Are We There Yet? Determining a Baseline Using a Data-Driven Boiler Market Characterization

Susan Haselhorst and Isaac Wainstein, ERS, North Andover, MA
Michael Smalec, DNVGL, Middleton CT
Antonio Larson, National Grid, Waltham, MA

ABSTRACT

Mature energy efficiency programs offering incentives for high efficiency equipment must keep an eye out for market transformation – that point at which the high efficiency equipment becomes standard practice and assistance or incentives are no longer required to sustain the high efficiency equipment sales. However identifying that inflection point can be difficult since markets are dynamic and complex and no one party has perfect knowledge of the whole market. This paper presents an approach that combines traditional market actor surveys with a novel, relatively straightforward and inexpensive methodology for estimating the overall size of the Massachusetts boiler market with a particular focus on units in the 300 - 2,000 MBH (thousand Btus per hour) range . The two methods together provide a higher level of certainty together than either would alone. The emphasis of this paper is on the novel method of estimating market size using individual commercial and industrial (C&I) gas-customer billing-usage data for all the C&I customers in the state. Customer-by-customer monthly gas usage is analyzed to estimate base and weather-sensitive loading. Hourly weather data is analyzed to determine the operating profile of the weather-sensitive load; typical base-load profiles, mapped by SIC code, are used to characterize the thermal design load. The thermal load can then be used to derive a heating system capacity that will meet that load.

The end product is a rich, "bottoms up" estimate of the installed base of C&I natural gas-fired boilers in the state, which can be grouped by capacity range, building type, community, and energy efficiency provider. In conjunction with the market actors surveys and a few key assumptions (such as the median age of a boiler), this study estimates that 2500 boilers are sold statewide each year in the new construction and replacement C&I market. A key finding of the study is that about 25% of the boilers sold each year receive an incentive. The number of boilers sold that meet the high efficiency standard is between 25% and 75% of all boilers sold.

Introduction

Boilers constitute about 15%–25% of the custom and 25%–50% of the prescriptive natural gas program savings in the Massachusetts large commercial and industrial (LC&I) energy efficiency program, depending upon the program year. The program incentivizes the installation of boilers exceeding a thermal efficiency of 90%, with an additional incentive for boilers under 300 MBH exceeding Annual Fuel Utilization Efficiency (AFUE) of 96%. To meet these efficiencies, the boilers must be condensing. A fundamental assumption of the program is that without the incentive, the installed boiler would be a code compliant boiler. However, early in 2011, there were several indications that a large majority of boilers installed in Massachusetts were program eligible and may not have received incentives, indicating that standard practice may greatly exceed the code compliance threshold.

The Massachusetts LC&I Evaluation Working Group commissioned a study to estimate the portion of boiler sales, in both the new construction and replacement market that is high efficiency. The Working Group membership includes the Massachusetts energy efficiency program administrators (PAs)

and the Energy Efficiency Advisory Committee (EEAC) technical consultants. The EEAC is responsible for overseeing the execution of state-mandated energy efficiency programs in Massachusetts.

There have been studies that estimate the number of boilers installed in the US and also Canada. These estimates are developed from sources such as the American Boiler Manufacturers Association compilation of boiler sales data and surveys of commercial and industrial customers, such as the Manufacturing Energy Consumption Survey (MECS). However, these studies do not provide state specific results. There is also a large boiler emphasis illustrated by a statement in one study that dismisses smaller boilers, those less than 10,000 MBH, as "large hot water heaters". However, these smaller boilers are exactly the market of interest for the Massachusetts program.

The stakes for the outcome of the study are high, given that boilers account for such a large portion of the natural gas program savings, particularly lifetime savings. If the assessment demonstrated that a high percentage of non-incentivized boilers were high efficiency boilers, it would be fair to conclude that the incentives may no longer be required or targeted at an unreached corner of the market, diminishing a large contributor measure from the program portfolio. This was particularly an important question for the prescriptive program, which targets boilers in the 90–1700 MBH capacity range. The essential study questions were:

1. How many natural gas boilers, both new construction and replacement, are sold in the C&I Massachusetts sector every year?
2. What percentage of the units sold are high efficiency, program-eligible boilers?

Methodology

The study approached the task from two complimentary directions:

1. Survey of market actors to gather sales data and expert opinions
2. A novel approach using an analysis of statewide natural gas billing data to estimate boiler market size

Surveying market actors and the manufacturers and distributors of the boilers is a direct and obvious method for determining market size, *if* almost all of the market actors can be recruited and *if* their responses are candid. However, market actors are often very reluctant to share specific market share information since it is viewed as proprietary and competitive. In addition, market actors only know with certainty their own sales data and therefore cannot provide a complete view of the market as a whole. Another construct risk is self-selection, given that market actors representing high efficiency products are more likely to participate in a survey. Those market actors representing ineligible products may perceive programs as threatening and would have no intrinsic reason to participate. Since the foundational purpose of the study was to determine the size of the market and the penetration of high efficiency boilers, it was particularly important to gather data from those market actors that may have been the least inclined to respond, so that the denominator of the market share ratio is not understated.

As a complimentary approach to the market sales, the team developed an innovative way to estimate the size of boiler replacement market, which could help answer the question about the overall size of the market, providing a context for the individual market actor responses. The method uses an analysis of the natural gas bills of all C&I natural gas customers in the state to establish the design thermal load for each account; hence the heating system size (in MBH). This method leads to an estimate of the installed boiler base (number of boilers installed statewide) which in turn forms the basis for estimating the number of boilers requiring replacement each year. Unlike the piecemeal view of individual market actors, the billing approach provides a view of the whole natural gas C&I replacement market. It also has the advantage of being able to easily tabulate other market indicators, such as the distribution of boilers by size or by PA. This method does not, however, provide direct estimates of the number of boilers sold

into the new construction market, nor does it provide the vital answer to how many boilers sold are high efficiency vs. standard efficiency.

Survey Market Actors

The first step in conducting surveys was to establish the population frame. The focus of the surveys was narrowed to boilers in the 90 – 2,000 MBH range, which included the size range specifically addressed by the prescriptive program as well as a large portion of the boilers incentivized in the custom program as well. This eliminated contending with the many specialty manufacturers of larger boilers, with few sales. The Air Conditioning, Heating, and Refrigeration Institute (AHRI) identifies thirty-five C&I boiler manufacturers with products in the capacity range incentivized by the prescriptive program. Of those listed, twenty were judged to have large enough sales in the northeast to warrant an interview.

Care was taken to include a balance of different manufacturers who made high efficiency, mid-efficiency and standard efficiency boilers so that interview responses were representative of the spectrum of boiler types. Similarly, the participants were chosen to also represent a distribution of large and small capacity boilers in the targeted 90 – 2,000 MBH range.

In order to maximize the survey completion rate, the EEAC was a signatory on a letter issued to the manufacturer requesting their cooperation. The letter attempted to leverage the value of the gas efficiency program with the manufacturers and also reinforced that all information would be treated confidentially. Care was taken to never link individual sales numbers with a particular manufacturer at any point in the study. Comments made about the Massachusetts boiler program would also be "blind" and sanitized. In addition, the team targeted those individuals who were believed to be the most "Massachusetts boiler market savvy" based on the collective judgment of the PAs and the team.

The survey itself was designed expecting that most market actors would be reluctant to share explicit sales numbers, and therefore explicit quantitative questions were posed to the market actors as ranges. For example, the explicit question concerning sales asked the respondent to indicate annual sales in one of five ranges (0–10, 25–50, 51–100, 101–200, 200+). However, since the surveys averaged an hour in length and were for the most part open-ended, explicit values were solicited in the course of the interview and were sometimes shared.

Attempts were made to interview all twenty manufacturers active in the Massachusetts market. Of the twenty attempted interviews, sixteen agreed to the surveys and thirteen provided credible and useful indicators of sales in 2012. While the respondents represented a little over half of the manufacturers, those that did agree to participate were judged to represent the vast majority of the market.

Survey-Based Estimates of Market Size

The boiler market is not monolithic, with larger firms with multiple products serving all sectors on one side of the spectrum and specialty manufacturers with a single product offering, typically a high efficiency product, on the other. The offering and target market by interviewee is summarized in Table 1.

Interviewed Boiler Manufacturer's Product Line: Model Types & Sizes			
Boiler Market Sector	**Residential**	**Small C&I**	**Large C&I "Key Accounts"**
Boiler manufacturer "N"	Gas only, condensing only		
Boiler manufacturer "O"	Gas/oil, noncondensing		
Boiler manufacturer "P"	Gas only, condensing only		
Boiler manufacturer "Q"	Gas only, firetube only condensing/non-		
Boiler manufacturer "R"	Gas/oil, condensing & noncondensing		
Boiler manufacturer "S"		Gas C&I condensing only	
Boiler manufacturer "T"	Gas only, condensing only		
Boiler manufacturer "U"		Gas C&I condensing only	
Boiler manufacturer "V"	Many models: gas/oil, condensing/non-, firetube & cast iron		
Boiler manufacturer "W"	Gas/propane firetube condensing & noncondensing		
Boiler manufacturer "X"		Oil & gas cast iron noncondensing only	
Boiler manufacturer "Y"	Wide spectrum of gas/oil, cast iron/fire tube condensing/non -->		
Boiler manufacturer "Z"		Largest gas & oil industrial boilers, many types -->	

Table 1. Interviewed Manufacturer's Product Line: Boiler Types and Sizes

Each market actor's view of the market was unique and often blurred important program distinctions (i.e., residential vs. commercial sector or natural gas vs. oil-fired). When each respondent could not or would not specify sales to the natural gas C&I market, assumptions were required to translate to a C&I, gas-only sales range. Based on the responses and some judgment, 2012 boiler sales were estimated to be in the 1500 to 3000 unit range, with between 25% and 75% of sales for high efficiency units.

Estimate Boiler Market Size from Billing Data

The direct market outreach described above is a critical component in understanding the proportion of eligible and ineligible boilers sold, but because each manufacturer can only report their sales with certainty, and not all manufacturers provided data, it is not possible to know for certain whether or not a major piece of the market was overlooked.

This second method is based on an analysis of a data set of all Massachusetts C&I gas company accounts. The analysis has an algorithm for determining heating system size for each of the natural gas accounts included in the dataset. The results provide a basis for aggregation by PA, by business type, and by other convenient categories. Since this method focuses on C&I gas accounts, the results yield information for C&I gas-only boilers and provides a cross-check to the survey respondents where the distinction between oil and natural gas and the C&I and residential markets were not clear.

Using Billing Data to Estimate Boiler Market Size

The size or capacity of a boiler measured in MBH is largely driven by the building design load that it serves, which is the theoretical maximum amount of heat required to maintain building temperature on a design day. Using techniques developed in the Massachusetts 2011 Combined Heat and Power (CHP) Impact Evaluation Study, a design thermal load was calculated for every gas account. Once the design thermal load was defined, a boiler was sized to meet that load using standard engineering assumptions. An additional factor accounted for systems that are likely to be boilers vs. those that are not. This process ended in a final data set of an installed base of "virtual" boilers that were linked to specific gas accounts,

and hence to a PA and a building type through the account Standard Industrial Classification (SIC) or North American Industry Classification System (NAICS) coding.

The research question however, is not, "What is the installed boiler base?" but rather, "How many boilers are sold each year?" Boilers eventually fail and have to be replaced. The boiler replacement rate was estimated as the inverse of the median life of a boiler. Therefore, since boilers have a median life of 25 years, on average, 1/25 or 4% of all boilers will be replaced in any one year. This factor was applied to the overall number of boilers determined in the previous steps to arrive at the size of the boiler replacement market.

The link to specific gas accounts provides a high level of certainty as to the fuel type, location, customer type, and magnitude of the boiler size. While there is error in the application to a particular site of a factor such as heating system type, the statewide proportions will correctly match the expected statewide allocation.

The steps used to achieve this result are as follows, and a detailed description of each step is provided below.

1. Determine the design thermal load (maximum hourly usage) for each account (MBH) as a proxy for boiler size.
2. Filter out accounts that are too small to be served by a boiler and the portion of accounts served by non-boilers.
3. Adjust the count of boilers for facilities with multiple boilers per account.
4. Use a typical lifetime to determine the number of boilers replaced per year.
5. Summarize results by program administrator, boiler size and facility type.

Determine design thermal load – The account-specific, weather-sensitive load is distributed using a weather-driven hourly profile; the account-specific base thermal usage is distributed using a building type hourly profile. While the shape of the profile is not wholly unique to a customer (profiles are weather- and building-type determined), the sum of the hourly usage must equal that particular customer's billed usage, which provides very specific results for each account.

The theoretical optimal boiler size for any facility is equal to the maximum hourly usage during the most extreme outside conditions. This ensures that at all times the required heating load can be met. For this analysis the maximum hourly usage is calculated as the total usage divided by the facility's respective full load hours (FLH). Since FLH are different for the base and weather-dependent loads, the following equation was used to calculate the optional design thermal load:

$$Design\ thermal\ load = ((Base\ usage)/(Base\ FLH) + (Weather\ usage)/(Weather\ FLH)) \times Oversize\ factor$$

Base usage – For each account, the base usage was determined as the average monthly billed usage during the summer multiplied by 12 months.

Weather dependent usage – The weather dependent usage was the difference between the annual and base usages.

Base FLH – The base full load hours were calculated using a typical day hourly profile. Eleven separate profiles were defined for eleven facility types.

Weather dependent FLH – The weather-dependent full-load hours were calculated using an 8760 typical meteorological year 3 (TMY3) profile. For each hour there was considered to be 0% loading at the balance temperature and 100% loading at lowest temperature of the year with a linear relationship for each temperature in between. For each account the closest TMY3 station

was used to determine the outside air temperature, and the facility type was used to determine the respective base temperature.

Oversize factor – Each account's maximum capacity was multiplied by the ASHRAE-stated oversize factor of 120%. This ensures that the boiler is adequately sized even under the most extreme outside conditions.

Remove non-boiler accounts – The current dataset represents all natural gas accounts. Accounts with a design thermal capacity too small to be a boiler were removed. A review of boiler equipment and also program data indicated that all accounts with a maximum thermal load of less than 90 MBH are likely non-boiler accounts. According to the Energy Information Agency's Commercial Building Energy Consumption Study (CBECS) data, about 30% of the commercial space is heated by equipment other than a boiler, including heat pumps, packaged direct-fired units, and unit heaters.

Account for side-by-side boilers – The billing dataset represents the thermal load and total number of accounts served by boilers. The market-actor interviews indicated that about a quarter of the boilers were installed in a side-by-side configuration, which would include redundant as well as modular designs, where multiple smaller boilers serve the load rather than a single boiler or a single boiler with backups (redundant). The modular design will increase the number of small boilers and decrease the number of large boilers sold, as a site that has the thermal load for a larger boiler is instead served by multiple smaller boilers. In a redundant boiler design, each boiler is designed to serve the load (or is slightly undersized so that the lag boiler is required infrequently), reducing the annual run hours on the boiler pair; hence theoretically extending the life of each boiler.

Determine replacement schedule – The analysis thus far presents the installed boiler base. This figure was then divided by the boiler life of 25 years (ASHRAE) to determine the average number of boilers replaced per year.

Sensitivity analysis - By definition, the billing analysis approach includes only commercial gas-fired accounts, which removes some of the ambiguity inherent in the survey responses. However, the method does rely upon significant assumptions. A sensitivity analysis examined a range of boiler sales using the following ranges:

- Minimum range, assumes 60% of commercial space is heated by boilers, 15% of boilers are located in side-by-side designs, and a median boiler life of 30 years
- Most likely range, assumes 70% of commercial space is heated by boilers, 20% of boilers are located in side-by-side designs, and a medial boiler life of 30 years
- Maximum range, assumes 80% of commercial space is heated by boilers, 25% of boilers are in side by side designs, and a median boiler life of 20 years

Note that the sensitivity analysis assumes concurrent worst and best case assumptions and should be interpreted as representing unlikely extremes in sales and not the bounds of the likely range of boilers sold.

Billing Analysis Market Results

Table 2 tabulates the impact of each of the screening steps in terms of number of accounts and related usage affected, the number of accounts remaining after the screening, and as well as lower and upper bounds using the parameters above to identify upper and lower bounds on the boiler count. The final two columns present the estimated number of boilers that replace existing boilers each year and an estimate of the total market including new construction boilers. The billing analysis method yields the replacement boiler value directly, since the model is based on previous gas usage and a boiler installed at a location would, by definition,

replace the previous gas consuming equipment. The estimate of the new construction sales is based on the market actor surveys and their aggregated response about the proportion of new construction to the replacement market. Note that new construction represents not only ground up new buildings, but also fuel switching scenarios.

	Initial Population	Low Usage Screen		Sites Served by Boiler		Adjust for Sites Served by Multiple Boilers		Number of Boilers Replaced Each Year	Total Market with New Construction Estimate
Screening impact									
Count		(136,248)	-70%	(17,642)	-9%	6,213	3%		
Total gas sales		(70,416,788)	-6%	(346,041,491)	-28%				
Estimated heating capacity		(4,095,133)	-7%	(15,997,144)	-28%				
Remaining population									
Count	195,056	58,808		41,166		47,378		**1,895**	**2,527**
Total gas sales, therms	1,223,888,426	1,153,471,638		807,430,147		807,430,147		32,297,206	40,371,507
Heating capacity, MBH	57,418,948	53,323,815		37,326,670		37,326,670		1,493,067	1,866,334
Low range count				35,285		38,817		1,165	1,456
High range count				47,046		58,792		2,940	4,199

Table 2. Estimated Number of Boilers Sold in the Massachusetts Natural Gas C&I Boiler Market

Billing Analysis Results

The most obvious useful view of the market might be an examination of boiler sales by boiler size. Table 3 presents estimates of the base installed boilers, the expected replacement sales, and the number of incentives issued in 2012 by boiler capacity size intervals.

Boiler Capacity Range (MBH)	Number of Installed Boilers	Projected Replacements	Total with New Construction	Program Incentives 2012	Estimated Market Penetration
90–300	23,688	948	1,263	242	19%
301–500	10,362	414	553	245	44%
501–1000	7,983	319	426	120	28%
1001–1700	2,299	92	123	54	44%
1700+	3,047	122	163	14	9%
Total	**47,378**	**1,895**	**2,527**	**675**	**27% (avg)**

Table 3. Number of Boilers Replaced by Boiler Size

Since the billing analysis approach has an estimate of boiler capacity by geographic location, customer type, and program administrator, it is possible to estimate more refined market sub-segments and to create useful views of the market. Some of the possible aggregations include:

- By program administrator
- By customer type
- By customer sales range (or quartile sales)

Table 4 shows an example in which the PAs are interested in the statistics for their service territories.

	Boiler Sales by Boiler Size Range MBH					
PA	**90–300**	**301–500**	**501–1000**	**1001–1700**	**1700+**	**PA Totals**
Columbia Gas	313	132	98	26	38	608
Berkshire Gas	50	19	16	4	5	94
National Grid Gas	653	293	226	68	85	1,324
NSTAR Gas	238	105	83	23	33	482
Unitil Gas	9	4	3	1	1	18
Boiler size totals	**1,263**	**553**	**426**	**123**	**163**	

Table 4. Projected Number of Boilers Installed by PA

Conclusions

The billing analysis shows that about 2500 boiler are sold in the C&I natural gas market each year in Massachusetts. This value corroborates the market actor survey estimate of 1500 to 3000 boilers sold and, more importantly, implies that no major player was missed in the survey. The billing approach sensitivity analysis extremes also encompass the range in sales derived from the surveys. The two methods yielded consistent results, affirming the conclusions of the study as a whole.

The relatively straightforward and inexpensive methodology outlined in this paper can identify site-specific estimates of system installed capacity using readily available information. Customer-specific information, including service address, building type, specific weather, and most importantly, monthly gas usage are used to characterize system size. These same customer attributes allow for aggregation of the results in a variety of ways, providing insights into the boiler market subsegments.

However, the method does require noteworthy assumptions and may work most effectively in conjunction with a market-actor survey. A comparison of the two methods follows in Table 5:

	Surveys	**Billing**
Facilities with a natural gas boiler	Not known	41,000 sites
Number of replacement boilers sold each year	Based on survey responses, estimated to be 75% of total sales.	1900
Number of new construction boilers sold each year	Based on survey responses, estimated to be 25% of total sales.	Not directly known
Estimate of total C&I natural gas-fired boilers installed each year	1500–3000 boilers sold in the 90–1700 MBH capacity range	2500 Assuming 25% of market is new
Percentage of the market that is energy efficient (meets program eligibility requirements)	25%–75%	Cannot be derived
Strengths	• Specific boiler characteristics (e.g., efficiency) • Expert judgment • Includes estimates of new construction	• Best estimate of installed natural gas systems and sizes • Location specific
Weaknesses	• Unknown upper bound • Oil vs. gas and also resi- vs. nonresi is ambiguous	• No basis for estimating new construction or proportion of high efficiency units • Infer replacements from EUL and boiler vs. non-boiler systems

Table 5. Summary of Survey and Billing Analysis Approaches

While both methods contributed to the understanding of the boiler market, the portion of the market that is high efficiency boilers is not known with enough certainty (estimated at 25%-75% of the market) to lead to an action plan. The team is proposing to share the report with willing market actors to cross-check their understanding of the market with the findings of the study. There is particular interest in testing their responses to the total sales and distribution by size results from the billing analysis with the intention of ultimately narrowing the market penetration estimate for high efficiency boilers.

The technique outlined in this study could provide a valuable supplement to a traditional technical or economic potential study that relies purely on broader market indicators, such as statewide gas sales or market actor surveys that might provide an incomplete picture of the market.

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