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2014 Nonresidential Downstream Deemed ESPI Pipe Insulation Impact Evaluation Report

Prepared for
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Executive Summary

This report documents the activities undertaken by the Nonresidential Downstream Deemed ESPI Impact Evaluation of the 2013-2014 investor-owned utilities' (IOU) energy efficiency programs.[1] The overall goal of this study is to perform an impact evaluation on the deemed savings and measure-parameters associated with the pipe insulation measures that were identified in the Efficiency Savings and Performance Incentive (ESPI) decision.[2]

The objective of this study is to perform a measure and/or measure-parameter impact evaluation, utilizing new primary evaluation data, in order to update existing gross and/or net savings estimates and inform future savings values for the pipe insulation measures identified in the ESPI decision. In order to implement this approach in meeting the overall study goal, a number of research objectives were targeted. The following tasks have been performed by collecting new primary data from participant phone surveys and on-site verification analyses:

- Confirm installations (verification). This step includes on-site verification of measure installations that represent a significant percentage of ex ante claimed natural gas savings.
- Estimate baseline (pre-retrofit) and replacement (post-retrofit) pipe heat loss rates and operating hours to support the estimate of unit energy savings values.
- Estimate participant free-ridership to support the development of net-to-gross ratios and net savings values.
- Based on the above, estimate first year and lifetime gross and net ex post impacts (therm) for pipe insulation measures.

Pipe insulation measures are generally classified into two groups: hot applications (leading to natural gas savings) and cold applications (leading to electric savings). The Pipe Insulation – Hot Application measure contributes 1.6% to the statewide portfolio's overall therm savings in 2013, and increasingly so (2.3%) in 2014. However, the Pipe Insulation – Cold Application measure contributes insignificantly to overall portfolio kWh and kW savings in 2013 and 2014. As a result, the hot application savings are the focus of this study, and the cold application measure group is not assessed in this study.

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1 This report focuses on the ESPI measures that were identified for the 2013 program cycle.

2 D.13.09.023, Decision Adopting Efficiency Savings and Performance Incentive Mechanism. http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M076/K775/76775903.PDF

The evaluation team designed a sampling approach to achieve statistically significant results at the measure level; the initial sample design was generated using 2013 and 2014 program participants. Per 2013-14 tracking data, the most significant savings are generated from hot water and medium pressure steam boilers within PG&E and SCG service territories. As a result, the initial sample design included only sites within these territories and with insulation on hot water and medium pressure steam pipe runs. Phone surveys and on-sites were initially attempted for only the projects in the preliminary sample; however, due to lower-than-expected response rate and the limited population, a census was eventually attempted to meet the desired sample of 30 on-sites.

1.1 Key Findings

Two distinct evaluation activities were performed, as summarized below.

Gross Energy Savings Analysis. The primary objective of this activity was to develop gross and net realization rates (ratio between *ex post* and *ex ante* savings) that can be applied to the participant population for the pipe insulation measure, such that population estimates of net and gross savings can be estimated for both first year and lifecycle savings. For each sampled project in the analysis, ex post savings were evaluated by separately establishing a number of impact parameters including installation rates; annual operating hours; bare pipe and surrounding air temperatures; and boiler combustion efficiencies. These parameters were estimated based on performing on-site audits on 31 projects that encompassed 93 distinct pipe runs at commercial and industrial facilities. Measurement and verification was performed for each distinct pipe run in the sample of 31 projects.

Net-To-Gross Analysis. The objective of this analysis was to develop net-to-gross ratios (NTGRs) for the pipe insulation measure group. The approach for estimating NTGRs was based on a self-report methodology utilizing 49 participant survey phone responses. This methodology was based on the large non-residential free ridership approach developed by the NTGR Working Group and documented in Appendix C of that report, *Methodological Framework for Using the Self-Report Approach to Estimating Net-to-Gross Ratios for Non-residential Customers*. The methodology estimated three separate measurements of free ridership from different inquiry routes and then averaged the values to derive the final free ridership estimate at the measure level.

Table 1-1 presents the overall results for this study. Shown are the net and gross ex ante and ex post values, along with NTGRs, gross realization rates (GRRs), and net realization rates (NRRs), for the first year therm savings from pipe insulation measures. [3] Results are presented by IOU.

[3] All IOU ex ante data are derived directly from the 2013-2014 quarterly tracking data posted to Energy Division's Central Server with the vintage of 11/02/2015. These ex ante data originate directly from the IOUs.

These savings represent all pipe insulation (hot application) measures that were evaluated as part of this study. Overall 65% of the first year net ex ante therm savings were realized through the evaluation. Lifecycle realization rates are similar to the first-year realization rates listed in Table 1-1 as evaluators used the same effective useful life as the IOUs in the lifecycle savings calculation.

Table 1-1: Aggregate First Year Therm Savings and Realization Rates by IOU for 2014 Pipe Insulation Measure Population

	First Year Gross Therms Savings				First Year Net Therms Savings			
PA	**Ex ante Savings**	**Ex post Savings**	**GRR**	**Relative Precision**	**Ex ante Savings**	**Ex post Savings**	**NRR**	**Relative Precision**
PG&E	370,701	341,227	92%		247,569	167,377	68%	
SCG	905,293	709,301	78%		543,176	347,923	64%	
SDG&E	6,903	4,676	68%		4,142	2,294	55%	
Statewide	**1,282,898**	**1,055,204**	**82%**	**13%**	**794,886**	**517,593**	**65%**	**17%**

1.2 Conclusions

This section presents the conclusions developed for this evaluation. Section 6 of the report explains each of these conclusions in more detail.

Installation Rates

- All rebated insulation was determined to be 100% installed as tracked. However, the field auditors determined that 9% of the rebated insulated piping required minimally-compliant baseline insulation;[4] this baseline adjustment resulted in a 5% reduction of the GRR.

Operating Hours

- Boiler annual operating hours in large commercial and industrial facilities were found to be 5,560 and 6,560 hours per year, respectively.

Pipe Temperature

- The hot water bare pipe temperature was found to be 136°F and 135°F at commercial and industrial facilities, respectively. The medium-pressure steam bare pipe temperature was found to be 292°F and 317°F at commercial and industrial facilities, respectively.

[4] OSHA requires that pipes with a surface temperature of 140°F or greater that are "located within 7 feet measured from floor or working level or within 15 inches measures horizontally from stairways, ramps, or fixed ladders shall be covered with a thermal insulating material or otherwise guarded against contact."

Surrounding Air Temperature

- The hot water piping's surrounding air temperature was found to be 81°F and 76°F at commercial and industrial facilities, respectively. The medium-pressure steam piping's surrounding air temperature found to be 79°F and 87°F at commercial and industrial facilities, respectively.

Boiler Combustion Efficiency

- The hot water boiler combustion efficiency was found to be 78%, but no difference was found for the IOU-assumed medium-pressure steam boiler combustion efficiency of 83%.

Pipe Diameter

- The average diameter of insulated pipe was considerably higher for all customers and fluid types in the higher-diameter tier. Greater-than-assumed diameter leads to higher savings per insulated linear foot.

Net-to-Gross Ratio

- The pipe insulation measure NTGR was found to be 0.49.

2

Introduction and Overview of Study

This report documents the activities undertaken by the Nonresidential Downstream Deemed ESPI Impact Evaluation of the 2013-2014 IOUs' energy efficiency programs[5]. The overall goal of this study is to perform an impact evaluation on the deemed savings and measure-parameters associated with the pipe insulation measures that were identified in the ESPI decision.[6]

This report is informed by Attachment 2 and 3 of the ESPI decision for program year (PY) 2013 and details the goals and objectives of the impact evaluation to meet those requirements. Likewise, the report will discuss the researchable issues, information on the measure groups evaluated as well as the data sources used, the approach for sampling, the verification analysis and the methods used to determine ex post energy and demand impacts. Finally, the report will present the results and findings from the analysis that can then be used to update the impact parameters, unit energy savings (UES), NTGRs, and gross/net first year and lifecycle savings for the measures detailed in the ESPI decision.

2.1 Evaluation Research Objectives

The objective of this study is to perform a measure and/or measure-parameter impact evaluation, utilizing existing evaluation data and new primary evaluation data, in order to update existing gross and/or net savings estimates and inform future savings values for the pipe insulation measures identified in the ESPI decision. Attachment 2 of the ESPI decision provides an overview of the portfolio parameters that have been identified as potentially requiring ex post verification. The parameters associated with deemed measure verification for pipe insulation include: measure installation/verification, UES, NTGRs, gross and net energy savings values, effective useful life (EUL), bare pipe temperature, ambient temperature, annual hours of operation, and boiler combustion efficiency.

In order to implement this approach in meeting the overall study goal, a number of research objectives were targeted. The following tasks have been performed by collecting new primary data from participant phone surveys and on-site verification analyses. A more thorough

5 This report focuses on the ESPI measures that were identified for the 2013 program cycle.

6 D.13.09.023, Decision Adopting Efficiency Savings and Performance Incentive Mechanism. http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M076/K775/76775903.PDF

discussion of how these research objectives are applied to the pipe insulation measures and the algorithm by which they have been evaluated are discussed in Section 4, but to summarize:

- Confirm installations (verification). This step includes on-site verification of measure installations that represent a significant percentage of ex ante claimed natural gas savings.
- Estimate baseline (pre-retrofit) and replacement (post-retrofit) pipe heat loss rates and operating hours to support the estimate of unit energy savings values.
- Estimate participant free-ridership to support the development of net-to-gross ratios and net savings values.
- Based on the above, estimate first year and lifetime gross and net ex post impacts (therm) for pipe insulation measures.

2.2 Studied Measure Groups

Table 2-1 presents the pipe insulation measure group's contribution to each PA's portfolio electric and natural gas energy savings[7] (as well as the statewide contribution) for 2013 and 2014.

Table 2-1: Summary of Deemed ESPI Pipe Insulation Measure Expressed as a Percentage of each PA's 2013 and 2014 Portfolio Gross Ex ante Savings

	2013 Savings				2014 Savings			
	SW	PG&E	SCG	SDG&E	SW	PG&E	SCG	SDG&E
kW	0.1%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
kWh	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Therms	1.6%	0.6%	3.2%	1.7%	2.3%	1.2%	4.3%	0.3%

As evidenced above in Table 2-1, pipe insulation contributes insignificantly to overall portfolio kWh savings in 2013 and 2014. As a result, the Pipe Insulation – Cold Application measure group is not assessed in this study. On the other hand, Pipe Insulation – Hot Application contributes significantly to the portfolio's therm savings, and increasingly so in 2014, as indicated in Table 2-1. Therefore, hot application savings from pipe insulation is the focus of this study.

Different levels of rigor have been applied to most appropriately assess the performance of the pipe insulation measure. These levels of rigor are informed by the availability and reliability of

7 These savings do not include those associated with Codes and Standards.

existing data sources along with the need to gather new primary data. Table 2-2 summarizes the levels of rigor applied to pipe insulation measure groups.

Table 2-2: Percent Portfolio Savings, Levels of Rigor and Data Sources for 2013-14 Deemed ESPI Measures

Measure Group	2013-14 Savings (% of total kWh or therm)	Level of Rigor	Existing Data Source	New Data Collection		Monitoring Source
				Phone Survey	On-Site	
Pipe insulation cold application	0.0%	Do Nothing	No	No	No	Do Nothing
Pipe insulation hot application	2.0%	High	No	Yes	Yes	New

The energy savings associated with each level of rigor (as a percentage of the statewide deemed ex ante ESPI savings) is provided below along with a brief discussion of how these levels of rigor have been applied:

- **High** – 0% of deemed pipe insulation kWh and kW savings; 100% of deemed pipe insulation therm savings
  - For the hot application pipe insulation measure, new primary data has been collected utilizing a phone and on-site survey instrument, including the measurement of combustion efficiency and the installation of temperature loggers.
- **Do Nothing** – 100% of deemed pipe insulation kWh and kW savings
  - For the cold application pipe insulation measure, which comprises no more than 0.1% of any IOU's portfolio kWh or kW savings, there are no existing data sources to utilize and no new primary data has been collected.

2.3 Overview of Impact Evaluation Approach

For pipe insulation measures, the general approach used to estimate ex post gross savings values was based on developing hourly heat loss profiles for both baseline (bare or less-insulated pipe) and as-built (insulated pipe) conditions. Heat loss calculations reflect conduction, convection, and radiation heat transfer processes. Metered data characterizes specific parameters included in the following algorithm:

$$\Delta Q = \frac{t * (Q_p - Q_i)}{100{,}000 * E_b}$$

Where,

ΔQ = annual energy savings (in therms). This parameter represents the ex post savings objective of this study.

t = annual operating time, in hours. Metered data on pipe surface temperature indicates when the insulated pipe transmits heated fluid. Metered data, gathered over 2-8 weeks, was extrapolated to represent a full year, after accounting for any seasonal variations determined from facility staff interviews. For long spans of insulated pipe, installed meters were deployed as close to the pipe span's midpoint as possible.

Qp = Heat Loss Rate from Bare (or Less-Insulated) Pipe[8] (Btu/hr/ft). Bare pipe experiences heat loss from convection and radiation processes. Both convection and radiation heat losses are primarily dependent on the following parameters: pipe diameter, pipe surface temperature, and ambient air temperature, the latter two of which were determined from interval metered data. Other pipe and insulation parameters were collected during the site visit. Remaining relevant parameters such as pipe conductivity and pipe emissivity were referenced from a heat transfer resource[9] based on material type.

Qi = Heat Loss Rate from Insulated Pipe (Btu/hr/ft). Insulated pipe features convection and radiation heat transfer processes, as described above, but also involves conduction heat transfer between the pipe and insulating material. Key insulation characteristics such as thickness and material were confirmed during each site visit. The insulation's surface temperature was spot-measured during the site visit, and relevant insulation parameters (conductivity and emissivity) were referenced from manufacturer data.

Eb = Combustion efficiency (%) of the boiler being used to generate the hot water or steam in the pipe. Combustion efficiency was spot-measured during each site visit or referenced from manufacturer testing data.

100,000 = conversion factor (1 therm = 100,000 Btu).

To develop the UES values, each of the above parameters is informed by metered and/or collected data from site inspections.

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8 Should the affected pipe have required insulation per OSHA guidelines, the baseline reflects the minimum level of insulation needed to comply. Information on OSHA compliance and minimum insulation requirements were gathered through discussions with facility staff.

9 An example resource is: *Introduction to Heat Transfer*, Frank Incropera and David DeWitt, John Wiley & Sons, Inc, New York, NY, 2002.

The remainder of this report will discuss how these UES values were generated for the ESPI pipe insulation measure along with the following:

- Section 3 discusses the data sources that were utilized to estimate each of the individual measure-parameters, the sample design, and resulting data used in the evaluation.
- Section 4 presents the methods used for estimating each individual impact parameter, including the installation rate, the various temperature values, the pre- and post-operating hours, and the NTGRs.
- Section 5 presents the final study results, including a discussion of how the UES values were applied to the population to develop gross and net realization rates and total population level ex post energy savings values.
- Section 6 summarizes the key findings and conclusions from this measure study.
- Appendix A presents the participant telephone survey instrument.
- Appendix B presents the on-site survey instrument.
- Appendix C presents the phone survey banners.
- Appendix D presents the detailed project level data and results.
- Appendix AA presents the standardized high level savings for both gross and net first year and lifecycle.
- Appendix AB presents the standardized per unit savings for both gross and net first year and lifecycle.

3

Data Sources, Sample Design, and Data Collection

3.1 Data Sources

A number of data sources were utilized to support the development of each impact parameter in order to update UES values, installation rates and NTGRs for the ESPI pipe insulation measure researched in this study. As discussed in Section 2, the impacts associated with the pipe insulation measure rely exclusively on new primary on-site data collection: (1) engineering on-site assessments to evaluate the gross impacts associated with those measures and (2) new phone surveys to generate NTGRs. The various sources of data are discussed in more detail below.

3.1.1 On-Site Data Collection

Verification data was collected to support installation rates, pipe characteristics (length, diameter, material), and insulation characteristics (length, thickness, material). The onsite involved collecting spot-reads on a number of parameters affecting insulation savings, including fluid pressure and temperature (via gauge readings), boiler combustion efficiency (via spot combustion analyzer) and insulation surface temperature (via infrared temperature gun). Both spot and long-term measurements of bare pipe temperature as well as insulation surface temperature occurred at similar sections of the pipe run, at the pipe run's midpoint when possible. Field staff noted the installed insulation quality by inspecting the insulation for gaps and contact with the pipe wall.

Self-report data was also gathered on the pre-existing pipe configuration insulation condition to help define the baseline condition. Data was gathered on preexisting insulation quality, such as missing sections, gaps, or sagging, through interviews with facility staff. If possible, preexisting insulation quality was assessed by examining areas of the facility that did not receive a recent pipe insulation enhancement.

Information on the layout of affected pipes was also noted. Specifically, OSHA requires that pipes with a surface temperature of 140°F or greater that are "located within 7 feet measured from floor or working level or within 15 inches measures horizontally from stairways, ramps, or fixed ladders shall be covered with a thermal insulating material or otherwise guarded against contact." This study assessed if these safety compliance measures apply to any of the projects selected in this sample.

3.1.2 Time of Use Loggers

As part of the on-site visit, a selection of insulated pipe(s) was monitored for a period of two to eight weeks, depending on facility schedule and variability, to gather interval data to support key energy savings parameters. Specifically, type-K temperature probes with HOBO data loggers were deployed on the pipe's exterior surface to inform fluid temperature and boiler operating hour parameters. HOBO ambient temperature loggers were deployed among a selection of facility spaces with insulated pipe in order to inform the surrounding air temperature, which affects pipe heat loss.

3.1.3 Participant Phone Survey

A phone survey was conducted to recruit customers for the on-site visit, as well as collect data useful for the NTG analysis and various other components of the evaluation. One other key use of the phone survey was to gather information on annual operating hours and schedule variability of facility boiler(s) prior to the site visit. This information allowed the field team to more accurately estimate the logging interval and duration to maximize data resolution. A copy of the participant phone survey script is included in Appendix A.

3.2 On-Site and Phone Survey Data Collection

As mentioned above, the on-site visits collected data to support a number of the impact parameters including the installation rates, bare pipe and surrounding temperatures, and combustion efficiencies for pipe insulation measures. The on-site sample was designed to develop statistically significant results at the measure level. The 2013-14 Nonresidential Downstream Deemed ESPI Impact Evaluation Research Plan[10] for this study discusses the sample design in greater detail, but the resulting design focuses on developing estimates of key impact parameters that can be used to augment existing data in order to update ex ante net and gross therm savings values for each ESPI measure.

The initial sample design for pipe insulation measures was generated using 2013 and 2014 program participants. According to the ESPI decision, the therms savings associated with steam and hot water pipe insulation are unclear given uncertainties regarding the internal and surrounding temperatures of typical pipes. As presented in Table 2-2, the ex ante statewide therms savings for hot application pipe insulation was roughly 2.0% of portfolio level savings. As presented in Table 3-1, the most significant savings for each PA are generated from hot water and medium pressure steam boilers within PG&E and SCG service territories. As a result, the initial sample design included only sites within these territories and with insulation on hot water and medium pressure steam pipe runs.

10 http://www.energydataweb.com/cpucFiles/pdaDocs/1210/PY2013-2014%20Deemed%20ESPI%20Research%20Plan_PDA.pdf

Table 3-1: 2013-14 Therms Savings for Hot Application Pipe Insulation by Measure Category and PA

PA	Measure Name	Population Sites	Therms Savings	% Therms Savings
PG&E	PIPE INSULATION PIPE DIAMETER <1" - HOT STEAM < 15PSI	2	16,126	3%
PG&E	PIPE INSULATION PIPE DIAMETER <1" - HOT STEAM >= 15PSI	65	143,704	25%
PG&E	PIPE INSULATION PIPE DIAMETER <1" - HOT WATER	9	18,104	3%
PG&E	PIPE INSULATION PIPE DIAMETER >= 1" - HOT WATER	10	156,571	27%
PG&E	PIPE INSULATION PIPE DIAMETER >=1" - HOT STEAM < 15PSI	2	10,504	2%
PG&E	PIPE INSULATION PIPE DIAMETER >=1" - HOT STEAM >= 15PSI	61	228,694	40%
SCG	PIPE INSULATION - INDUSTRIAL - HOT WATER < 1" PIPE, INDOOR	6	19,790	1%
SCG	PIPE INSULATION - INDUSTRIAL - HOT WATER >= 1" PIPE, INDOOR	20	177,459	12%
SCG	PIPE INSULATION - INDUSTRIAL - HOT WATER >= 1" PIPE, OUTDOOR	1	22,090	1%
SCG	PIPE INSULATION - INDUSTRIAL - LOW PRESSURE STEAM <15 PSI < 1" PIPE, INDOOR	1	2,957	0%
SCG	PIPE INSULATION - INDUSTRIAL - LOW PRESSURE STEAM <15 PSI >= 1" PIPE, INDOOR	3	41,251	3%
SCG	PIPE INSULATION - INDUSTRIAL - MEDIUM PRESSURE STEAM >=15 PSI < 1" PIPE, INDOOR	15	66,149	4%
SCG	PIPE INSULATION - INDUSTRIAL - MEDIUM PRESSURE STEAM >=15 PSI >= 1" PIPE, INDOOR	34	763,937	50%
SCG	PIPE INSULATION - INDUSTRIAL - MEDIUM PRESSURE STEAM >=15 PSI >= 1" PIPE, OUTDOOR	1	27,746	2%
SCG	PIPE INSULATION - LG COM >=12 HR - HOT WATER < 1" PIPE, INDOOR	10	41,353	3%
SCG	PIPE INSULATION - LG COM >=12 HR - HOT WATER >= 1" PIPE, INDOOR	26	135,247	9%
SCG	PIPE INSULATION - LG COM >=12 HR - LOW PRESSURE STEAM <15 PSI < 1" PIPE, INDOOR	1	1,366	0%
SCG	PIPE INSULATION - LG COM >=12 HR - LOW PRESSURE STEAM <15 PSI >= 1" PIPE, INDOOR	2	5,476	0%
SCG	PIPE INSULATION - LG COM >=12 HR - MEDIUM PRESSURE STEAM >=15 PSI < 1" PIPE, INDOOR	4	6,345	0%
SCG	PIPE INSULATION - LG COM >=12 HR - MEDIUM PRESSURE STEAM >=15 PSI >= 1" PIPE, INDOOR	13	164,854	11%
SCG	PIPE INSULATION - SM COM <12 HR - HOT WATER < 1" PIPE, INDOOR	2	231	0%
SCG	PIPE INSULATION - SM COM <12 HR - HOT WATER >= 1" PIPE, INDOOR	6	6,292	0%
SCG	PIPE INSULATION - SM COM <12 HR - LOW PRESSURE STEAM <15 PSI < 1" PIPE, INDOOR	1	66	0%
SCG	PIPE INSULATION - SM COM <12 HR - LOW PRESSURE STEAM <15 PSI >= 1" PIPE, INDOOR	1	1,545	0%

Table 3-2: 2013-14 Therms Savings for Hot Application Pipe Insulation by Measure Category and PA

PA	Measure Name	Population Sites	Therms Savings	% Therms Savings
SCG	PIPE INSULATION - SM COM <12 HR - MEDIUM PRESSURE STEAM >=15 PSI < 1" PIPE, INDOOR	4	12,291	1%
SCG	PIPE INSULATION - SM COM <12 HR - MEDIUM PRESSURE STEAM >=15 PSI >= 1" PIPE, INDOOR	5	24,785	2%
SDG&E	PIPE INSULATION - HOT WATER APPLIC. >=1 IN.	2	7,652	23%
SDG&E	PIPE INSULATION - LOW PRESSURE (<=15 PSI) STEAM APPLIC. >=1 IN.	1	18,130	55%
SDG&E	REPLACED HOT WATER LINE INSULATION (ELECTRIC)	248	-	0%
SDG&E	REPLACED HOT WATER LINE INSULATION (GAS)	325	6,914	21%

Phone surveys and on-sites were initially attempted for only the projects in the preliminary sample; however, due to lower-than-expected response rate and the limited population, **a census was eventually attempted to meet the desired sample of 30 on-sites**. Table 3-3 summarizes the sample design for hot application pipe insulation along with the actual number of phone surveys and on-sites completed, which was stratified by boiler type and project size, in terms of the magnitude of therm savings. The sample frame includes PG&E and SCG hot application participants from program year 2013 and 2014. Please note that the actual number of completed on-sites is 31, as compared with the initial sample goal of 30.

Table 3-3: Pipe Insulation Sample Design and Achieved Data Collection by Boiler Type and Project Size – PY2013-14

Boiler Type	Project Size (Therms)	Percent of Ex ante Savings	Population*	Initial Sample Design	Actual Completed On-sites	Actual Completed Phone Surveys*
Hot Steam	> 25,000	34%	11	6	6	5
Hot Steam	10,000 - 25,000	16%	20	7	7	9
Hot Steam	< 10,000	18%	91	7	7	17
Hot Water	> 25,000	15%	8	3	3	3
Hot Water	10,000 - 25,000	6%	9	4	4	7
Hot Water	< 10,000	7%	49	3	4	15
Total		**95%**[11]	**170**	**30**	**31**	**49**

* The column sums up to more than the total because some participants installed multiple measures across various strata.

Participating customers often featured more than one unique pipe run insulated with IOU assistance. When possible, field engineers independently assessed each unique pipe run at each project in the sample of 31. Therefore, this study assessed 93 distinct pipe runs (hereafter referred to as “observations”) at the 31 participating facilities in the evaluation sample. The on-site sample represented 36% of the ex ante therm savings claim and the phone survey represented 46% of the ex ante therm savings claim.

[11] The total sums to 95% because SDG&E is not included in the sample design and represents 5% of savings.

4

Evaluation Methodology

This section provides an overview of the methods used to estimate the key impact parameters, the ex post UES values and the NTGRs for the deemed pipe insulation ESPI measure identified for PY 2013.

4.1 Overview of Approach

The primary objective of this evaluation is to perform a measure and measure-parameter impact evaluation, utilizing new primary evaluation data, in order to update existing gross and net savings estimates and inform future savings values for the pipe insulation measure identified in the ESPI decision. Researched parameters, including operating hours, bare pipe temperature, surrounding temperature, boiler combustion efficiency, installation rates, RULs and estimates of free ridership, can be used to measure ex post performance for PY 2013.

More specifically, these parameter level results will be aggregated in order to develop therm UES values and NTGRs for the pipe insulation measure identified in Appendix 3 of the ESPI decision.

As discussed in more detail below, the impact parameter estimates were developed at different levels of segmentation in order to generate unique UES values by market segment and pipe characteristic. For example, operating hours were generated by market segment, whereas bare pipe temperature and surrounding air temperature values were generated by fluid type. However, only a single NTGR was developed for the overall measure group. Unless otherwise indicated, all parameter-level averages have been weighted by insulation length (in feet) among the various segments of interest.

This section discusses, in detail, the inputs that were used to develop these parameter estimates. They also inform the general approach that was used to develop the UES values. The algorithm that was applied to estimate unit energy savings for a specific hour is:

$$\Delta Q = \frac{t * (Q_p - Q_i)}{100{,}000 * E_b}$$

Where,

ΔQ = annual energy savings (in therms). This parameter represents the ex post savings objective of this study.

t = annual operating time, in hours. Metered data on pipe surface temperature indicates when the insulated pipe transmits heated fluid. Metered data, gathered over 2-8 weeks, was extrapolated to represent a full year, after accounting for any seasonal variations determined from facility staff interviews. For long spans of insulated pipe, installed meters were deployed as close to the pipe span's midpoint as possible.

Qp = Heat Loss Rate from Bare (or Less-Insulated) Pipe[12] (Btu/hr/ft). Bare pipe experiences heat loss from convection and radiation processes. Both convection and radiation heat losses are primarily dependent on the following parameters: pipe diameter, bare pipe surface temperature, and ambient air temperature, the latter two of which were determined from interval metered data. Other pipe and insulation parameters were collected during the site visit. Remaining relevant parameters such as pipe conductivity and pipe emissivity were referenced from a heat transfer resource[13] based on material type.

Qi = Heat Loss Rate from Insulated Pipe (Btu/hr/ft). Insulated pipe features convection and radiation heat transfer processes, as described above, but also involves conduction heat transfer between the pipe and insulating material. Key insulation characteristics such as thickness and material were confirmed during each site visit. The insulation's surface temperature was spot-measured during the site visit, and relevant insulation parameters (conductivity and emissivity) were referenced from manufacturer data.

Eb = Combustion efficiency (%) of the boiler being used to generate the hot water or steam in the pipe. Combustion efficiency was spot-measured during each site visit or referenced from manufacturer testing data.

100,000 = conversion factor (1 therm = 100,000 Btu).

12 Should the affected pipe have required insulation per OSHA guidelines, the baseline reflects the minimum level of insulation needed to comply. Information on OSHA compliance and minimum insulation requirements were gathered through discussions with facility staff.

13 An example resource is: Introduction to Heat Transfer, Frank Incropera and David DeWitt, John Wiley & Sons, Inc, New York, NY, 2002.

The remainder of this section will discuss the following:

- The approach for estimating each individual impact parameter, including the installation rate, the various temperature values and the operating hours.
- The approach for estimating the NTGRs.

4.2 Installation Rate Analysis

The installation rate is defined as the percentage of equipment found to be installed and operable. The installation rate is estimated for each site based on data gathered during the on-site visit. As part of these on-site visits, an objective of the auditor was to attempt to identify and assess the quantity and operability of all pipe insulation installed.

The key measure count that is identified on site is the length (in feet) of pipe insulation that is currently installed and in working condition. Field auditors used a combination of spot measurement, staff interviews, and review of project invoices to confirm the quantity of incented pipe insulation in feet. The installation rate is calculated directly from this measurement:

$$Installation\ Rate = \frac{Length\ of\ pipe\ insulation\ installed\ and\ operable\ from\ on-site\ visit}{Length\ of\ pipe\ insulation\ reported\ installed\ in\ tracking\ system}$$

In addition to identifying the amount of equipment that was installed and operable, the auditor was also prepared to identify the length of insulation that was:

- Failed and in place – The length of pipe insulation currently installed but not in working condition (failed).
- Failed and replaced – The length of pipe insulation that had been installed, but then had failed and was replaced with different insulation.
- Removed and not replaced - The length of pipe insulation that had been installed, but had been removed (either due to failure or other reasons), but was not replaced, such that the pipe is now bare.

For all 31 pipe insulation projects in the sample, the field auditors found the pipe insulation to be 100% installed as tracked, through visual inspection, spot measurement, and review of project invoices.

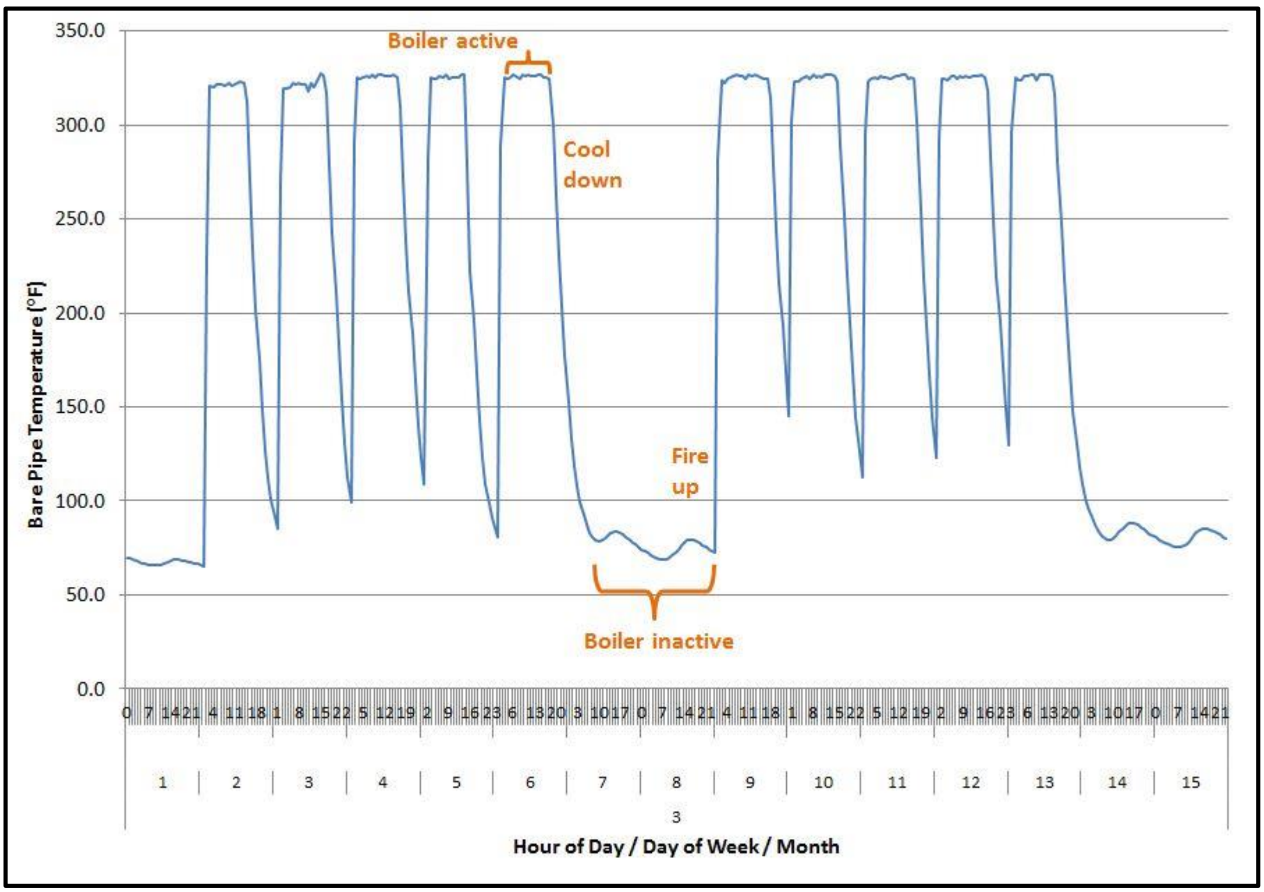
It is important to note that the field auditors also found that 9% of the rebated insulated piping required insulation to minimally comply with OSHA. OSHA requires that pipes with a surface temperature of 140°F or greater that are “located within 7 feet measured from floor or working level or within 15 inches measures horizontally from stairways, ramps, or fixed ladders shall be covered with a thermal insulating material or otherwise guarded against contact." Such piping requires a minimally-compliant amount of insulation, reducing the program savings due to baseline adjustment.

4.3 Operating Hour Analysis

One of the primary inputs to the gross savings calculations is the number of annual hours that the insulated pipe is heated. This section will discuss the development of the annual operating hours value from the analysis of logger data.

As discussed throughout this report, type-K temperature loggers were installed on representative sections of insulated pipe at sampled facilities. These loggers not only provide information on key temperature inputs in the heat loss calculation (see Section 4.4) but also indicate when the measured pipe was heated, providing insight into the parent boiler's operating schedule. An example analysis of operating hours from temperature data is illustrated in Figure 4-1; the analysis considered the "boiler active" periods as the operating hours over the metering period.

Figure 4-1: Calculation of Operating Hours from Bare Pipe Temperature Profile



Because loggers were not installed for a full year, the logger data needed to be extrapolated out to a full year of 8,760 hours. In general, the analysis calculated the ratio between the number of hours the insulated pipe was heated over the metering period and the total number of hours in the metering period; this ratio was applied to 8,760 hours to determine the total number of annual hours that the insulated pipe was heated.

While on site, the field auditors gathered information on any seasonal changes in facility operation (e.g., a vineyard that featured an increase in shifts during the grape harvest); these seasonal effects were considered in the extrapolation on a case-by-case basis. Industrial customers typically quantified seasonal effects through an estimate in the weekly number of shifts by season, whereas commercial customers typically indicated changes in hours open.

The final step after extrapolating each individual logger to an annual operating hours value is to aggregate each logger to a customer type. IOUs classify participating customers as small commercial, large commercial, and industrial, each with a unique ex ante annual operating hours assumption. Table 4-1 compares the ex ante operating hours assumption with the ex post finding for each customer type.

Table 4-1: Comparison of Ex Ante and Ex Post Annual Operating Hours by Customer Type

Customer Type	Sites	Observations	Ex Ante Operating Hours	Ex Post Operating Hours
Small Commercial*	0	0	2,425	N/A
Large Commercial	11	33	4,380	5,560
Industrial	20	60	7,752	6,560

* No small commercial projects were featured in the sample.

Industrial participants were confirmed to operate for more annual hours than large commercial participants, though the difference is smaller than reflected within ex ante assumptions. Large commercial customers were found to operate 27% more than assumed within IOU deemed savings, while industrial customers were found to operate 15% less. The sample of 31 projects featured no small commercial customers, due to their relatively low contribution to overall measure savings. As sampled projects often featured multiple different unique pipe runs, the evaluation team assessed nearly three times as many “observations” as sites in the sample.

4.4 Temperature Analysis

In addition to indicating boiler operating schedule, deployed temperature loggers also provided valuable data on key temperatures influencing the hourly heat loss calculation discussed in Section 4.1 . This section will discuss the use of metered data in characterizing bare pipe temperatures and surrounding air temperatures among a sample of participating customers.

4.4.1 Bare Pipe Temperature

Pipe heat loss is a combination of conductive, convective, and radiative heat losses, each of which is a function of bare pipe temperature. Field auditors collected relevant information related to bare pipe temperature using a combination of three methods:

- **Data metering** – The type-K thermocouple loggers provided interval data on bare pipe temperature throughout the 2- to 8-week metering period.
- **Gauge readings and spot measurement** – Field auditors supplemented long-term metered data with spot readings from infrared temperature guns and inspection of fluid gauges. As pipe material is highly conductive, fluid temperature and bare pipe temperature values are typically within one percent.
- **Customer interviews** – Metered temperature data was confirmed as representative of the facility's process over an entire year through interviews with facility contacts on site and/or over the phone, as needed.

The heat loss calculation tool determined the average bare pipe temperature when the pipe was heated (i.e., during "boiler active" periods of Figure 4-1). As IOUs classify heating processes based on fluid temperature and pressure, Table 4-2 compares ex ante bare pipe temperature assumptions with ex post findings for three fluid categories: hot water, low-pressure steam, and high-pressure steam.

Table 4-2: Comparison of Ex Ante and Ex Post Bare Pipe Temperature by Fluid Type

Fluid Type	Observations	Ex Ante Bare Pipe Temperature (°F)	Ex Post Bare Pipe Temperature (°F)
Hot Water	36	150.0	135.3
Low-Pressure Steam	4	243.0	256.3
Medium-Pressure Steam	53	328.0	312.5

Hot water and medium-pressure steam piping, which account for the most significant shares of total measure savings, featured slightly lower bare pipe temperatures than reflected within IOU deemed savings assumptions. Please note that only four low-pressure steam runs were encountered in the sample of projects, due to the infrequency of low-pressure steam piping in the participant population.

Evaluators further assessed variation in hot water and medium-pressure steam bare pipe temperature as a function of customer type, as summarized in Table 4-3. Each of the customer-fluid permutations resulted in an ex post bare pipe temperature lower than the ex ante assumption.

Table 4-3: Comparison of Ex Ante and Ex Post Bare Pipe Temperatures by Fluid and Customer Type

Customer Type Fluid Type	Observations[1]	Ex Ante Bare Pipe Temperature (°F)	Ex Post Bare Pipe Temperature (°F)
Commercial			
Hot Water	21	150.0	135.5
Medium-Pressure Steam	10	328.0	291.6
Industrial			
Hot Water	15	150.0	135.2
Medium-Pressure Steam	43	328.0	317.3

[1] Excludes low-pressure steam data due to low observation count.

4.4.2 Surrounding Air Temperature

Convective and radiative heat loss is also a function of the temperature of the air surrounding the pipe. Field auditors collected relevant information related to surrounding air temperature using a combination of three methods:

- **Data metering** – Air temperature loggers were deployed at a representative location near the insulated pipe, providing interval data on surrounding air temperature throughout the 2- to 8-week metering period.
- **Gauge readings and spot measurement** – Field auditors supplemented long-term metered data with spot readings from infrared temperature guns.
- **Customer interviews** – Air temperature data was confirmed as representative of the facility's process over an entire year through interviews with facility contacts on site and/or over the phone, as needed.

The heat loss calculation tool determined the average bare pipe temperature when the pipe was heated (i.e., during "boiler active" periods of Figure 4-1). Any seasonal adjustment, such as weather fluctuation for insulated pipe located outdoors, was factored into the extrapolation on a case-by-case basis. As most insulated pipe was assumed to be located indoors, IOUs assumed a surrounding air temperature of 75°F for all customer types and fluid types. Table 4-4 presents evaluator findings in surrounding temperature as a function of fluid type.

Table 4-4: Comparison of Ex Ante and Ex Post Surrounding Air Temperature by Fluid Type

Fluid Type	Observations	Ex Ante Surrounding Air Temperature (°F)	Ex Post Surrounding Air Temperature (°F)
Hot Water	36	75.0	77.6
Low-Pressure Steam	4	75.0	102.3
Medium-Pressure Steam	53	75.0	85.8

Evaluators determined surrounding air temperature to be similar to the ex ante assumption for hot water piping, while medium-pressure steam was found to feature a surrounding air temperature 14% higher than the ex ante assumption. The comparatively low number of low-pressure steam observations resulted in a weighted average surrounding temperature significantly higher than hot water and medium-pressure steam values. Field engineers often encountered insulated piping in boiler rooms or industrial spaces not mechanically cooled; each of the surrounding air temperatures for low-pressure steam piping were above 96°F on average.

Evaluators further assessed variation in hot water and medium-pressure steam surrounding air temperatures as a function of customer type, as summarized in Table 4-5. Each of the customer-fluid permutations resulted in an ex post surrounding air temperature higher than the ex ante assumption of 75°F.

Table 4-5: Comparison of Ex Ante and Ex Post Surrounding Air Temperature by Customer and Fluid Type

Customer Type Fluid Type	Observations[1]	Ex Ante Surrounding Air Temperature (°F)	Ex Post Surrounding Air Temperature (°F)
Commercial			
Hot Water	21	75.0	81.3
Medium-Pressure Steam	10	75.0	79.2
Industrial			
Hot Water	15	75.0	76.1
Medium-Pressure Steam	43	75.0	87.3

1 Excludes low-pressure steam data due to low observation count.

4.5 Combustion Efficiency Analysis

Finally, pipe insulation savings are dependent on the combustion efficiency of the boiler generating the heated fluid. Field auditors collected relevant information related to boiler combustion efficiency using a combination of two methods:

- **Combustion efficiency measurement and skin loss estimate** – Field auditors spot-measured the combustion efficiency of boiler(s) with insulated pipes.
- **Equipment nameplate reference and research** – Not all boilers were accessible for a combustion efficiency measurement. In some cases, the field auditors collected nameplate information on the affected boiler(s) and researched manufacturer's combustion efficiency testing data.

IOUs assumed combustion efficiencies based on fluid type. Table 4-6 compares ex ante combustion efficiency estimates with ex post values by fluid type.

Table 4-6: Comparison of Ex Ante and Ex Post Combustion Efficiencies by Fluid Type

Fluid Type	Observations	Ex Ante Combustion Efficiency	Ex Post Combustion Efficiency
Hot Water	36	82.0%	77.6%
Low-Pressure Steam	4	83.0%	82.9%
Medium-Pressure Steam	53	83.0%	83.9%

Low-pressure steam and medium-pressure steam boilers will found to feature combustion efficiencies within 1% of the ex ante assumption, while hot water boilers were determined to be 4% less efficient than the ex ante value, leading to additional pipe insulation measure savings. Please note that only four low-pressure steam runs were encountered in the sample of projects, due to the infrequency of low-pressure steam piping in the participant population.

4.6 Development of Unit Energy Savings Values

The annual operating hours, bare pipe temperature, surrounding air temperature, and boiler combustion efficiency parameter estimates are then applied to the hourly heat loss equation (as presented in Section 4.1) for all customer type and fluid type combinations. Table 4-7 presents the unit energy savings (UES) values as a function of customer type and fluid type. UES values were generated for all sites in the sample, some of which featured both hot water and steam piping, leading to two UES values for a single project; therefore, Table 4-7 site count is greater than the overall sample of 31 projects. Due to constraints in sample size, not all customer-fluid combinations were reflected in the evaluation sample; these cells are noted with N.D. (no data).

Table 4-7: Ex Post UES Values by Customer and Fluid Type

Customer Type Pipe Fluid and Size	Obsv.	Ave. Pipe Dia.	Delta Temp.	Annual Operating Hours	Boiler Combustion Efficiency	UES (therms per foot)
Small Commercial						
Hot Water (≤1” Pipe)	0	N.D.	N.D.	N.D.	N.D.	N.D.
Hot Water (>1” Pipe)	0	N.D.	N.D.	N.D.	N.D.	N.D.
Low-Pressure Steam (≤1” Pipe)	0	N.D.	N.D.	N.D.	N.D.	N.D.
Low-Pressure Steam (>1” Pipe)	0	N.D.	N.D.	N.D.	N.D.	N.D.
Medium-Pressure Steam (≤1” Pipe)	0	N.D.	N.D.	N.D.	N.D.	N.D.
Medium-Pressure Steam (>1” Pipe)	0	N.D.	N.D.	N.D.	N.D.	N.D.
Large Commercial						
Hot Water (≤1” Pipe)	6	0.7”	57.3	6,457	75.6%	2.1
Hot Water (>1” Pipe)	15	3.3”	50.8	5,752	86.7%	5.5
Low-Pressure Steam (≤1” Pipe)	0	N.D	N.D.	N.D.	N.D.	N.D.
Low-Pressure Steam (>1” Pipe)	2	2.8”	244.7	8,760	80.0%	60.6
Medium-Pressure Steam (≤1” Pipe)	1	1.0”	200.6	8,760	80.0%	19.7
Medium-Pressure Steam (>1” Pipe)	9	1.9”	213.3	3,167	84.3%	11.9
Industrial						
Hot Water (≤1” Pipe)	5	0.7”	70.2	4,387	76.4%	1.8
Hot Water (>1” Pipe)	10	2.3”	75.7	7,560	76.2%	8.9
Low-Pressure Steam (≤1” Pipe)	0	N.D.	N.D.	N.D.	N.D.	N.D.
Low-Pressure Steam (>1” Pipe)	2	3.7”	143.5	6,213	83.3%	26.8
Medium-Pressure Steam (≤1” Pipe)	8	0.8”	222.4	6,322	83.4%	12.9
Medium-Pressure Steam (>1” Pipe)	35	2.7”	231.2	6,130	84.0%	36.3

* The sample draw of 31 projects featured no small commercial customers, due to their relatively low contribution to overall measure savings.

Some observations from the UES data:

- Medium-pressure steam UES values vary by fluid type and customer type, from those higher than used by the IOUs[14] (large commercial customers with less than 1” diameter pipe, due to higher operating hours and lower boiler combustion efficiency; industrial customers with greater than 1” pipe, due to higher delta-temperature), to those lower (industrial customers with less than 1” pipe, due to lower annual operating hours). Please note the low observation count for large commercial customers with less than 1” diameter medium-pressure steam piping.

[14] Per PGE workpaper PGECOHVC104 Revision #5, dated June 1, 2012.

- The UES for large commercial hot water piping with greater than 1" diameter is higher than the IOU-assumed value, due to higher operating hours and lower boiler combustion efficiency. However, UES for industrial hot water piping (both size tiers) are lower than the IOU-assumed values, due primarily to lower annual operating hours.
- Low-pressure steam piping features UES values higher than those used by the IOUs due to higher annual operating hours (for large commercial customers), higher average pipe diameter, and higher delta-temperature. Please note the low observation count for low-pressure steam piping, as mentioned previously in this report.

4.7 Net-to-Gross Analysis

For program years 2013 and 2014, the approach for estimating NTGRs was based on the same approach utilized for the 2010-12 Nonresidential Downstream Lighting Impact Evaluation[15], which relied solely on participant phone survey data. The NTGR methodology utilized for the 2010-12 Nonresidential Downstream Lighting Impact Evaluation was based on the large non-residential free ridership approach developed by the NTGR Working Group and documented in Appendix C of that report, *Methodological Framework for Using the Self-Report Approach to Estimating Net-to-Gross Ratios for Non-residential Customers*. The NTGR is calculated as the average of three program attribution indices (PAI) known as PAI-1, PAI-2, and PAI-3. Each of these scores represents the highest response or the average of several responses given to one or more questions about the decision to install a program measure. The participant phone survey was the basis for the inputs to each score.

- **Program Attribution Index 1 (PAI–1)** is a score that reflects the influence of the most important of various program-related elements in the customer's decision to select a given program measure. The PAI-1 score is calculated as the highest program influence factor divided by the sum of the highest program influence factor and the highest non-program influence factor. Some example non-program factors are: previous experience with the measure, recommendation from an engineer, standard practice, corporate policy, compliance with rules or regulations, organizational maintenance or equipment replacement policies and "other – specify." Payback is treated as a program influence factor if the rebate/incentives played a major role in meeting payback criteria, but is treated as a non-program influence factor if it did not play a major role in meeting payback criteria.
- **Program Attribution Index 2 (PAI–2)** is a score that captures the perceived importance of program factors (including rebate/incentives, recommendation, and training) relative to non-program factors in the decision to implement the specific measure that was eventually adopted or installed. This score is determined by asking respondents to assign

15 http://www.energydataweb.com/cpuc/deliverableView.aspx?did=1155&uid=0&tid=0&cid=

importance values to the program and most important non-program influences so that the two total 10. The program influence score is adjusted (i.e., divided by 2) if respondents had made the decision to install the measure before learning about the program. The final score is divided by 10 to be put into decimal form, thus making it consistent with PAI-1.

- **Program attribution index 3 (PAI–3)** is a score that captures the likelihood of various actions the customer might have taken at the given time and in the future if the program had not been available (the counterfactual). This score is calculated as 10 minus the likelihood that the respondent would have installed the same measure in the absence of the program. The final score is divided by 10 to put into decimal form, thus making it consistent with PAI-1 and PAI-2.

The NTGR was estimated as an average of these three scores. If one of the scores was not available (generally due to respondents giving a “don’t know” or “refusal” response), then the NTGR was estimated as the average of the two available score. If two or more scores were missing, results were discarded from the calculation.

Table 4-8 presents the ex ante and ex post NTGR values weighted by ex ante therm savings. Recall that only hot applications were evaluated for pipe insulation, so only therm based NTGRs were developed. Overall, at the statewide level, the ex post NTGR is approximately 80% of the ex ante value. The weighted average program attribution scores for the population were 0.49 for PAI-1, 0.52 for PAI-2 and 0.47 for PAI-3. All scores were within 5% of the overall NTGR.

Table 4-8: Ex Ante and Ex Post NTGRs by Measure, Weighted by Ex Post Therms

Measure	n	Weight	Ex Ante NTGR	Ex Post NTGR	Relative Precision
Pipe Insulation	49	Therms	0.61	0.49	10%

5

Evaluation Results

This section presents the gross and net realization rates for first year and lifecycle therm savings, as well as aggregate ex post population-level savings for first year and lifecycle therms.

5.1 Gross First Year Realization Rates

Once all the UES values have been created, as discussed in Section 4, these values can be applied to the population of participants. Gross realization rates (GRRs) are then estimated for therm savings by looking at the ratio of the aggregate evaluated gross savings to the aggregate ex- ante gross savings. Specifically, the GRR for customer-fluid type segment j is estimated as:

$$Gross\_Realization\_Rate_j = \frac{\sum_{i=1}^{n} Gross\_Ex\_Post\_Impact_{i,j}}{\sum_{i=1}^{n} Gross\_Ex\_Ante\_Impact_{i,j}}$$

Where,

> $Gross\_Ex\_Post\_Impact_{i,j}$ is the site-specific gross ex post impact estimate for customer i, in the population, who is in customer-fluid type segment j.
>
> $Gross\_Ex\_Ante\_Impact_{i,j}$ is the site-specific gross ex ante impact estimate for customer i, in the population, who is in customer-fluid type segment j.

Table 5-1 presents the therm first year gross realization rates, by customer and fluid type. Also shown are the aggregate ex post and ex ante savings values for the sample by segment that were used to develop the realization rates.

Table 5-1: First Year Gross Therm Realization Rates by Customer and Fluid Type

Customer Type - Fluid Type	First Year Gross Therms Savings				
	Sample Size	Ex Ante Savings Onsite Sample	Ex Post Savings Onsite Sample	GRR	Relative Precision
Agricultural/Industrial - Steam	39	561,681	442,033	79%	8%
Agricultural/Industrial - Hot Water	13	115,712	71,752	62%	40%
Large Commercial - Steam	14	43,719	54,333	124%	45%
Large Commercial - Hot Water	18	24,604	16,667	68%	30%

As discussed throughout Section 4, the ex post impacts and ex ante claims are products of several unique parameters that are generated in the impact algorithm. The underlying ex ante assumptions regarding each parameter vary by measure as do the ex post impacts. Below is a brief discussion of some of those underlying differences and how they affected the overall realization rates.

For **agricultural or industrial** facilities, several factors led to lower ex post first-year therm savings as compared with ex ante:

- Lower-than-anticipated annual operating hours—15% lower than assumed within IOU deemed savings, per Table 4-1—primarily reduced the ex post annual therm savings.
- Table 4-2 indicated that field auditors determined a weighted average medium-pressure steam bare pipe temperature of 313°F as compared with the IOU assumption of 328°F. Table 4-4 indicated an evaluated surrounding air temperature of 86°F as compared with the IOU assumption of 75°F. This difference in bare pipe and surrounding air temperatures further reduced the ex post savings for medium-pressure steam piping, due to the high prevalence of medium-steam pipe runs at industrial facilities.
- As noted earlier in Section 2.3, if the insulated pipe is proximate to work areas, an OSHA minimum compliance baseline is appropriate; field auditors determined that 11% of evaluated insulated pipe at industrial facilities required an OSHA baseline, thereby reducing ex post savings by 5%.
- Counteracting the three reductions in ex post savings listed above, the field auditors determined that insulated pipe at industrial facilities was larger in diameter than assumed within IOU deemed savings calculations. Evaluators found that industrial hot water piping was 35% higher-diameter than the IOU assumption of 1.7”, and industrial medium-steam piping 59% higher-diameter. Higher diameter pipe leads to higher baseline heat loss rates, leading to higher therm savings for insulated pipe.

For **commercial** facilities, steam piping savings were 24% higher than reported by IOUs, while hot water piping was 32% lower. The following factors led to these savings differences:

- Nearly a third of the commercial pipe runs encountered in the sample of 31 projects was medium-pressure steam piping. The lower-than-anticipated bare pipe temperature and higher-than-anticipated surrounding air temperature for medium-pressure steam piping led to lower ex post therm savings.
- Similarly as with industrial facilities, 5% of insulated steam piping at large commercial facilities was determined to require a baseline reflecting OSHA minimum compliance.
- However, Table 4-1 indicates that evaluators determined 27% higher annual operating hours at commercial facilities as compared with the IOU assumption. Additionally, insulated pipe at commercial facilities was generally of higher diameter than assumed by the IOU; each of these factors serve to counteract the savings reductions noted above.
- Hot water boilers at commercial facilities were found to operate at 78% combustion efficiency, 4% lower than the ex ante assumption. This difference in combustion efficiency resulted in higher ex post savings for hot water piping at commercial facilities.

Table 5-2 presents the first year gross realization rates along with the corresponding ex ante and ex post first year therms savings for hot application pipe insulation measure by PA and statewide. The corresponding relative precision at the statewide level is also included. The relative precision is not shown at the PA level given the fact that evaluation was not conducted at that level, but rather at the overall facility type and pipe fluid type level.

Table 5-2: 2014 Aggregate First Year Ex Post Gross Therm Savings by PA

PA	First Year Gross Therms Savings			
	Ex Ante Savings	**Ex Post Savings**	**GRR**	**Relative Precision**
PG&E	370,701	341,227	92%	
SCG	905,293	709,301	78%	
SDG&E	6,903	4,676	68%	
Statewide	**1,282,898**	**1,055,204**	**82%**	**13%**

The objective of this study was to develop GRRs that could be used to estimate IOU level therms savings across all nonresidential hot application pipe insulation measures. The differences in GRR at the IOU level are predicated on differences in the distribution of facility types and pipe fluid types as well as differences in the unique parameters that comprise the overall impact of each measure. The first year GRRs range from 92% in PGE to 68% in SDG&E. The statewide GRR was estimated at 82% at a 13% relative precision.

5.2 Lifecycle Gross Realization Rates

Table 5-3 presents the lifecycle GRRs along with the corresponding ex ante and ex post first year therms savings for hot application pipe insulation measure by PA and statewide. The corresponding relative precision at the statewide level is also included. Again, the relative precision is not shown at the PA level given the fact that evaluation was not conducted at that level, but rather at the overall facility type and pipe fluid type level. Lifecycle savings values are equal to the first year savings multiplied by the EUL. Because this study did not evaluate the EULs, the ex ante EUL was used. Therefore, first year and lifecycle realization rates are very similar.

Table 5-3: 2014 Aggregate Lifecycle Ex Post Gross Therm Savings by PA

	LifeCycle Gross Therms Savings			
PA	**Ex Ante Savings**	**Ex Post Savings**	**GRR**	**Relative Precision**
PG&E	4,198,936	3,892,468	93%	
SCG	9,958,220	7,802,311	78%	
SDG&E	75,937	51,441	68%	
Statewide	**14,233,093**	**11,746,220**	**83%**	**13%**

5.3 Net First Year Realization Rates

Net savings are estimated in a manner similar to the gross savings. UES values are multiplied by the corresponding NTGRs to get net savings values. Net realization rates (NRRs) are then estimated for therm savings by looking at the ratio of the aggregate evaluated gross savings to the aggregate ex ante gross savings. Specifically, the NRR for PA-Measure segment j is estimated as:

$$Net\_Realization\_Rate_j = \frac{\sum_{i=1}^{n} Net\_Ex\_Post\_Impact_{i,j}}{\sum_{i=1}^{n} Net\_Ex\_Ante\_Impact_{i,j}}$$

Where,

> $Net\_Ex\_Post\_Impact_{i,j}$ is the site-specific net ex post impact estimate for customer i, in the population, who is in PA-Measure segment j.
>
> $Net\_Ex\_Ante\_Impact_{i,j}$ is the site-specific net ex ante impact estimate for customer i, in the population, who is in PA-Measure segment j.

Table 5-4 presents the therm first year net realization rates, by PA and measure, along with statewide totals. Also shown are the aggregate ex post and ex ante savings values by segment that were used to develop the realization rates.

Table 5-4: 2014 Aggregate First Year Ex Post Net Therm Savings by PA

	First Year Net Therms Savings			
PA	**Ex Ante Savings**	**Ex Post Savings**	**NRR**	**Relative Precision**
PG&E	247,569	167,377	68%	
SCG	543,176	347,923	64%	
SDG&E	4,142	2,294	55%	
Statewide	**794,886**	**517,593**	**65%**	**17%**

The NRRs differ for the same reasons discussed above for GRRs; however, they are also influenced by differences between ex post and ex ante NTGRs. For the most part, the ex post NTGRs are less than ex ante NTGRs (about 80% of ex ante), which explains why NRRs are lower than GRRs (about 80% of the GRRs).

5.4 Lifecycle Net Realization Rates

Lifecycle NRRs are estimated in a similar way as lifecycle GRRs by looking at the ratio of the evaluated ex post net lifecycle savings to the ex ante net lifecycle savings. The approach is identical to that for the lifecycle GRRs, but using net savings instead of gross. As with the first year values, the lifecycle NRRs in Table 5-4 are very similar to the first-year NRRs in Table 5-5.

Table 5-5: 2014 Aggregate Lifecycle Ex Post Net Therm Savings by PA

	LifeCycle Net Therms Savings			
PA	**Ex Ante Savings**	**Ex Post Savings**	**NRR**	**Relative Precision**
PG&E	2,795,989	1,909,313	68%	
SCG	5,974,932	3,827,149	64%	
SDG&E	45,562	25,232	55%	
Statewide	**8,816,483**	**5,761,695**	**65%**	**17%**

6

Key Findings and Conclusions

This section presents findings and conclusions of this research study.

Conclusion 1 [Section 4.2]: All rebated insulation was determined to be 100% installed as tracked. Field auditors determined that all incented insulation was installed and operable via visual inspection, spot measurement, and review of project invoices. However, field auditors also determined that 9% of the rebated insulated piping required minimally-compliant baseline insulation.[16]

Conclusion 2 [Section 4.3]: Affected boilers at participating large commercial facilities operate 27% more than assumed within IOU deemed savings values, while affected boilers at participating industrial facilities operate 15% less. Boilers at large commercial facilities were assumed to operate 4,380 hours per year, but evaluators determined that they operate 5,560 hours per year. Boilers at industrial facilities were assumed to operate 7,752 hours per year, but evaluators determined that they operate 6,560 hours per year.

Conclusion 3 [Section 4.4.1]: Ex post bare pipe temperatures were lower than ex ante assumptions for all customer type-fluid type permutations. The hot water bare pipe temperature was found to be 136°F and 135°F at commercial and industrial facilities, respectively. The medium-pressure steam bare pipe temperature was found to be 292°F and 317°F at commercial and industrial facilities, respectively.

Conclusion 4 [Section 4.4.2]: Surrounding air temperatures exceeded the IOU assumption for all fluid type and customer sector segments. Evaluators determined that insulated hot water piping features an average surrounding air temperature of 81°F and 76°F at commercial and industrial facilities, respectively. Medium-pressure steam piping features an average surrounding air temperature of 79°F and 87°F at commercial and industrial facilities, respectively. IOU deemed savings values reflected a surrounding air temperature assumption of 75°F for all fluid segments.

[16] OSHA requires that pipes with a surface temperature of 140°F or greater that are "located within 7 feet measured from floor or working level or within 15 inches measures horizontally from stairways, ramps, or fixed ladders shall be covered with a thermal insulating material or otherwise guarded against contact."

Conclusion 5 [Section 4.5]: Hot water boilers at participating facilities feature a combustion efficiency 5% lower than assumed within IOU deemed savings values. Evaluators determined that hot water boilers feature a combustion efficiency of 78% on average, as compared with the IOU assumption of 82%. Evaluators determined no significant difference from the IOU assumption of 83% for medium-pressure steam boilers.

Conclusion 6 [Section 5.1]: The average diameter of insulated pipe was considerably higher for all customers and fluid types in the higher-diameter tier. The IOUs separated pipe insulation measures by diameter: less than 1” (0.7” average assumed in IOU calculations) and greater than or equal to 1” (1.7” average assumed in IOU calculations). Evaluators determined a greater average diameter for the latter tier, for all fluid-customer permutations: large commercial hot water (3.3” diameter on average), large commercial medium-pressure steam (1.9”), industrial hot water (2.3”), and industrial medium-pressure steam (2.7”). Greater-than-assumed diameter leads to higher savings per insulated linear foot.

Conclusion 7 [Section 4.7]: The evaluation team surveyed 49 participating customers and determined a NTGR of 0.49. This value is 20% lower than the current program assumption of 0.61 reflected in reported data.