long lifetimes of conventional boilers and the ability to maintain boilers to operate well beyond these lifetimes, this Initiative will explore opportunities for early replacement programs. The goal of such programs is to replace older, functioning boilers performing at low efficiencies with high efficiency options.

4.2.5 Outreach to Market Actors

In order to help transform the market towards higher efficiency commercial boiler systems, efficiency programs should consider adding outreach components to key market players. The typical distribution channel relies on five main players—manufacturer, manufacturer representative or wholesaler, contractor, design engineer, and building owner. In addition to these five, CEE has identified facilities managers as key stakeholders for moving the market towards high efficiency commercial boiler systems. To address some of the existing market and technology barriers, programs should be proactive about providing guidance and training for building owners, design engineers, contractors, and facilities managers. This Initiative will explore opportunities for supporting efficiency program efforts in reaching out to these various market actors. By voluntarily adopting consistent messaging and definitions, efficiency programs will be better positioned to engage these key decision makers in encouraging the transition to higher efficiency commercial boiler systems. The sections below provide additional context for efficiency programs.

4.2.5.1 Building Owner and Design Engineer Education and Awareness

In attempt to overcome split incentives, programs should provide information to building owners and design engineers as to the attributes and benefits of high efficiency commercial boiler systems. This should target both retrofit and new construction markets. For the retrofit market, programs should educate these parties about the necessary considerations for upgrading to condensing systems. In new construction, boiler systems are traditionally design “on spec”. This process emphasizes keeping the costs low, rather than improving the efficiency of the system. Changing these “specs” to incorporate high efficiency will be a key component of transforming the market for high efficiency systems. Through this Initiative, CEE will work with member programs to develop talking points and other guidance that programs can use in this outreach to these groups as appropriate.

4.2.5.2 Contractor Training

One barrier to high efficiency commercial boiler systems is the technical requirements for condensing equipment. It is important for contractors to understand these requirements for quality installation to help ensure the system will achieve the expected savings. Therefore, contractor training is an important aspect of a member program. Initiative participants are encouraged to sponsor contractor training opportunities that focus on quality installation and the value of high efficiency equipment. Programs should provide guidance on advanced venting, condensate drains, local energy code requirements, quality maintenance practices, and matching controls to the system. Additionally, programs should provide educational training to contractors on marketing and selling energy efficient systems and quality installation. This can help contractors to both work with design engineers to include more high efficiency considerations and make a higher value sale.

4.2.5.3 Facility Managers

In many commercial buildings, facilities managers are the decision makers regarding energy and system operation. Educating facility managers on the importance of quality maintenance and opportunities for efficiency upgrades may help in transforming the market for high efficiency commercial boiler systems. Programs should explore training and other educational opportunities for facilities managers to promote enhanced energy management through efficient commercial boiler system operation.
5 Initiative Participation

As with all Initiatives of CEE, participation in the High Efficiency Commercial Boiler Systems Initiative is voluntary. To be considered an Initiative participant, however, a program must meet a minimum set of requirements. For this Initiative, these requirements emphasize the need for programs to go beyond incentivizing the boiler alone and to provide a comprehensive strategy for capturing savings through system optimization. Participant requirements are as follows:

- Incorporate the CEE Equipment and Functionality Specification for boiler systems in an educational or incentive based program.
- Undertake awareness and system optimization measures related to quality installation and quality operations and maintenance.

Efficiency programs that must use CE due to regulator requirements may still be considered Initiative participants if they adopt the functionality requirements in the CEE Equipment and Functionality Specification, adopt reasonable boiler performance levels, and undertake the necessary awareness and system optimization measures related to quality installation, operation, and maintenance. Reasonable boiler performance levels would conform to the savings expected from Tier 0 mid efficiency boilers and Tier 1 condensing boilers.

6 CEE Role in Initiative Promotion

CEE’s role to accomplish these objectives will be to:

- Facilitate collective member understanding of the energy efficiency opportunities in commercial boiler systems
- Encourage the adoption of the Initiative into voluntary programs
- Develop guidelines, tools, and other resources to support programs in all aspects of the Initiative approach and serve as a clearinghouse for relevant information
- Reach out to industry stakeholders to identify potential opportunities for collaborating on the development of abovementioned guidance, tools, and other resources
- Provide to members and industry stakeholders information on member program efforts via annual program summaries that capture all voluntary program measures addressing commercial boiler system
- Work closely with manufacturers and industry associations to track industry and government efforts related to commercial boiler systems and provide regular updates to CEE members
Appendix A    Acronyms

ABMA – American Boiler Manufacturers Association
ACCA – Air Conditioning Contractors of America
AFUE – Annual Fuel Utilization Efficiency
AHRI – Air-Conditioning, Heating and Refrigeration Institute
ANSI – American National Standards Institute
ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME – American Society of Mechanical Engineers
BTS – Boiler Testing Standard
Btu – British Thermal Units
CBECS – Commercial Buildings Energy Consumption Survey
CE – Combustion Efficiency
CEE – Consortium for Energy Efficiency
DOE – United States Department of Energy
EPCA – Energy Policy and Conservation Act
FEMP – Federal Equipment Management Program
h – hour
HVAC – Heating Ventilation and Air Conditioning
NO – Nitric oxide
NO\textsubscript{2} – Nitrogen dioxide
NO\textsubscript{x} – Nitrogen oxides
ppm – Parts per million
SCAQMD – South Coast Air Quality Management District
TE – Thermal Efficiency
Appendix B  Definitions

Annual Fuel Utilization Efficiency (AFUE) – measurement of annual efficiency for residential boilers; measures the amount of heat delivered to the space compared to the amount of fuel supplied to the boiler, which takes into account changes in operation throughout the year.

Atmospheric Draft Burner – a burner where the gas and air enter the combustion as a result of gas pressure and the natural draft (also known as natural draft burners).

Boiler Cycling – the turning on and off of the boiler as there is a demand for space heating and then the need is met.

Boiler System – captures the entire system of heat distribution, including the boiler, controls, piping, and other distribution components.

Building Heat Loads – the amount of heat that must be supplied to a building in order to maintain a specific temperature in the space; this takes into account the building type and size, infiltration rates, shell loss, and ambient air temperatures.

Category IV Venting – venting used for units that operate at positive pressure and condensing operation (i.e. flue gas temperatures below the dew point).

Combustion Efficiency – measurement of efficiency for commercial boilers; measures how completely the burner transforms the fuel into useable heat, also equal to 100 percent minus the energy lost through exhaust gases; measurement does not take into account changes in the boiler operation throughout the year.

Commercial Boiler – a low pressure boiler with rated capacity of 300,000 Btu per hour or more used for space heating and service water heating; the DOE excludes boilers used for domestic water heating in their definition of “commercial packaged boiler”.

Condensing Boiler – a boiler with a power burner or pulse combustion that can operate at efficiencies above 88 percent by capturing some of the latent heat resulting from the phase change of the water vapor in the exhaust gases.

Convection – the transfer of heat by the circulation of the heated gas.

Convection Losses – loss of energy through the convection of heated gas from the boiler to the surrounding space.

Conventional Boiler – a boiler with an atmospheric draft burner and cast iron heat exchangers, which uses natural convection for venting and results in efficiencies between 80 and 83 percent.

Custom Program – for the purposes of this document, a type of program approach that provides a customized incentive for each project based on the specific needs of that project; often a more resource intensive approach that allows for better matching of incentive to expected energy savings.

Design Day – in regards to heating, this is defined as the temperature experienced for the coldest 2.5 percent of the year, which is used to determine the heat load requirements of a building in sizing the heating system.
High Efficiency Commercial Boiler Systems Initiative Description

Domestic Hot Water Heating – water used in any building for domestic purposes, principally drinking, food preparation, sanitation, and personal hygiene; also considered to be potable water; this does not include water used for space heating or process heat

Early Replacement – replacement of the boiler before the end of its useful life

Full Load Operation – the operation of a unit (in this case a boiler) at 100 percent of the rated load of that unit

Heat Exchanger – a device for transferring the heat of one substance to another (i.e., the heat of combustion air to the water in a boiler used for space heating)

Hot Water Supply Boiler – a type of boiler used to heat domestic hot water, or potable water; these boilers are not included in the DOE definition of a “commercial packaged boiler”

Hybrid Boiler System – a system that combines both condensing and conventional boilers into a single system

Latent Heat – heat absorbed or radiated during a change of phase (i.e. from gas to water)

Major Renovation Project – a project in an existing building that goes beyond the replacement of only the boiler or a couple components, but rather addresses a redesign of the entire system

Manual N Calculations – manual developed by ACCA for commercial load calculations that provides instruction to help contractors and designers satisfy energy, ventilation, and comfort requirements

Mid Efficiency Boiler – a boiler with a forced draft power burner that has relatively high efficiencies (between 83 and 88 percent) and may condense during a transition period such as start up of the boiler

Modulating Burner – a type of burner that provides improved control over the combustion of flue gases, allowing the burner to reduce the firing rate when there is lower demand

New Construction – a project in a new building where there are limited constraints on the design of the boiler system

Oversizing (as related to a boiler) – sizing a boiler such that it meets a higher demand than that of a specific application

Part Load Operation – a unit (or boiler) operating at less than 100 percent of the rated unit capacity

Power Burner – burners that use a blower to move the combustion air and gases through the combustion chamber (also known as a forced draft or induced draft burner)

Prescriptive Program – for the purposes of this document, a type of program approach that provides a standardized incentive for a given product category

Pulse Combustion – natural gas burner characterized by a periodic (or intermittent) combustion process

Quality Installation – a standard of key actions that must be undertaken during installation of the boiler system to help ensure the system will operate efficiently
Quality Maintenance – performing a set of ongoing, routine actions that are conducted over the life of the product to keep the system in good working order and ensure it is operating efficiently

Radiation – the process in which energy is emitted, in this case transmitted through the boiler jacket or piping to the surrounding space

Radiation Losses – loss of energy from radiation (see radiation above)

Residential Boiler – a low pressure boiler with a rated capacity of less than 300,000 Btu per hour used for space heating

Retrofit – a project that looks only at replacement of the boiler itself or some components within the system

Return Water Temperature – the temperature of the water returning to the boiler (also the inlet water temperature), which dictates the efficiency of the boiler

Seasonal Efficiency – a measure of the efficiency of the boiler throughout the year taking into account the variance in demand throughout the year

Rightsizing (as related to a boiler) – sizing a boiler such that it meets the demands of a specific application

Service Water Heating – heating water for domestic or commercial purpose other than space heating and process requirements; this may include domestic water heating

Space Heating – heating of the conditioned space of a building

Stack – a vertical vent pipe for gases from the escape of gases from the combustion process

Stack Losses – the loss of energy via emission of combustion gases through the stack

Steady State Efficiency – a measure of efficiency assuming the boiler is operating and the same rate throughout the year regardless of the demand

Steam Boiler – boilers that generate steam, rather than hot water, used for space heating or process heating

Supply Water Temperature Reset Control Functionality – a means of reducing the temperature of the supply water to the lowest required to meet the system demand

Thermal Efficiency (TE) – measurement of efficiency for commercial boilers; measures energy transferred to the system, also equal to 100 percent minus the energy lost through exhaust gases and jacket losses; measurement does not take into account changes in the boiler operation throughout the year

Tune-Up – a set of actions that aims to get the equipment back to its original performance

Turndown – an indication of the burner’s minimum firing capability compared to the maximum firing rate
## Appendix C  Commercial Boiler Manufacturers

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Appendix D  References and Resources


AHRI. Directory of Certified Product Performance.


Cleaver Brooks Fact Sheet: “Maximizing Heating System Gains with Hybrid Boiler Plants”.


Raypak. “Hybrid Heating Systems.”


