Massachusetts 2013
Prescriptive Gas Impact Evaluation
Steam Trap Evaluation Phase 1: FINAL

Massachusetts Gas Program Administrators and Massachusetts Energy Efficiency Advisory Council
Prepared by DNV GL (KEMA, Inc.)
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1 EXECUTIVE SUMMARY & OVERVIEW

The Massachusetts Program Administrators (PAs) and the Energy Efficiency Advisory Council (EEAC) engaged DNV GL to conduct an impact evaluation of the steam trap measure for the Massachusetts Prescriptive Gas Program. This document presents the objectives, approach, and findings of Phase 1 for prescriptive steam trap which consists of research and a measure lifetime study, and presents recommendations for Phase 2 that will focus on an update of deemed savings values based on those findings.

1.1 Background

As part of its annual scoping effort, the Massachusetts Commercial and Industrial Evaluation Contract (CIEC) Gas Evaluation Team conducts a comprehensive review of the combined statewide gas efficiency program data, identifies the program year and lifetime savings for each prescriptive measure, and assesses any changes from the previous program years. In the most recent scoping effort, undertaken during the summer/fall of 2014, the Gas Evaluation Team determined that it would be worthwhile to conduct an impact evaluation focused on steam traps in order to benefit the gas program.

Savings associated with the steam trap measure, which exists in both the custom and prescriptive gas programs in Massachusetts, has been steadily increasing for three years, and the overall gas savings potential for customers is significant. Figure 1-1 shows that steam trap measures provided a significant portion of total gas program savings in 2013. The lifetime savings contribution of the measure relies on the lifetime assumption which is a key focus for this Phase 1 study.

Figure 1-1: 2013 Program Year and Lifetime Savings by Measure

1.2 Objective and Approach

In light of the overlap between the prescriptive and custom steam trap programs, we conducted a broad-spectrum Phase 1 investigation. The primary focus of the research was to identify the best
available deemed savings calculation methods and measure lifetime assumptions; however, we also used the opportunity to solicit general feedback on program delivery and other factors. Since steam trap lifetime references are not well established in the literature, we supplemented our literature review with information solicited directly from steam trap vendors/manufacturers, and investigated the existence of Massachusetts gas customer facility records that could: 1) provide historical documentation of steam trap replacement, and 2) directly support steam trap measure lifetime conclusions.

DNV GL conducted five major tasks to meet the objectives of this Phase 1 evaluation:

- **Task 1**: Conduct in-depth industry and literature research on the steam trap measure with a focus on the measure lifetime assumption being used
- **Task 2**: Conduct and provide a summary of meetings with vendors/manufacturers most active with repair/replacement of steam traps in Massachusetts
- **Task 3**: Collect actual Massachusetts gas customer facility data that supports steam trap lifetime conclusions
- **Task 4**: Provide a technical discussion of steam trap savings calculations currently in use in the industry and other efficiency programs
- **Task 5**: Provide recommendations for the best approach to adjusting the current steam trap prescriptive program deemed savings value

If approved by the PAs and EEAC, Phase 2 of this evaluation will develop an updated and revised prescriptive steam trap deemed savings value for Massachusetts gas programs, informed by the findings in this Phase 1 report.

### 1.3 Results, Conclusions, and Recommendations

#### 1.3.1 Recommendations for Immediate Implementation

1. **Continue providing two steam trap programs: prescriptive and custom**

The research in this Phase 1 study suggests that it is appropriate and useful to continue providing two different energy efficiency programs (prescriptive and custom) to assist customers with repairing and replacing steam traps. This conclusion is based on the following:

- There is a wide variation of steam pressures and sizes/types of steam traps.
- Customers who have steam traps differ dramatically—from small dry cleaners with a dozen traps, to large industrial facilities with hundreds of traps, to municipal/government customers with multi-facility applications that correspond to thousands of traps. The savings values associated with customers’ steam trap projects also differ dramatically as does the process a particular customer is able to follow for effecting steam trap repairs at their particular facility.
- The rigorous site-level survey inspection and savings calculation method associated with the custom program is not practical for smaller steam trap applications, and the simple process associated with the prescriptive program (which relies on a single deemed savings value) is not appropriate for larger applications. Therefore we recommend continuing both programs in order to efficiently and effectively measure savings from the full range of steam trap measures. Research of other programs and evaluation work identifies that frequently a single steam trap program is effective for a single market segment but not others.

2. **Increase measure lifetime from three to six years**
DNV GL reviewed over twenty steam trap lifetime references from available technical reports, energy efficiency evaluations, manufacturer publications, energy efficiency program resource manuals, and other savings documentation. Our research found that all source materials except for the Massachusetts and Rhode Island Technical Resource Manuals utilized a lifetime assumption of five to six years for steam trap measures and was based largely on Delphi method of manufacturer interviews. Our analysis of data for Massachusetts gas customer facilities that had annual steam trap surveys conducted on an ongoing basis provided support for a lifetime assumption of six years. When Massachusetts customer data was found that contained sufficient details on each individual trap to be used to calculate average steam trap life; the average lifetime was greater than six years.

1.3.2 Proposed Next Steps for Phase 2

1. **Convene a steam trap stakeholder group to coordinate adoption of standardized savings algorithms**

   Our review of the relevant literature showed that there are several analytic methods to calculate the energy savings achieved from the repair or replacement of failed steam traps. Massachusetts appears to have the only efficiency program that uses two calculation methods that have been effectively “calibrated” to both provide consistent savings values.

   The latest version of National Grid’s Custom Express Steam Trap Savings Tool uses Grashof’s Formula\(^1\) to produce accurate savings values. Eversource has developed a savings tool that is based on the modified Napier’s Equation, which yields similar reproducible results. Meetings conducted with steam trap vendors and the PAs’ subcontractors suggest that adoption or refinement of a small number of common assumptions would further increase the accuracy and consistency between the two existing tools.

   We recommend convening a stakeholder group—composed of PA staff members directly involved with steam traps, program implementation subcontractors, and steam trap repair/replacement vendors—to identify common assumptions/inputs to use in the savings algorithm, with the goal of improving program accuracy and consistency at the state-wide level. Any changes recommended by the stakeholder group would ultimately be approved by the individual PAs.

2. **Develop a new prescriptive steam trap deemed savings value**

   We recommend using the savings algorithm developed in Phase 2 (per the recommendation above) to develop an updated and revised prescriptive steam trap deemed savings value. This algorithm would be applied to a combination of:

   - Retrospective recalculation of 2012 – 2014 prescriptive applications, and
   - Simultaneously, perform as many pre-post site-level evaluations employing 2015 real-time applications that occur during the next phase of evaluation. This involves a coordinated effort with steam trap vendors while performing steam trap surveys at customer facilities.

3. **Leverage the steam trap stakeholder group to identify approaches to increase program participation and savings**

   In our research for this Phase 1 study, gas customers, vendors, and manufacturers indicated that gas savings through steam trap repair and replacement can be increased through both broader

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\(^1\) Grashof's Formula and Napier's Equation are presented in more detail in Section 6- Task 4: Technical Discussion of Savings Calculations
participation and heightened customer awareness. To provide additional value—subsequent to its work on the savings algorithm—the stakeholder group described above could help identify program changes that would increase participation in both the prescriptive and the custom programs. We recommend initiating a first stakeholder meeting in early 2015 to enable quick progress for Phase 2.

2 INTRODUCTION & STUDY APPROACH

The Massachusetts Program Administrators (PAs) and the Energy Efficiency Advisory Council (EEAC) engaged DNV GL to conduct an impact evaluation of the steam trap measure for the Massachusetts Prescriptive Gas Program. This document presents the objectives, approach, and findings of Phase 1 of our prescriptive steam trap impact evaluation, and presents recommendations for Phase 2 based on those findings.

Currently, steam trap repair and replacement services are being offered to customers in Massachusetts by a relatively small group of market participants, each with a high level of technical expertise. Since the involvement of these specialized contractors would be necessary for a pre-post evaluation, the study team determined that in-person meetings with the steam trap repair/replacement contractors would be an appropriate first step.

The primary goal of these meetings was to gather information on the steam trap measure lifetime assumption. The meetings also provided a platform to discuss issues such as the preferred savings algorithm, deemed savings value, and perhaps most importantly each contractors’ willingness to help in the next phase of the evaluation effort.

We conducted research on the savings calculation methods and the measure lifetime assumptions from available technical reports, energy efficiency evaluations, manufacturer publications, energy efficiency program resource manuals, and other savings documentation in parallel with the vendor meetings. The primary goal of this research was to identify the best available savings calculation methods and measure lifetime assumptions.

Since steam trap lifetime references are not well established in the literature, we also investigated the existence of Massachusetts gas customer facility records that could: 1) provide historical documentation of steam trap replacement, and 2) directly support steam trap measure lifetime conclusions. We contacted end-use customers in a number of ways to acquire this information; the results of this effort are presented in Section 5 of this report.

Table 2-1 shows the five major tasks DNV GL conducted as part of this Phase 1 evaluation, and the associated chapters of this report. These tasks were defined in a Work Plan submitted and approved in late November 2014 for the 2013 prescriptive gas program.
Table 2-1: Tasks Conducted in Phase 1

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Description</th>
<th>Findings of Task Presented in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conduct in-depth industry and literature research on the steam trap measure with a focus on the measure lifetime assumption being used</td>
<td>Section 3</td>
</tr>
<tr>
<td>2</td>
<td>Conduct and provide a summary of meetings with vendors/manufacturers most active with repair/replacement of steam traps in Massachusetts</td>
<td>Section 4</td>
</tr>
<tr>
<td>3</td>
<td>Collect actual Massachusetts gas customer facility data that supports steam trap lifetime conclusions</td>
<td>Section 5</td>
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<td>4</td>
<td>Provide a technical discussion of steam trap savings calculations currently in use in the industry and other efficiency programs</td>
<td>Section 6</td>
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<tr>
<td>5</td>
<td>Provide recommendations for the best approach to adjusting the current steam trap prescriptive program deemed savings value</td>
<td>Section 7</td>
</tr>
</tbody>
</table>

3 TASK 1: INDUSTRY/LITERATURE RESEARCH ON MEASURE LIFETIME

For this task, we gathered, reviewed, and summarized all worthwhile steam trap lifetime references from available technical reports, energy efficiency evaluations, manufacturer publications, energy efficiency program resource manuals, and other savings documentation. The end goal was to provide a thorough summary to inform a recommendation for the steam trap lifetime assumption, in order to support the Gas Evaluation Team’s requirements related to updating the Massachusetts Technical Resource Manual.

Our research focused on existing literature on the Effective Useful Life (EUL) values used by various energy efficiency programs, and their references and citations. Table 3-1 shows the sources considered and the EUL value provided by each source. “TRM” refers to Technical Resource Manual, the term used by most programs to describe their book of savings calculation methods.

Table 3-1: EUL Sources

<table>
<thead>
<tr>
<th>Document</th>
<th>EUL Value</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massachusetts TRM (2013-5)</td>
<td>3 yrs.</td>
<td>Assumption</td>
</tr>
<tr>
<td>Wisconsin TRM (2014)</td>
<td>5 yrs.</td>
<td>None</td>
</tr>
<tr>
<td>Wisconsin Measure Life</td>
<td>6 yrs.</td>
<td>ORNL Study and SCG workpaper</td>
</tr>
<tr>
<td>Michigan workpaper</td>
<td>5 yrs.</td>
<td>2006-8 SCG workpaper</td>
</tr>
<tr>
<td>Illinois TRM (2012)</td>
<td>6 yrs.</td>
<td>2006-8 SCG workpaper</td>
</tr>
<tr>
<td>California CPUC DEER (2013)</td>
<td>6 yrs.</td>
<td>Vendor Conversations</td>
</tr>
<tr>
<td>Delaware TRM (2014)</td>
<td>6 yrs.</td>
<td>None</td>
</tr>
<tr>
<td>PG&amp;E workpaper (2006)</td>
<td>6 yrs.</td>
<td>2006-8 SCG workpaper</td>
</tr>
</tbody>
</table>

A brief discussion of each source is provided below.

This document provides an EUL value of three years, which is currently under review by this study. While the TRM does not cite any sources directly, it includes the following note:

"Massachusetts Common Assumption. Most sources suggest a measure life or equipment life of five years. Massachusetts PAs have traditionally taken equipment life and applied a factor to account for measure persistence when determining measure life."

This note is included to account for the fact that Massachusetts’ three-year value does not align with other current program values.


The Rhode Island TRM, which is primarily used by National Grid Rhode Island, also uses the “Massachusetts Common Assumption” described above.

3.3 Connecticut Program Savings Document, 8th Edition for 2013 Program Year

The EUL value used by Connecticut comes from the Massachusetts Measure Life Study. Connecticut references the measure life for operations and maintenance measures shown in an appendix table. While somewhat contradictory that another state uses a value determined by Massachusetts that Massachusetts does not currently use, the following explanation from the same report offers some guidance:

Operation and maintenance projects do not have an equipment lifetime. Absent quantitative data, we recommend using a default rate of 5 years for measure life.

The absence of quantitative data and the fact that this lifetime is generalized for all C&I retrofit custom O&M measures obscures the direct applicability to steam traps. Connecticut uses this value for both steam traps and compressed air leak repairs.

3.4 Wisconsin Focus on Energy Technical Reference Manual

Wisconsin uses a value of five years for the steam trap measure life. However, the TRM used in Wisconsin often fails to provide sources for its estimates.

Paradoxically, a different but well-researched steam trap savings value is offered in a measure life study published for use in Wisconsin, described below.

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2 (Massachusetts Electric and Gas Energy Efficiency Program Administrators, 2012)
3 (National Grid, 2013)
5 (Energy & Resource Solutions, 2005)
6 (The Cadmus Group, 2014)
3.5 Focus on Energy Evaluation. Business Programs: Measure Life Study (Wisconsin)

This study cites a number of whitepapers and informal studies to support its estimate of six years for steam trap measure life. The report provides little by way of explanation, but it does state that the steam trap measure life is based on the following two sources:

- Steam System Survey Guide: Based on data obtained from a variety of textbooks on steam systems.
- SCG Steam Traps work paper for PY2006-2008: Review of a number of studies on steam trap failures. Described in more detail below.

3.6 Consumers Energy 2010 Business Workpapers (Michigan)

This document functions largely as a TRM for Michigan. It contains the proposed savings estimates for Consumers Energy, which end up in Michigan’s calculation tool—called the Michigan Efficient Measure Database (MEMD).

This report also claims to be based on the SCG work paper described below. However, while the SCG workpaper recommends a measure life of six years, the Michigan work paper recommends a value of five years. The reason for this inconsistency remains unclear.


This TRM uses a value of six years, based on a citation of the Consumers Energy workpapers (above), which draw their EUL estimate from the SCG workpaper (below).


This workpaper determined an EUL for a variety of steam trap types based primarily on conversations with and data supplied by vendors and manufacturers. The applicable text follows:

"During the course of conversations with vendors to collect cost data for this workpaper, steam trap life was also discussed. Vendors and manufacturers did not provide references for rigorous studies, but suggested that inverted bucket steam traps have a typical life in the range of 5-7 years, float and thermostatic of 4-6 years, and thermodynamic disc of 1-3 years. Thermodynamic steam traps at refineries have a life of only 2-3 years. However, three years at a refinery is over 25,000 hours,"

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7 (PA Consulting Group & KEMA, 2009)
8 (Harrell, Gary with Oak Ridge National Laboratory., 2002)
9 (Energy and Environmental Analysis, Inc, 2006)
10 (KEMA, 2010)
12 (Energy and Environmental Analysis, Inc, 2006)
14 Private conversation with large oil refinery in Southern California, Nov. 21, 2006.
while 6 years at a commercial dry cleaner is less than 15,000 hours of operation. A value of 6 years is used in this workpaper as the recommended steam trap life.”

3.9 Delaware Technical Resource Manual, an Update to the Mid Atlantic TRM\textsuperscript{15}

This TRM uses a value of six years, but does not provide any sources for its estimate. The Delaware TRM represents an expansion of the Mid-Atlantic TRM, which does not address steam traps.

3.10 Retention Study of Pacific Gas and Electric Company’s 1996 & 1997 Industrial Energy Efficiency Incentive Programs\textsuperscript{16}

This workpaper determined its estimate of six years as follows:

"Vendor discussions were used to generate a consensus of average life. The life of the trap varies mainly by steam trap type and usage. The life can vary from as little as one to three years in a 24 hour per day high steam pressure refinery to five to seven years in a commercial dry cleaner. For this workpaper an average life of 6 years was chosen."

This paper also lists the exact same sources as the SCG workpaper discussed above, suggesting that the conversations referenced were the same conversations with the same vendors. This is corroborated by the fact that both utilities are in California and their estimates match.

3.11 Conclusion

Based on the sources this research has been able to uncover, the state-of-the-art for steam trap EUL value is not advanced in comparison to many other energy efficiency measures. Numerous factors—including but not limited to the variation of steam operating pressure, steam trap applications, steam quality, and types of traps—contribute to the lack of a simple lifetime value. A large percentage of EUL citations appear to reflect conversations that Energy and Environmental Analysis Incorporated had with steam trap vendors (for the SCG workpaper) approximately 10 years ago.

As the most robust source for steam trap EUL assumptions, the SGC workpaper supports the recommendation that Massachusetts adopt a value of six years for steam trap EUL. The methodology employed by this common citation is also consistent with the approach used in Task 2 of this Phase 1 evaluation, which was to talk to local vendors and steam trap manufacturers involved with the Massachusetts market.

To build on what the steam trap lifetime research delivers the next section adds specific-Massachusetts-steam- trap-market information from the vendors doing the majority of steam trap repair and replacement work in addition to interviews with manufacturers. Section 5: Task 3: Massachusetts Customer Records/Documentation incorporates a more analytic approach to lifetime calculation that was not found in the research where actual lifecycle documentation is investigated.

\textsuperscript{15} (Opinion Dynamics Corporation, 2012)
\textsuperscript{16} (Pacific Gas & Electric, 1998)
4 TASK 2: MASSACHUSETTS STEAM TRAP VENDOR MEETINGS

DNV GL’s review of the prescriptive and custom steam trap program data—and our discussions with the Gas Evaluation Team—confirmed that a small number of implementation contractors account for the majority of efficiency program applications in the Northeast region for C&I steam trap repair and replacement services.

Steam trap vendors often act as a subcontractor to energy service companies (ESCOs) and other prime contractors to provide water and energy services. In this subcontractor capacity, the steam trap vendors serve several markets:

- Federal facilities (ESPC and UESC)
- Healthcare
- Scientific and medical research
- K-12 and higher education
- Industrial

Since the involvement of these specialized contractors would be necessary for a pre-post evaluation, the study team determined that in-person meetings with steam trap repair/replacement contractors would be a useful task for this Phase 1 study. The primary goal of these meetings was to gather information on the steam trap measure lifetime assumption. The meetings also provided a platform to discuss issues such as the preferred savings algorithm, deemed savings value, and contractors’ willingness to help in the next phase of the evaluation effort.

A survey instrument was not used in these meetings; however, a one-page discussion guide was forwarded to the vendors prior to the meetings to facilitate the exchange of ideas. The “Steam Trap Vendor Meeting Discussion Guide” is included in Appendix A of this report, and has been uploaded on the Prescriptive Gas Project SharePoint site. A summary of important comments from the vendors was presented to the Gas Evaluation Team during biweekly meetings.

Vendors were identified and invited to participate in the meetings based on a review of the program data. This list of invitees was supplemented with vendors drawn from National Grid’s list of pre-approved steam trap survey vendors. A vendor matrix and the list of pre-approved vendors are included in Appendix B of this report, and have been uploaded on the Prescriptive Gas Project SharePoint site. In initial conversations, all of these vendors indicated that they were interested in volunteering all responses non-confidentially.

Task 1 of this study identified that, outside of Massachusetts, the method of determining EUL values for steam traps was largely based upon manufacturer/distributor/vendor interviews where an analytic approach was not used (see Section 3.11). In addition to vendors, two manufacturers were included in our vendor meetings: one Massachusetts-based manufacturer, and one large global entity representing significant market share that had a locally-based account representative interested in participating in the study.

These two steam trap manufacturers were included largely due to their willingness to contribute to the study. Their input was also considered worthwhile because:

- The Massachusetts statewide steam trap inventory appears to contain a higher percentage of traps from the Massachusetts-based manufacturer than other, non-Northeast Region trap inventories.
• The global steam products manufacturer is responsible for much of the historical savings calculation method development that exists in the industry (i.e., the modified Napier’s Equation, also known as the Spirax Sarco equation, which is discussed further in Section 6).

In general, steam trap manufacturers commonly offer a one-year new product warranty with normal operational disclaimers. Product literature and marketing case studies from the manufacturers claim that trap life of up to 10 years of continuous service can be attained, but they do not provide more qualitative reference data on trap life.

4.1 Summary of Important Findings by Topic

Below we provide a summary of important findings from the in-person meetings with the manufacturers and the most active steam trap contractors operating in Massachusetts.

1. **Please provide prescriptive gas steam trap measure program feedback.**

Please see the summary under question 2; we combined the discussion for these two questions because vendor responses were closely related.

2. **Please provide custom gas steam trap program feedback.**

All steam trap vendor responses were supportive of the Massachusetts efficiency program, including the steam trap measure, which helps customers realize natural gas savings through repair or replacement of steam traps.

Vendor responses to questions 1 and 2 varied due to the wide spectrum of the steam trap measure. Overall, vendors agreed that it would be difficult for a single steam trap program to meet the needs of all steam trap customers—which include everything from small businesses with a dozen low-pressure steam traps to multi-building campuses of hospitals, universities, and industrial facilities. The consensus among vendors was that Massachusetts should maintain both programs so that the customers’ needs can be best matched to one of the two programs.

Each of the vendors indicated that their staff had considerable expertise performing on-site steam trap inspection surveys to identify traps in customer facilities that had failed. For most customers, vendors agreed that surveys performed on an annual basis was the best way to operate from an energy efficiency standpoint.

The majority of the vendors indicated that more projects flowed through the custom program than the prescriptive program. Vendors expressed that the process for the custom program—which consists of an on-site survey, reporting, a program application/offering, and trap replacement/repair—does not work for certain customers because of the size of their business or their own administrative policies.

Vendors indicated that the requirement to complete actual trap repair/replacement within 90 days of the incentive offering becomes problematic in situations where: 1) they are working with institutional customers, and 2) the steam trap vendor is a subcontractor to an energy service provider. Vendors repeatedly cited the advent of large performance contracting where the scope of work entails multiple facilities as an example of work that went outside of the program. The suggestion to further explore the “ESCO project/90 day program” conflict during the proposed stakeholder discussions seems worthwhile.

Vendors liked that the Massachusetts program allows either repair or replacement of a failed trap, citing that the action should be guided by what provides the customer the most value. There were
negative comments regarding programs in other states that mandate a replacement with a completely new trap. Vendors felt these were outdated policies that were not in tune with modern steam trap technology where many types of traps exist.

3. **Share your thoughts about a deemed savings value concept for steam valve measure.**

Because of the wide variation of steam trap pressures, sizes, types, duty cycles, and applications, vendors indicated that it is extremely difficult to identify a single value for savings; at best, an average value for a certain application can be done.

Vendors indicated that the “deemed savings value”—meaning a single savings value assumption, which is currently 257 Therms/year per replaced/repaired valve for the prescriptive program—targets a smaller commercial steam trap typically encountered in the prescriptive population. Traps in the custom population tend to be higher pressure industrial applications with greater operating hours and higher savings values.

4. **What are your comments on the Massachusetts steam trap repair/replacement market?**

Vendors indicated that the largest difficulty in the steam trap market in Massachusetts (and elsewhere) is customer recognition of energy wastes associated with blowing steam traps, which are occurring on a daily basis. The insidious nature of a steam system being able to operate for years with live steam wastefully leaking through the condensate venting system masks the value that is lost by not taking remedial actions. For the majority of customers, but not all, the program requirement of a report that documents a list of failed steam traps and the associated energy lost and payback period of repair is a valuable component of the process.

5. **What energy savings algorithm do you utilize when making proposals to customers?**

Vendors stated that the true steam trap savings value is commonly understated due to multiple factors. First, since the calculation method is complex and multiple assumed values are involved, the result is almost always conservative rather than overstated with regard to actual energy savings. Second, any steam system has losses, so there is the perception that there will always be a trap with a leaking seal.

Vendors cited having trap savings calculation methods on their websites that are based on:

- Napier’s Equation
- Grashof’s formula
- Modified Napier Equation or Spirax Sarco equation

No one professed to believe that one calculation method was superior to others, and there was consensus agreement that the assumptions used in the calculations influence the savings value significantly.

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17 Grahof’s Formula and Napier’s Equation are presented in more detail in Section 6- Task 4: Technical Discussion of Savings Calculations.
6. **Can you suggest an average steam trap lifetime assumption that would be appropriate to be used by energy efficiency program administrators?**

There was general agreement that the expected average lifetime of a steam trap was greater than five years. While there was repeated firsthand knowledge of particular traps that would be replaced year after year, there was also consensus vendor recognition of the silent majority of traps that performed without failure for many years, often matching the age of the building.

Vendors indicated that their business often involves analyzing and remediating problems with a particular customer’s steam quality/water quality, which can be the key factor influencing overall trap life.

7. **Discuss the differences that you see between steam trap repair and replacement.**

Please see the summary under question 8; we combined the discussion for these two questions because vendor responses were closely related.

8. **What are the determining factors for repair/replacement?**

Vendors most often cited “the customer’s best interest” as the most important consideration for repair vs. replacement. Each of the vendors suggested that years of experience helped to provide their staff with instinctive knowledge on the best approach to use in each situation.

Vendors also indicated relying on experience to make decisions regarding replacing a particularly troublesome trap that failed frequently with a different type of trap that would perform better in that specific circumstance. Depending on the type of trap involved, a decision could be made to use a replacement kit if it existed. The design of other types of traps lend themselves to either rebuilding in place or a physical change-out. Site-specific piping considerations also factored into the repair/replace decision.

9. **Have you performed service work for select customers on an ongoing basis with or without a service contract?**

Each vendor explained that their desired way of doing business with their customers is to perform annual on-site trap surveys to identify the specific steam traps that have failed, and then to schedule the repairs. This method of repeat business was the way they were best able to maximize value to their customers. While a necessary service, responding to a customer’s urgent problem call represented less trap repairs in a given day, and therefore less value to their customer.

10. **Are you aware of certain customers that have steam trap inventory systems where data on the repair/replacement of traps could be used to provide analytic data to prove average steam trap lifetime assumptions? Can you suggest end use customers who may have their own steam trap inventory information and would they be interested in possibly sharing information?**

The vendors knew which customers had inventories and which did not. It turned out that the vendors had better inventory systems than most of the customers. In almost all cases of trying to attain actual customer facility data, the customer relied on the steam trap vendor’s data more heavily than the actual customer data system. The field work performed by the steam trap vendor and report appears to be the more common source of the data for most of the customer steam trap inventory systems.
11. **When performing steam trap diagnostic work, what inspection equipment is used and how is it used?**

Vendors used a combination of ultrasonic inspection and real-time thermal imaging cameras. The ultrasonic inspection refers to listening to the trap for detection of proper or failed operation, which is a skill that incorporates a considerable amount of interpretation that is developed from actual field experience. Recent advances in the technology of the thermal imaging cameras provide the best diagnostic tool available. Even with the most advanced equipment, the steam trap survey tasks remain interpretive rather than conclusive. Consider that even a perfectly working trap still cycles on and off, so the sounds and thermal conditions are commonly in a state of flux at any point in time.

The vendors were strongly opinionated that these minimum tools should be mandatory for an acceptable trap survey, and they suggested to program administrators that anyone trying to do a survey with anything less should not be viewed as to having completed a valid trap survey. The specialized equipment and skills are the reason why more repair/replacement work is being performed by the approved vendors rather than customer in-house personnel or general HVAC contractors.

12. **Discussion of potential future arrangements and site recruiting coordination to support evaluation, including willingness to support and degree of involvement desired.**

The steam trap vendors value the program (two programs) that are offered in Massachusetts and are supportive of the evaluation effort. Actual field scheduling of steam trap surveys being performed at customer sites will be challenging to coordinate yet possible.

### 4.2 Steam Trap Types and Prevalence in Massachusetts

This section provides some educational background on the various types of steam traps, as defined by the US Department of Energy. Initial conversations with vendors about the prevalence, common uses, and average lifetime of each type of steam trap commonly found in Massachusetts would be worthwhile in order to distinguish the Massachusetts inventory from other areas. Our understanding of Massachusetts inventory could be further expanded during the proposed steam trap stakeholder discussions, and during the calculation of a new deemed savings value in Phase 2 of the evaluation.

Developed by the US Department of Energy, Figure 4-1 shows the inner workings of the most commonly used steam trap varieties. Table 4-1: provides additional detail on each type of trap.
Figure 4-1: Steam Trap Diagrams from the DOE\(^{18}\)

18 (DOE Industrial Technologies Program, 2004)
### Table 4-1: Types of Steam Traps – General Description; Massachusetts Prevalence and Common Uses Proposed for Phase 2

<table>
<thead>
<tr>
<th>Trap Type</th>
<th>Description</th>
<th>Massachusetts Prevalence</th>
<th>Common Uses (Sector, Pressure)</th>
<th>Avg. EUL (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermostatic</strong></td>
<td>Thermostatic traps use temperature differential to distinguish between condensate and live steam. This differential is used to open or close a valve. Under normal operating conditions, the condensate must cool below the steam temperature before the valve will open. Common types of thermostatic traps include bellows and bimetallic traps.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bellows</strong></td>
<td>Bellows traps include a valve element that expands and contracts in response to temperature changes. Often a volatile chemical such as alcohol or water is inside the element. Evaporation provides the necessary force to change the position of the valve. At start-up, the bellows trap is open due to the relative cold condition. This operating condition allows air to escape and provides maximum condensate removal when the load is the highest. <strong>Bellows traps can fail either open or closed.</strong> The configuration of a bellows steam trap is shown in Figure 4-1 (see image labeled “Figure 4”).</td>
<td></td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td><strong>Bimetallic</strong></td>
<td>Bimetallic traps rely on the bending of a composite strip of two dissimilar metals to open and close a valve. Air and condensate pass freely through the valve until the temperature of the bimetallic strip approaches the steam temperature. After steam or relatively hot condensate heats the bimetallic strip and causes it to close the valve, the trap remains shut until the temperature of the condensate cools sufficiently to allow the bimetallic strip to return to its original shape and thereby open the valve. <strong>Bimetallic traps can fail in either the open or the closed position.</strong> The configuration of a bimetallic steam trap is shown in Figure 4-1 (see image labeled “Figure 5”).</td>
<td></td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td><strong>Mechanical</strong></td>
<td>Mechanical traps use the difference in density between condensate and live steam to produce a change in the position of a float or bucket. This movement causes a valve to open or close. There are a number of mechanical trap designs that are based on this principle. They include ball float, float and lever, inverted bucket, open bucket, and float and thermostatic traps.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ball Float</strong></td>
<td>Ball float traps rely on the movement of a spherical ball to open and close the outlet opening in the trap body. When no condensate is present, the ball covers the outlet opening, thereby keeping air and steam from escaping. As condensate accumulates inside the trap, the ball floats and uncovers the outlet opening. This movement allows the condensate to flow continuously from the trap. Unless they are equipped with a separate air vent, ball float traps cannot vent air on start-up.</td>
<td></td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
</tbody>
</table>

---

19 (DOE Industrial Technologies Program, 2004)
<table>
<thead>
<tr>
<th>Trap Type</th>
<th>Description</th>
<th>Massachusetts Prevalence</th>
<th>Common Uses (Sector, Pressure)</th>
<th>Avg. EUL (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float &amp; Lever</td>
<td>Float and lever traps are similar in operation to ball float traps except the ball is connected to a lever. When the ball floats upward due to accumulation of condensate inside the trap body, the attached lever moves and causes a valve to open. This action allows condensate to continuously flow from the trap. If the condensate load decreases and steam reaches the trap, downward ball movement causes the valve to close, thereby keeping steam from escaping. Unless they are equipped with a separate air vent, float and lever traps cannot vent air on start-up.</td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td>Inverted Bucket</td>
<td>Inverted bucket traps are somewhat more complicated than float and lever traps. At start-up, the inverted bucket inside the trap is resting on the bottom of the trap body and the valve to which the bucket is linked is wide open. The trap is initially filled with condensate. As steam enters the trap and is captured inside the bucket, it causes the bucket to move upward. This upward movement closes the valve and keeps steam from escaping. When the condensate collects and cools the steam, the bucket moves downward. This movement causes the valve to open, thereby allowing the condensate to escape. Unlike closed float traps, inverted bucket traps have intermittent discharge. <strong>These traps can be depleted of their condensate seal when applied in superheated steam service. If this occurs, the trap will continuously discharge live steam.</strong> This trap type is not recommended for superheated steam service, unless special installation conditions are met. The configuration of an inverted bucket steam trap is shown in Figure 4-1 (see image labeled “Figure 6”).</td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td>Open Bucket</td>
<td>Open bucket traps consist of an upright bucket that is attached to a valve. At start-up, the bucket rests on the bottom of the trap body. In this position, the valve is wide open. As condensate accumulates in the trap body on the outside of the bucket, the bucket floats upward, causing the valve to close. When sufficient condensate accumulates outside the bucket, it spills over the top and fills the inside of the bucket. At this time, the bucket sinks, causing the valve to open. <strong>This trap is also prone to failure when applied in superheated steam</strong> service because of the loss of the condensate seal. Like inverted bucket traps, open bucket traps have intermittent discharge.</td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td>Float &amp; Thermostatic</td>
<td>Float and thermostatic (F&amp;T) traps are similar to float and lever traps except they include a thermostatic element that allows air to be discharged at start-up and during operation. The thermostatic elements used in these traps are the same as those used in thermostatic traps. The configuration of a float and thermostatic steam trap is shown in Figure 4-1 (see image labeled “Figure 7”).</td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td>Trap Type</td>
<td>Description</td>
<td>Massachusetts Prevalence</td>
<td>Common Uses (Sector, Pressure)</td>
<td>Avg. EUL (yrs)</td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
<td>--------------------------</td>
<td>--------------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td><strong>Thermodynamic (Category)</strong></td>
<td>Thermodynamic traps use the difference in kinetic energy (velocity) between condensate and live steam to operate a valve. The disc trap is the most common type of thermodynamic trap, but piston or impulse traps are sometimes used.</td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td><strong>Disc</strong></td>
<td>Disc traps use the position of a flat disc to control steam and condensate flow. When condensate flows through the trap, the disc is raised, thereby causing the trap to open. As steam and air pass through the trap, the disc moves downward. The force that causes the disc to move downward is generated by the difference in pressure between the low-velocity steam above the disc and the high-velocity steam that flows through the narrow gap beneath the disc. Disc traps commonly have an intermittent discharge and, <strong>when they fail, they normally fail open</strong>. The configuration of a disc steam trap is shown in Figure 4-1 (see image labeled “Figure 8”). Generally, the air removal capability of this trap type is poor unless equipped with additional components.</td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td><strong>Piston</strong></td>
<td>Piston or impulse traps utilize the heat energy in hot condensate, and the kinetic energy in steam, to open and close a valve. Like disc traps, piston traps are phase detectors that sense the difference between a liquid and gas or vapor. They continuously discharge any air and condensate. <strong>Their primary failure mode is open.</strong></td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td><strong>Lever</strong></td>
<td>Lever traps are a variation of the thermodynamic piston trap. They operate on the same principal as a piston trap but with a lever action to pass large amounts of condensate and air on a continuous basis. <strong>Their primary failure mode is open.</strong></td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
<tr>
<td><strong>Orifice</strong></td>
<td>Orifice traps are of two basic types: orifice plate and short tube. Both trap types operate under the exact same principles. A simple orifice plate steam trap consists of a thin metal plate with a small-diameter hole (orifice) drilled through the plate. When installed, condensate that accumulates is continuously removed as the steam pressure forces the condensate through the orifice. During conditions when no condensate is present, a limited amount of steam flows through the orifice. The report Review of Orifice Plate Steam Traps on page 49 of the Where to Find Help section provides information for making informed decisions about when orifice plate steam traps should be considered for use in new or existing steam systems.</td>
<td>To be collected in Phase 2</td>
<td>To be collected in Phase 2</td>
<td></td>
</tr>
</tbody>
</table>
5 TASK 3: MASSACHUSETTS CUSTOMER RECORDS/DOCUMENTATION

This task investigated the existence of actual end-use Massachusetts gas customer facility records that could: 1) provide historical documentation of steam trap replacement, and 2) directly support steam trap measure lifetime conclusions.

DNV GL contacted end-use customers to acquire this information in a number of ways. Most often, contact was facilitated by the customer’s steam trap vendor. This was a discussion point brought up during the initial vendor meetings. The four major vendors were very cooperative; each provided assistance with their customer information. In other cases, contact was facilitated by the evaluators’ review of program data, and then via project files furnished by program administrators.

For this task we sought out customers who had steam trap inventory systems where documentation on the repair/replacement of traps could provide analytic data to support the average steam trap lifetime assumption. Customers often maintained an inventory of the steam traps in their facility. Many customers distinguished between individual steam traps with identification tags; this practice—often required by risk insurers—has become a protocol that is associated with good facility operational guidelines. Another source of data was customers’ applications for the custom program, which include a report containing the itemized inventory of all steam traps for purposes of individualized steam trap savings values.

These records and facility inventory datasets indicate the number of steam traps that are operational and which are failed/replaced. Facilities that have regular on-site surveys done year after year provide even more valuable data; these facilities served as the focal point for data collection and examination for this task.

In total, we collected customer-volunteered data from more than 50 buildings representing 2,650 steam traps. Ultimately, this data did not prove to be valuable from a lifetime conclusion perspective (see the discussion about data challenges after Table 5-2), but it does offer insight with regard to the variations in failure rates and average savings rates, as shown in Table 5-1.

<table>
<thead>
<tr>
<th>Site Description</th>
<th>Total Number of Steam Traps at Site</th>
<th>Number of Failed Steam Traps at Site</th>
<th>Steam Trap Failure Percentage</th>
<th>Steam Trap Site Savings, Therms</th>
<th>Unit Savings (Savings per Failed Steam Trap), Therms</th>
<th>Savings Algorithm: (1) Deemed Savings (2) Grashof’s Formula (3) Napier’s Equation</th>
<th>Massachusetts Pre-Approved Steam Trap Vender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Municipal Buildings</td>
<td>1733</td>
<td>295</td>
<td>17%</td>
<td>75,815</td>
<td>257</td>
<td>(1)</td>
<td>Yes</td>
</tr>
<tr>
<td>Industrial Textile Mfg.</td>
<td>208</td>
<td>132</td>
<td>63%</td>
<td>32,065</td>
<td>243</td>
<td>(2)</td>
<td>Yes</td>
</tr>
<tr>
<td>Courthouse</td>
<td>65</td>
<td>2</td>
<td>3%</td>
<td>792</td>
<td>396</td>
<td>(3)</td>
<td>Yes</td>
</tr>
<tr>
<td>Rehabilitation Hospital</td>
<td>300</td>
<td>107</td>
<td>36%</td>
<td>17,097</td>
<td>160</td>
<td>(3)</td>
<td>Yes</td>
</tr>
<tr>
<td>Corporate Office</td>
<td>295</td>
<td>6</td>
<td>2%</td>
<td>4,199</td>
<td>700</td>
<td>(3)</td>
<td>Yes</td>
</tr>
<tr>
<td>University Buildings</td>
<td>49</td>
<td>7</td>
<td>14%</td>
<td>3,487</td>
<td>498</td>
<td>(3)</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Total in ±50 Buildings</strong></td>
<td><strong>2650</strong></td>
<td></td>
<td><strong>22,243</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average in ±50 Buildings</strong></td>
<td><strong>24%</strong></td>
<td></td>
<td><strong>376</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The documentation associated with some of the customer information allowed for further breakdown and classification of the failed traps by trap type, and then by average steam type savings value (see Table 5-2). While interesting, these values are representative of where customer data existed and could be found rather than a statistically designed sample of the population. The savings values were influenced by the specific pressure, application, and types of traps where the data existed.

Table 5-2: Average Savings Value by Steam Trap Type

<table>
<thead>
<tr>
<th>Steam Trap Type</th>
<th>Average Savings Value, Therms per failed trap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiator Type</td>
<td>196</td>
</tr>
<tr>
<td>Inverted Bucket Type</td>
<td>90</td>
</tr>
<tr>
<td>Float &amp; Thermostatic Type</td>
<td>464</td>
</tr>
</tbody>
</table>

As noted above, the customer-volunteered data did not prove to be valuable in terms of determining a defensible lifetime measure assumption. While many of the gas customer buildings we analyzed were “mature” and may have been 20 years old, they did not yield results largely because periodic trap inspection had not occurred, so it can be assumed that many of the traps existed in either a failed or operational state for a long period of time. As such, these older buildings without periodic maintenance records did not provide conclusions or lend themselves to meaningful analysis.

On the other end of the spectrum, new buildings less than 10 years old that had proactive maintenance and good records were also lacking in useful data. These buildings would yield average lifetimes that were increasing with each new year of service. This was really just reflective of the majority of the traps in the building being newer vintage, and the individual trap lifetimes not yet established.

The ideal situation is where the majority of the facility’s steam traps are mature (or at least mostly past their first lifetime generation), and there have been trap failure surveys performed on an ongoing periodic basis. When the trap inventory list is available for a three- to five-year period from surveys, this data becomes more useful.

Unfortunately, even among these ideal cases many customers were missing a key data point: the installed date and the trap age. This information is not usually kept in survey documentation, but we were able to compile the information in a few cases with help from the steam trap vendor and customer plant personnel.

The last component of our investigation was going through the steam trap list to check when each trap had any work done on it. For this purpose, if a trap had any work on it (such as a repair, changing a cage, or installing a screen) it was interpreted for purposes of this investigation as “re-starting the lifetime clock.”

Below we present analysis of data from two customer facilities where “installed date” information existed or was extrapolated with the help of the vendor and customer.

Customer 1:

- High-rise, 20+ floor office building in Boston
- Application: comfort heating, 15 psi, saturated steam
• National Grid gas customer
• Total steam traps in facility: 242
• Age of building/mechanical system: 12 years
• Detailed steam trap records: 2012 – 2015
• Steam trap ID tags existed on all traps: 2002 – 2015
• Majority of replaced traps are combination float and thermostatic ¾” traps

Table 5-3 shows four consecutive years of steam trap inventory data for this customer. Building facility personnel indicated that in-house staff performed steam trap maintenance prior to 2012, and purchasing records indicated that 10 to 12 traps were replaced each year for a period of five years between 2006 and 2011. Through interviews we discovered that there were only a few repairs done prior to 2006, in the first five years of building operation.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Steam Traps Tested</th>
<th>Number of Steam Traps Failed (leaking, blocked, failed, etc)</th>
<th>Average Annual Steam Trap Failure Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>231</td>
<td>15</td>
<td>6%</td>
</tr>
<tr>
<td>2013</td>
<td>242</td>
<td>16</td>
<td>7%</td>
</tr>
<tr>
<td>2014</td>
<td>240</td>
<td>18</td>
<td>7%</td>
</tr>
<tr>
<td>2015</td>
<td>238</td>
<td>26</td>
<td>11%</td>
</tr>
</tbody>
</table>

Calculations on the average steam trap life using the inventory data show a trap lifetime of greater than 10 years; however, this is largely due to the fact that the majority of the traps are still first generation steam traps. Both the customer and steam trap vendor anticipate that the failure rate will increase as many of the existing first generation traps are replaced over the next few years, which would lower the average lifetime value, but probably not significantly. This site in particular will be interesting to re-visit over the next few years to see how the average lifetime changes with increasing trap age.

Customer 2:
• Manufacturing/industrial site
• Multiple steam pressures and multiple steam loops
• Multiple buildings of varying ages, from 100+ years to just a few years
• Total number of steam traps: 650
• The inventory list shows a large variety of traps: many different types, many different manufacturers

Table 5-4 shows three years of steam trap inventory data for this customer, based on redacted versions of annual survey reports. When the installed date of a trap was not known, we made estimations based on the vintage of the existing traps, the manufacturer, the type of trap, and the section of the plant. Our conservative estimate is that the average trap life in the plant was greater than eight years.
While two sites does not represent a statistically valid sample from a precision standpoint; these two were the only sites found where the level of steam trap documentation supported this type of analysis where the age of each individual steam trap at the facility was calculated and then averaged. One of the key components to this type of analysis is having periodic trap survey reports that contain detailed lists of each trap. It is interesting to note that this “report” is a direct program requirement of the Custom Program in Massachusetts. During the vendor meetings the vendors commonly remarked that the program requirement of the onsite survey report used in the custom program application which identifies and lists each individual steam trap at the applicant facility. This represents a hidden benefit to the customer for creating and maintaining a detailed trap inventory. It also means that this level of documentation can be useful in future lifetime investigation and perhaps also explains why it has not been attempted elsewhere.

6 TASK 4: TECHNICAL DISCUSSION OF SAVINGS CALCULATIONS

This section provides a technical discussion of the savings algorithm for this measure, including the equations used to calculate the energy savings of a steam trap that is repaired or replaced.

Through industry and literature research, we determined that there are a number of approaches actively being used to calculate energy savings for steam trap repair/replacement. For simplicity, from a historical perspective, no less than three different equations have been developed: the theory originates from work identified as Napier’s Equation, a different approach utilizes Grashof’s formula, and a more recent version is the modified Napier’s Equation (also known as the Spirax Sarco equation).

Failed steam traps can be a major contributor to steam system inefficiencies, according to the Department of Energy (Inspect and Repair Steam Traps, US DOE). The energy loss of a failed trap depends on the mode of failure. Traps failing in an open position allow steam to pass continuously into the condensate stream, as long as the system is energized. The rate of energy loss can be estimated based on the size of the orifice and system steam pressure. A trap failed in a closed or “plugged” position would not have the same energy loss, but requires repair nonetheless and presents a more urgent operational problem. Other modes of failure—such as partially open or closed—exist and actually represent different energy loss rates. Blowing or leaking also refers to steam escaping from the steam supply or condensate piping into the atmosphere or plant facility, and correlates to an energy loss that should also be remedied by repair.

Table 5-4: Customer-2 Steam Trap Records

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Steam Traps Tested</th>
<th>Number of Steam Traps Failed (leaking, blocked, failed, etc)</th>
<th>Average Annual Steam Trap Failure Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>576</td>
<td>129</td>
<td>20%</td>
</tr>
<tr>
<td>2013</td>
<td>585</td>
<td>67</td>
<td>10%</td>
</tr>
<tr>
<td>2014</td>
<td>578</td>
<td>46</td>
<td>7%</td>
</tr>
</tbody>
</table>

20 (DOE Industrial Technology Program, 2006)
As discussed in Section 4.1, the common steam trap survey performed by “approved” Massachusetts vendors currently incorporates a combination of ultrasonic acoustic inspection and thermal photography to determine if a trap is performing adequately, and (if not) which one of the various modes of failure has occurred. With a few exceptions, the energy savings value of the steam trap measure refers to the savings achieved by repair or replacement of the mix of all modes of a failed trap. Historically, this has proven to be more practical than attempting to apply a mode-specific savings value, since the real-world failure mode can be complex (e.g., an older trap reaching the end of its lifetime that is not sealing completely and is allowing constant live steam into the condensate system, but is also leaking live steam and hot condensate into the atmosphere).

6.1 Comparative Program Technical Discussion of Savings Calculations

DNV GL reviewed and compared the savings calculation methodologies used for steam trap measures by 14 different sources, including the Massachusetts TRM and the National Grid Custom Express Tool. Table 6-1 shows the sources considered. After the table we provide a brief discussion of the method used by each source.
### Table 6-1: Steam Trap Savings Estimation Methodologies

<table>
<thead>
<tr>
<th>Program</th>
<th>Value (therms/trap)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massachusetts</td>
<td>257 (Prescriptive Program deemed savings)</td>
<td>National Grid 2008 Study</td>
</tr>
<tr>
<td>National Grid Custom Express Tool</td>
<td>Calculator (Custom Program)</td>
<td>National Grid Design Report</td>
</tr>
<tr>
<td>National Grid Design Report</td>
<td>78-130 (&lt; 15 psig, Com., by region) 781 (&lt; 50 psig Ind.) 1,476 (51-100 psig Ind.) 2,153 (101-150 psig Ind.) 2,854 (&gt;150 psig Ind.)</td>
<td>Textbooks, Interviews, Whitepapers</td>
</tr>
<tr>
<td>SCIA Report</td>
<td>15 (Small Com.) 794 (&lt;15 psig Ind.) 2630 (&gt;15 psig Ind.)</td>
<td>On-sites, Phone Surveys, Billing Analysis</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>257</td>
<td>National Grid 2008 Study</td>
</tr>
<tr>
<td>Wisconsin New TRM</td>
<td>245</td>
<td>Wisconsin TRM 2013, No specific site</td>
</tr>
<tr>
<td>Wisconsin Old TRM</td>
<td>196 (&lt;50 psig) 756 (50-125 psig) 1084 (126-225 psig) 2075 (&gt;225 psig)</td>
<td>Industrial only. Based on DOE tip sheets and average leak orifice size estimates by EnerCheck Systems (now Ameresco Inc.)</td>
</tr>
<tr>
<td>Illinois TRM</td>
<td>Formula</td>
<td>Michigan Workpaper</td>
</tr>
<tr>
<td>Michigan TRM</td>
<td>298</td>
<td>SCG Workpaper</td>
</tr>
<tr>
<td>Connecticut</td>
<td>Lookup (3—148,000)</td>
<td>Boiler Efficiency Institute Paper</td>
</tr>
<tr>
<td>Delaware</td>
<td>15 (Com.) 638 (Low Press. Ind.) 2340 (High Press. Ind.)</td>
<td>SCIA Report</td>
</tr>
<tr>
<td>SCG Whitepaper</td>
<td>139 (Com. Dry Cleaners) 638 (&lt;15 psig Ind.) 2342 (&gt;15 psig Ind)</td>
<td>Enbridge Whitepaper and Dry Cleaner Econometric Analysis and Customer Surveys (Itron)</td>
</tr>
<tr>
<td>Enbridge Whitepaper</td>
<td>974</td>
<td>Summary of Data from 216 Industrial Sites</td>
</tr>
<tr>
<td>PG&amp;E Whitepaper</td>
<td>Inconclusive</td>
<td>Billing Analysis</td>
</tr>
</tbody>
</table>


The Massachusetts TRM uses a value of 257 Therms to apply to steam trap replacement. This value accounts for an average savings value across all sectors, as discussed in the citation note shown here (reorganized for clarity):

*National Grid [values] based on historical steam trap surveys. Steam losses in lbs./hr. are found using Steam Efficiency Improvement.*

Page 34, Table 4.1 under “Steam Leak Rate Through Holes.”

- Average loss rate for all trap sizes 1/32” to 1/4” for low steam pressures (5 psig and 10 psig) and high pressures (50 psig and 100 psig).
• Assume trap failure effective for 540 EFLH per year.
• \( \left( 80\% \times \frac{78.50 + 111.46}{2} \right) + \left( 20\% \times \frac{1108.04 + 1982.18}{2} \right) = 385.01 \text{\, BTU}_{\text{trap-year}} \)
• Assume that 50\% of traps fail in the open position and [divide] by the efficiency of the boiler supplying the steam.
• Net savings is 257 Therms per trap.

6.3 National Grid Custom Express Calculator

National Grid has used this tool for a number of years to estimate savings for steam trap projects.

<table>
<thead>
<tr>
<th>Trap Condition</th>
<th>% Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully Operational</td>
<td>N/A</td>
</tr>
<tr>
<td>Plugged</td>
<td>0%</td>
</tr>
<tr>
<td>Partial Leak</td>
<td>25%</td>
</tr>
<tr>
<td>Full Leak</td>
<td>50%</td>
</tr>
<tr>
<td>Partial Blow by</td>
<td>75%</td>
</tr>
<tr>
<td>Full Blow by</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 6-3: Percent of Leaking Steam Assumed Saved by Program Activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>% Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
<td>70%</td>
</tr>
<tr>
<td>Replace</td>
<td>100%</td>
</tr>
</tbody>
</table>

6.4 National Grid Steam Trap Program Design Report

This report presents a set of program design recommendations provided by Rise Engineering for National Grid. They presented the method below for determining steam trap savings, which was used as a starting place to build National Grid’s custom express calculation tool (discussed above).

While many of the calculation methods used by programs are based off Napier’s Equation, this tool follows Grashof’s formula. After some research, DNV GL determined that, while two equations are equivalent, Grashof’s formula offers more detail and makes fewer assumptions, as shown here:

\[
\text{Therm\ Savings} = \frac{0.70 \times 0.0165 \times 3600 \times A \times (P + 14.7)^{0.97} \times H \times (h_v - h_l)}{100,000 \times EF}
\]

Where:
- \( H = \text{Annual hours} \)
- 100,000 = Btu per Therm
- \( EF = \text{Boiler efficiency} \)
- \( h_v = \text{Enthalpy of saturated steam vapor (btu/lb) at the specified gauge pressure} \)
- \( h_l = \text{Enthalpy of saturated liquid (btu/lb) at the specified gauge pressure} \)
- 0.70 = \text{Coefficient of discharge for orifice} \)
- 0.0165 = \text{Constant in Grashof’s formula} \)
- 3,600 = \text{Seconds per hour} \)
- \( A = \text{Area of orifice in square inches} \)

\[23\] (Rise Engineering, 2013)
P = Pressure inside steam line in psig

Using this equation produces savings according to Figure 6-1, assuming a fully failed-open trap (100% leak rate) with 1500 run hours and a 75% efficient boiler.

![Figure 6-1: Therms Savings from the National Grid Custom Express Tool](image)

Assuming 7500 run hours, a partially failed trap (50% leak rate), and a 1/8” orifice size results in savings values shown in Table 6-4.

<table>
<thead>
<tr>
<th>Calculated Pressure (psig)</th>
<th>Pressure Range</th>
<th>Annual Savings (Therms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5, 10, 15</td>
<td>Commercial ≤ 15</td>
<td>NE: 126</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NY City: 78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Albany: 137</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Syracuse: 130</td>
</tr>
<tr>
<td>50</td>
<td>Industrial ≤ 50</td>
<td>781</td>
</tr>
<tr>
<td>100</td>
<td>Industrial 51-100</td>
<td>1,467</td>
</tr>
<tr>
<td>150</td>
<td>Industrial 101-150</td>
<td>2,153</td>
</tr>
<tr>
<td>200</td>
<td>Industrial &gt;150</td>
<td>2,854</td>
</tr>
</tbody>
</table>

This report also characterized the types of traps used in various applications, as shown in Table 6-5.

<table>
<thead>
<tr>
<th>Trap Type</th>
<th>Application</th>
<th>Orifice Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermostatic</td>
<td>Radiators</td>
<td>5/16”</td>
</tr>
<tr>
<td>Float &amp; Thermostatic</td>
<td>Air handlers, unit heaters, drip legs</td>
<td>7/32” &amp; 1/2”</td>
</tr>
<tr>
<td>Inverted Bucket</td>
<td>High Pressure</td>
<td>1/8” – 1/2”</td>
</tr>
<tr>
<td>Thermodynamic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This study included on-site evaluations, phone surveys, and billing analysis of both industrial and commercial laundry facilities. It represents one of the most thorough steam trap evaluations in that it combined measured data with customer and vendor self-reports.

Its primary conclusion was that industrial steam traps be rebated as a custom measure due to the extremely high variability of savings from one steam trap to the next. This variability resulted partly from a significant number of sites that were not operating or had all of their traps failed in a closed position.

While this extremely high variability calls into question a prescriptive savings approach for industrial steam traps, their average reported results are as shown.

### Table 6-6: Steam Trap Savings Results from SCIA Study

<table>
<thead>
<tr>
<th>Facility Type</th>
<th>Savings (therms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Commercial</td>
<td>15</td>
</tr>
<tr>
<td>Industrial Low Pressure (&lt;15psig)</td>
<td>794</td>
</tr>
<tr>
<td>Industrial High Pressure (&gt;15psig)</td>
<td>2630</td>
</tr>
</tbody>
</table>

This report used the following calculation methodology.

\[
\text{Therm Savings} = \frac{OA \times SP \times DC}{70} \times \frac{M \times LF \times CF \times OH \times HV}{100 \times BE}
\]

Where:
- \(OA\) = Orifice Area (in2) from manufacturer
- \(SP\) = Steam Pressure (psia) reported or observed
- \(DC\) = Discharge Coefficient (0.62)
- \(M\) = Steam Flow Rate
- \(LF\) = Leak Factor
- \(CF\) = Condensation Factor
- \(OH\) = Annual operating hours of steam trap
- \(HV\) = Heat of vaporization of steam (kBtu/lb)
- \(BE\) = Boiler Efficiency

Following are two selected quotes from this study, for reference.

"Over 70% of the phone survey sites report replacing all of their steam traps. The high removal share may be justified by the low incremental cost of the measure, the short expected useful life, and the difficulty associated with quickly and inexpensively determining that a trap is leaking. However, the high removal share is likely to result in the removal of both working and failed traps."

"Commercial steam traps represented 92% of the sites installing rebated steam traps but only 4% of the savings. The typical commercial steam trap applicant was a small dry cleaner replacing all or nearly all of their traps."

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24 (Itron, Inc., 2010)
The SCIA report was presented to the Massachusetts Gas Evaluation Team in February as one of two “best-in-class” steam trap evaluations found in the research. The report’s recommendation that industrial steam traps be rebated as a custom measure is of particular interest, because it supports the current Massachusetts two-program approach. This approach incorporates:

- A prescriptive program that allows for streamlined customer applications and administration using a straight-forward average deemed savings value (single value savings per trap), and
- A more rigorous custom program based upon on-site steam trap inspection surveys that are conducted in advance to identify failed traps. This program uses a more advanced analytic tool to calculate the savings based on site-specific conditions.


The Rhode Island TRM uses the value from Massachusetts and references it directly, using a summarized version of the same citation used by Massachusetts.

### 6.7 Wisconsin Focus on Energy Technical Reference Manual

Wisconsin uses a value of 245 therms for steam trap measure savings. However, the TRM used in Wisconsin often fails to provide sources for its estimates.

#### 6.7.1 Business Programs: Deemed Savings Manual V1.027

In past years, Wisconsin used deemed values by steam pressure category, as shown in Table 6-7.

<table>
<thead>
<tr>
<th>Steam System</th>
<th>Steam Trap Savings (therms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial HVAC</td>
<td>910</td>
</tr>
<tr>
<td>Industrial &lt;50 psig</td>
<td>196</td>
</tr>
<tr>
<td>Industrial 50-125 psig</td>
<td>756</td>
</tr>
<tr>
<td>Industrial 126-225 psig</td>
<td>1,084</td>
</tr>
<tr>
<td>Industrial &gt;225 psig</td>
<td>2,075</td>
</tr>
</tbody>
</table>

Commercial HVAC steam traps achieve higher savings than the low- and medium-pressure industrial traps because a steam system industry contact had suggested that steam trap orifice sizes are larger in HVAC systems than in industrial steam systems. This corroborates what is said in the National Grid Steam Trap Design Report (above), though that report still recommends much lower savings values (78-130 Therms) for commercial sites.

Primary sources used in the Wisconsin TRM include the following:

- DOE Steam Trap Performance Assessment
- DOE Steam Tip Sheet #1

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25 (National Grid, 2013)  
26 (The Cadmus Group, 2014)  
27 (Kuiken, Tamara et al, 2010)  
28 (Federal Energy Management Program, 1999)
- Enercheck Systems Website (now Ameresco)
- Steam Trap Monitoring article in ASME Magazine\(^{30}\)
- Phone Interview with Tim Thuemling\(^{31}\)


Illinois’ TRM calculates savings using a formula based upon a workpaper developed in Michigan, titled **CLEAResult** "Steam Traps Revision #1," and dated August 2011. This primary source is not publicly available, and we were unable to obtain a copy.

Illinois’ steam trap savings are based upon the following equation:

\[
\Delta \text{Therm} = S \times \frac{H_V}{B} \times \text{Hours} \times A \times L \times \frac{1 \text{ therm}}{100,000 \text{ Btu}}
\]

Where:
- \( S \) = Average Steam Loss (lb/hr/trap)
- \( H_V \) = Heat of Vaporization (Btu/lb)
- \( B \) = Boiler Efficiency (0.80 if not known)
- \( \text{Hours} \) = Annual operating hours of steam plant
- \( A \) = Adjustment Factor (0.50)
- \( L \) = Leaking and blow-through (1.0 for one trap)

The Illinois program documentation offer Table 6-8 and Table 6-9 which provide information on steam losses and the variation by sector, pressure and failure rates that are commonly encountered.

#### Table 6-8: Estimated Steam Trap Losses by Sector

<table>
<thead>
<tr>
<th>Steam System</th>
<th>Avg Steam Loss (lb/hr/trap)</th>
<th>Heat of Vaporization (Btu/lb)</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Dry Cleaners</td>
<td>38.1</td>
<td>890</td>
<td>2,425</td>
</tr>
<tr>
<td>Commercial Heating LPS</td>
<td>13.8</td>
<td>951</td>
<td>Rockford: 4272</td>
</tr>
<tr>
<td>(including Multifamily)</td>
<td></td>
<td></td>
<td>O'Hare: 4029</td>
</tr>
<tr>
<td>Industrial LPS &lt;15 psig</td>
<td>13.8</td>
<td>951</td>
<td>Springfield: 3406</td>
</tr>
<tr>
<td>Industrial MPS 15-30 psig</td>
<td>12.7</td>
<td>945</td>
<td>Belleville: 2515</td>
</tr>
<tr>
<td>Industrial MPS 30-74 psig</td>
<td>19.0</td>
<td>928</td>
<td>Marion: 2546</td>
</tr>
<tr>
<td>Industrial HPS 75-124 psig</td>
<td>67.9</td>
<td>894</td>
<td>7,752</td>
</tr>
<tr>
<td>Industrial HPS 125-174 psig</td>
<td>105.8</td>
<td>868</td>
<td>7,752</td>
</tr>
<tr>
<td>Industrial HPS 175-249 psig</td>
<td>143.7</td>
<td>846</td>
<td>7,752</td>
</tr>
<tr>
<td>Industrial HPS ≥250 psig</td>
<td>200.5</td>
<td>820</td>
<td>7,752</td>
</tr>
</tbody>
</table>

\(^{29}\) (DOE Industrial Technology Program, 2006)

\(^{30}\) (Prins, 2009)

\(^{31}\) (Thuemling, 2005)

\(^{32}\) (Illinois Energy Efficiency Stakeholder Advisory Group, 2014)
### Table 6-9: Estimated Steam Trap Losses by Scenario

<table>
<thead>
<tr>
<th>Steam System</th>
<th>Leaking &amp; Blow-Through</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custom</td>
<td>Custom</td>
</tr>
<tr>
<td>Commercial Dry Cleaners</td>
<td>27%</td>
</tr>
<tr>
<td>Industrial LPS ≤15 psig</td>
<td>16%</td>
</tr>
<tr>
<td>Industrial MPS &amp; HPS &gt;15 psig</td>
<td>16%</td>
</tr>
<tr>
<td>Commercial HVAC (including Multifamily) LPS</td>
<td>27%</td>
</tr>
</tbody>
</table>

### 6.9 Consumers Energy 2010 Business Workpapers (Michigan)

This document functions largely as a TRM for Michigan. It contains the proposed savings estimates for Consumers Energy, which end up in Michigan’s calculation tool—called the Michigan Efficient Measure Database.

Michigan uses 298 Therms for commercial steam trap savings, based upon the SCG Steam Trap Workpaper, using the following assumptions:

- Heating application as opposed to process
- Lansing weather (HDD) and resulting full load hours
- 75% system heating efficiency
- Typical trap sizes of 3/16, 1/4 and 5/16 inches
- 5 psig steam pressure
- 50% of failed traps failed open
- 75% of steam lost that is wasted

### 6.10 Connecticut Program Savings Document, 8th Edition for 2013 Program Year

Connecticut determines steam trap savings using a series of tables based on application (heating vs. process), pressure, orifice size, and whether the trap was leaking or failed. The tables are built around the following formula:

\[
CCF = \frac{lbm \times E \times EFLH \times Lf}{Eff \times 102,900 Btu/Therm}
\]

Where:

- ACCF = Annual natural gas savings
- lbm = Steam flow through orifice (varies by pressure)
- E = Enthalpy of steam (Btu/lbm, varies by pressure)
- EFLH = Equivalent full load hours (heating: 5376, process: 8760)
- Lf = Steam loss adjustment factor (50% for failed traps, 12.5% for leaking traps)
- Eff = Boiler efficiency (80%)
Depending on the inputs, the output values shown in the Connecticut lookup tables can vary from 3 Therms to 148,000 Therms per steam trap. The values are based on a document called Steam Efficiency Improvement, but this document does not specifically address steam traps.

### 6.11 Delaware Technical Resource Manual, an Update to the Mid-Atlantic TRM

Delaware uses deemed values for steam trap savings by sector and pressure, as shown in the following table.

<table>
<thead>
<tr>
<th>Steam System</th>
<th>Leaking &amp; Blow-Through</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>Custom</td>
</tr>
<tr>
<td>Industrial LPS</td>
<td>27%</td>
</tr>
<tr>
<td>Industrial HPS</td>
<td>16%</td>
</tr>
</tbody>
</table>

Delaware’s savings estimates are taken from the 2010 Itron study. Commercial building applications are limited to dry cleaners.


This workpaper is used to estimate savings for steam traps in SCG and Sempra service territories. This paper is summarized in another paper used by PG&E. System pressures were determined based on a study performed by Enbridge on 2372 industrial steam traps in Ontario, and two more studies performed at dry cleaners in California. Leak rates were determined based on a second Enbridge study and a survey of a southern California oil refinery, which found 27.7% of traps to be leaking or blow-through, compared to 6.3% blocked.

<table>
<thead>
<tr>
<th>Steam System</th>
<th>Avg. Hours</th>
<th>Avg. Pressure (psig)</th>
<th>Avg. Leak Rate (lb/hr)</th>
<th>Savings (therms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial (Dry Cleaners)</td>
<td>2425</td>
<td>82.8</td>
<td>5.1</td>
<td>139</td>
</tr>
<tr>
<td>Industrial LPS (&lt;15 psig)</td>
<td>7752</td>
<td>10.9</td>
<td>6.9</td>
<td>638</td>
</tr>
<tr>
<td>Industrial HPS (&gt;15 psig)</td>
<td></td>
<td>85.9</td>
<td>27.2</td>
<td>2342</td>
</tr>
</tbody>
</table>

37 (Dyer, 1987)
38 (Opinion Dynamics Corporation, 2012)
39 (Itron, Inc., 2010)
40 (Energy and Environmental Analysis, Inc, 2006)
41 (Pacific Gas & Electric Company Consumer Energy Efficiency Department, 2009)
42 (Enbridge, Inc)
43 (kW Engineering, 2006), (Armstrong, Inc)
44 (Enbridge Gas Distribution, 2005)
6.13 Enbridge Steam Saver Program

Enbridge kept data for 216 industrial sites representing 41,124 steam trap tests between 2000 and 2005. This subsection presents a summary of two studies performed by Enbridge.

The first and more extensive study found the following:

Table 6-12: Enbridge Industrial Steam Trap Survey 2000-2005 Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sites Surveyed</td>
<td>216</td>
</tr>
<tr>
<td>Traps Identified</td>
<td>52,451</td>
</tr>
<tr>
<td>No. of Traps Tested</td>
<td>41,124</td>
</tr>
<tr>
<td>Total Defective Traps</td>
<td>9,870</td>
</tr>
<tr>
<td>Traps Leaking / Blow-Thru</td>
<td>6,719</td>
</tr>
<tr>
<td>Percent of Traps Leaking / Blow-Thru</td>
<td>16.3%</td>
</tr>
<tr>
<td>Traps Blocked</td>
<td>3,151</td>
</tr>
<tr>
<td>Percent of Traps Blocked</td>
<td>7.7%</td>
</tr>
<tr>
<td>Annual Steam Loss (lb/yr)</td>
<td>707,231,938</td>
</tr>
<tr>
<td>Annual Fuel Loss (m3/yr)</td>
<td>26,705,063</td>
</tr>
<tr>
<td>Annual Fuel Loss (Therms)</td>
<td>9,613,823</td>
</tr>
</tbody>
</table>

The results of this survey suggest a savings of 974 Therms per defective steam trap, including both those which failed open and those that failed blocked.

In a more detailed survey of eight industrial customers, they found these results:

Table 6-13: Enbridge Detailed Steam Trap Survey Results

<table>
<thead>
<tr>
<th>Steam System</th>
<th>Number of Traps</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Tested</td>
<td>1720</td>
<td>100%</td>
</tr>
<tr>
<td>Leaking</td>
<td>176</td>
<td>10.2%</td>
</tr>
<tr>
<td>Blow Through</td>
<td>156</td>
<td>9.1%</td>
</tr>
<tr>
<td>Blocked</td>
<td>120</td>
<td>7.0%</td>
</tr>
</tbody>
</table>

Table 6-12 and Table 6-13 both suggest that about 70% of failed traps are leaking or blow-through, thus offering opportunities for energy savings. Blocked traps will not save energy once fixed.


This study included a billing analysis of both industrial and commercial laundry facilities. The results proved inconclusive, with different models producing dramatically different savings estimates,

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45 (Enbridge Gas Distribution, 2005)
46 (Enbridge, Inc)
47 (KEMA, Inc, 2007)
including some negative estimates. PG&E used this inability to quantify savings as evidence to support a significant decrease of savings for steam trap replacement under their programs.

7 CONCLUSIONS AND RECOMMENDATIONS

Savings associated with the steam trap measure, which exists in both the custom and prescriptive gas programs in Massachusetts, has been steadily increasing for three years. While the overall gas savings potential is significant, the steam trap measure is often neglected by customers. It is therefore important to continue improving the program offerings in order to maximize achieved savings.

As part of this Phase 1 study, DNV GL conducted an in-depth literature review to investigate measure lifetime assumptions and how savings were being calculated in the industry today. We found that there are a number of approaches actively being used to calculate energy savings for steam trap repair/replacement. The complexity associated with the savings calculation method is compounded by the many different types of steam traps operating at different steam pressures in varying steam system types at a wide assortment of facility types and applications.

Among the programs reviewed in this study, Massachusetts appears to have the only efficiency program that uses two calculation methods that have been effectively “calibrated” to both provide consistent savings values. The latest version of National Grid’s Custom Express Steam Trap Savings Tool uses Grashof’s formula to produce accurate savings values. Eversource has developed a savings tool that is based on the modified Napier’s equation, which yields similar reproducible results. In addition to being the most advanced calculation methods the two calculation tools also incorporate the individual method of trap failure and the steam system type into the savings algorithm which is not done in the other calculation methods.

Given that savings accuracy and consistency are key to energy efficiency program administration, our recommendation (discussed more below) is not for one savings method to supersede the other, but rather a to undertake a coordinated effort to improve and harmonize both calculation tools. The vendor suggestions we have collected are valuable and can be incorporated to improve accuracy and result consistency, but ultimately any changes to the individual tools will be the responsibility of the individual program administrators.

Our meetings with steam trap repair/replacement vendors and steam trap manufacturers in Massachusetts provided useful feedback on the current program and several suggestions for future improvement. Vendors expressed interest in increasing awareness of steam trap savings potential among commercial and industrial customers. While vendors preferred to perform on-site trap surveys to identify failed steam traps, there were certain instances where a simple “one-stop” trap change-out provided the most benefit to the customer. There was strong support among vendors for keeping both prescriptive and custom programs, so as not to miss opportunities that would be omitted by any single program.

The Phase 1 research, meetings with the Massachusetts vendors and manufacturers, and examination of actual Massachusetts gas customer facility data all support increasing the steam trap lifetime assumption from the existing value of three years.

Below we present recommendations for immediate implementation and the best approach to adjusting the steam trap prescriptive program deemed savings value.
7.1 Recommendations for Immediate Implementation

1. **Continue providing two steam trap programs: prescriptive and custom**

   The research in this Phase 1 study suggests that it is appropriate and useful to continue providing two different energy efficiency programs (prescriptive and custom) to assist customers with repairing and replacing steam traps. This conclusion is based on the following:

   - There is a wide variation of steam pressures and sizes/types of steam traps.
   - Customers who have steam traps differ dramatically—from small dry cleaners with a dozen traps, to large industrial facilities with hundreds of traps, to municipal/government customers with multi-facility applications that correspond to thousands of traps. The savings values associated with customers’ steam trap projects also differ dramatically.
   - The rigorous site-level survey inspection and savings calculation method associated with the custom program is not practical for smaller steam trap applications, and the simple process associated with the prescriptive program (which relies on a single deemed savings value) is not appropriate for larger applications. Therefore we recommend continuing both programs in order to efficiently and effectively measure savings from the full range of steam trap measures.

2. **Increase measure lifetime from three to six years**

   DNV GL reviewed over twenty steam trap lifetime references from available technical reports, energy efficiency evaluations, manufacturer publications, energy efficiency program resource manuals, and other savings documentation. Our research found that all source materials except for the Massachusetts and Rhode Island Technical Resource Manuals utilized a lifetime assumption of five to six years for steam trap measures. Our analysis of data for Massachusetts gas customer facilities that had annual steam trap surveys conducted on an ongoing basis also provided support for a lifetime assumption of six years.

7.2 Proposed Next Steps for Phase 2

1. **Convene a steam trap stakeholder group to coordinate adoption of a standardized savings algorithm**

   Our review of the relevant literature showed that there are several analytical methods to calculate the energy savings achieved from the repair or replacement of failed steam traps. Massachusetts appears to have the only efficiency program that uses two calculation methods that have been effectively “calibrated” to both provide consistent savings values.

   The latest version of National Grid’s Custom Express Steam Trap Savings Tool uses Grashof’s formula to produce accurate savings values. Eversource has developed a savings tool that is based on the modified Napier’s equation, which yields similar reproducible results. Meetings conducted with steam trap vendors and the PAs’ subcontractors suggest that adoption or refinement of a small number of common assumptions would further increase accuracy and consistency between the two existing tools.

   We recommend convening a stakeholder group—composed of PA staff members directly involved with steam traps, program implementation subcontractors, and steam trap repair/replacement vendors—to identify common assumptions/inputs to use in the savings algorithm, with the goal of improving program accuracy and consistency at the state-wide level. Any changes recommended by the stakeholder group would ultimately be approved by the individual PAs.

2. **Develop a new prescriptive steam trap deemed savings value**
We recommend using the savings algorithm developed in Phase 2 (per the recommendation above) to develop an updated and revised prescriptive steam trap deemed savings value. This algorithm would be applied to a combination of:

- Retrospective recalculation of 2012 – 2014 prescriptive applications, and
- Simultaneously, perform as many pre-post site-level evaluations employing 2015 real-time applications that occur during the next phase of evaluation. This involves a coordinated effort with steam trap vendors while performing steam trap surveys at customer facilities.

3. Leverage the steam trap stakeholder group to identify approaches to increase program participation and savings

In our research for this Phase 1 study, gas customers, vendors, and manufacturers indicated that gas savings through steam trap repair and replacement can be increased. To provide additional value—subsequent to its work on the savings algorithm—the stakeholder group described above could help identify program changes that would increase participation in both the prescriptive and the custom programs. We recommend initiating a first stakeholder meeting in early 2015 to enable quick progress for Phase 2.
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KEMA. (2010). *CONSUMERS ENERGY 2010 BUSINESS WORKPAPERS*.


Kuiken, Tamara et al. (2010). *Business Programs: Deemed Savings Manual V1.0*.


Copies of sources are available to the MA CIEC Gas Evaluation Team in the ”Steam Trap Research Bibliography” sub-folder of the Prescriptive Gas Evaluation Project SharePoint site at...

[https://meet.dnv.com/sites/Impact_Gas/P45/Forms/AllItems.aspx](https://meet.dnv.com/sites/Impact_Gas/P45/Forms/AllItems.aspx) (Project site); The Steam trap Research Bibliography (sub-folder within the project site)

[https://meet.dnv.com/sites/Impact_Gas/P45/Forms/AllItems.aspx?RootFolder=%2Fsites%2FImpact%5FGas%2FP](https://meet.dnv.com/sites/Impact_Gas/P45/Forms/AllItems.aspx?RootFolder=%2Fsites%2FImpact%5FGas%2FP)
APPENDIX A: STEAM TRAP VENDOR MEETING DISCUSSION GUIDE

Working copies of the “Steam Trap Vendor Meeting Discussion Guide” are available to the MA CIEC Gas Evaluation Team in the “Shared Folder – Program Administrators” sub-folder of the Prescriptive Gas Evaluation Project SharePoint site at...

https://meet.dnv.com/sites/Impact_Gas/P45/Forms/AllItems.aspx (Project site);

“The Steam Trap Vendor Meeting Discussion Guide”
https://meet.dnv.com/sites/Impact_Gas/_layouts/WordViewer.aspx?id=/sites/Impact_Gas/P45/Shared%20Folder%20-%20Program%20Administrators/Steam%20Trap%20Vendor%20Meeting%20Discussion%20Guide%20DRAFT%2012-18-14.docx&Source=https%3A%2F%2Fmeet%2Ednv%2Ecom%2Fsites%2FImpact%5FGas%2FP45%2FForms%2FAllItems.aspx%3FRootFolder%3D%2Fsites%2FImpact%5FGas%2FP45%2FForms%2FAAllItems%2Easpx%3FRootFolder%3D%2526FolderCTID%3D252D%2520Program%2520Administrators%2520Folder%26View%3D%7B7B6DA48D64%2D45EA%2DBDEE%2DC68CFF4B1E49%7D&DefaultItemOpen=1

APPENDIX B: STEAM TRAP VENDOR MATRIX & NATIONAL GRID PRE-APPROVED LIST OF STEAM TRAP VENDORS

National Grids provides a “Approved Steam Trap Repair & Replacement Vendor List” for its commercial and industrial customers. This list and a “Steam Trap Vendor Contact List” is available to the MA CIEC Gas Evaluation Team in the “Shared Folder – Program Administrators” sub-folder of the Prescriptive Gas Evaluation Project SharePoint site at...

https://meet.dnv.com/sites/Impact_Gas/P45/Forms/AllItems.aspx?RootFolder=%2Fsites%2FImpact%5FGas%2FP45%2FForms%2FAAllItems.aspx&FolderCTID=0x0120007FBDBE92FAAD54488BA58D62D5E1D10B%26View=%7B6DA48D64-17BE-45EA-BDEE-C68CFF4B1E49%7D
APPENDIX C: STEAM TRAP SAVINGS TOOLS
Steam trap savings calculation tools and copies of supporting references and other information sources are available to the MA CIEC Gas Evaluation Team in the “Steam Trap Research Bibliography” sub-folder of the Prescriptive Gas Evaluation Project SharePoint site. Individual program administrators may provide protected versions of steam trap savings tools that they have developed.
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