CARB

Final Report

Quantifying Methane Emissions from Natural Gas Residential Customer Meters in California

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Acknowledgement

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Table of Contents

Table of Figures

List of Tables

Abstract

This study examines methane emissions from natural gas residential customer meters within the state of California (CA). Natural gas, which is comprised of mostly methane, leaks from various components of a residential meter set assembly (MSA). The objective of the project was to evaluate and measure fugitive methane emissions from residential MSAs across the state. The project determined the proportion of MSAs with leaks and identified the leaking component. The project also investigated differences in the frequency and size of leaks on MSAs between coastal and non-coastal regions. This project is expected to provide additional information to improve the accuracy of the reporting of total emissions for natural gas local distribution companies.

Executive Summary

Methane emissions from natural gas pipelines continue to be a topic of interest to federal, state, and local organizations. Accurately quantifying fugitive emissions from natural gas pipelines will assist in understanding total greenhouse gas (GHG) emissions to the atmosphere, and development of plans and regulations to reduce those emissions in the future. The main objective of this project was to quantify fugitive emissions from natural gas residential meter set assemblies (MSAs) in California. A study completed in 2009 by Operations Technology Development (OTD) looked at emissions from residential MSAs on a national level. Since that study was completed, new equipment has been developed that enables a more precise measurement of leak flow rates.

To quantify fugitive methane emissions from residential MSAs, field visits with the three largest utilities within the state of California were conducted. Those companies are Southern California Gas Company (SoCal Gas), Pacific Gas and Electric (PG&E), and San Diego Gas and Electric (SDG&E). The target sample size of MSAs to survey was 500 randomly selected from the three utilities, as follows: 200 MSAs from each SoCal Gas and PG&E, plus another 100 MSAs from SDG&E. This study focused only on single family residential MSAs and did not capture multifamily MSAs. Additionally, this study did not attempt to quantify vented emissions from MSA regulators. Those emissions are intentional and occur when the gas pressure exceeds a certain threshold.

A combustible gas indicator (CGI) was used to identify leaks at each MSA. Only utility-owned components were included in the MSA survey. This included components from the top of the service riser to the first fitting, usually a tee connection, beyond the outlet of the meter. All the various components that make up the MSA were counted, and leak locations were recorded.

This study defined a “leak indication” as a reading of greater than 100 parts per million (ppm) on the CGI. A “soap test” was performed on all leak indications. Utility companies classify a leak on MSAs based on the formation of a bubble using a soap test. A soap solution was sprayed onto all the MSA components with leak indications, and the presence of soap bubbles was recorded. The team quantified emissions from both leaks that showed bubbles, as well as those that only showed indications greater than 100 ppm on the CGI, but did not bubble.

The only stratification of the sample set was to examine any difference in leak occurrence or severity on MSAs that were in proximity to coastal waters. The hypothesis being that proximity to salt water may increase the likelihood of atmospheric corrosion which could increase the likelihood or severity of leaks. To accomplish this task, the sample population was split into coastal and non-coastal MSAs (inland). The team surveyed the respective percentage of MSAs that each company had within the boundary of coastal areas as defined by the California Coastal Commission's zoning. The data collected showed that there was not an increased number or severity of leaks within the coastal versus non-coastal zones. Sixteen percent of the MSAs surveyed in the coastal zone had leak indications with a mean leak rate of 3.68E-05 versus 35% in the non-coastal zone with a mean leak rate of 9.18E-05.

Component counts for each MSA were recorded within this study. Each leaking component was identified and recorded. Components included: elbows, tees, caps, plugs, meters, regulators, bushings, flanges, couplings, unions, and valves. Plastic bushings were found to be nearly four times as likely to leak as any other fitting on an MSA. Of the 500 MSAs surveyed, 166 leak indications were found, or 33% of the sample size. Ninety-four of the 166 leak indications were measured to determine the average leak rate. A bootstrap statistical analysis is an estimation of the sampling distribution using a random sampling method of the measured leak rates. The entire leak measurement data were used to perform the analysis, with sample replacement. The bootstrapped mean leak rate was 8.65E-05 standard cubic feet per minute (SCFM) with 1.24E-04 SCFM 95% upper confidence limit (UCL) and 5.46E-05 SCFM 5% lower confidence limit (LCL).

The fugitive methane emissions from residential MSAs within this project were compared to the results of the 2009 OTD study. However, this is not a direct comparison; as the 2009 study was at the national level and included multifamily MSAs, some vented emissions, and did not utilize the same equipment and detection thresholds as in this study. The emission factor developed in the 2009 study was 2.08 lb CH_4/meter-year. The emission factor for this study is 0.64 lb CH_4/meter-year, which represents a considerable reduction. Consideration should be given into further studying emissions from multifamily MSAs as well as vented emissions to provide a more direct comparison.

Objective

The objective of the project was to quantify fugitive methane emissions from natural gas residential customer meters in CA. The project focused on conducting field measurements to gain an improved understanding of methane emissions from residential customer meters. The project developed and validated a field method to plan, conduct, and analyze measurements of fugitive methane leaks at randomly selected sites from various types of customer meters used in the CA gas distribution system.

Background

Methane emissions from residential MSAs is one of the major contributors of total methane emissions for Local Gas Distribution Companies (LDCs). Current emission factors for these sources are based on the 1996 GRI/EPA study[1]. Due to the growing concern over climate change and the reduction of GHG emissions, federal and state organizations and LDCs have recognized the need for updated and more accurate emission estimation methodologies.

A study[2] in 2009 sponsored by Operations Technology Developed (OTD) measured leaks from residential, commercial and industrial customer meters from utility sites across the U.S. The OTD study surveyed 2,400 residential MSAs (single and multi-family) nationwide to develop the EF.

All the residential MSAs that were surveyed in the 2009 OTD study were diaphragm meters with a maximum flowrate usually below 300 standard cubic feet per hour (SCFH). For that study, a variety of different MSA types and manufacturers were found. The most common type was the American AC250, but many other manufacturers and models were included. Some reconditioned MSAs were also surveyed. No difference in leak rates was found from the reconditioned MSAs.

In the previous study it should be noted that no residential MSAs were found with a leak from the meter body. The most common place for a leak to occur on residential MSAs was on the threaded connections on the riser. Leaks were also found on other threaded connections on the MSA.

In addition to the 2009 study stated above, there have been several studies commissioned by OTD[3] and the Environmental Defense Fund[4] that have collected leak rate measurements in the field to improve methane emission estimates for the distribution sector.

Most of these studies have focused on the largest sources of emissions such as pipelines. GTI recently completed a project for CARB that quantified fugitive methane emissions from natural gas distribution pipelines in CA. While individual leaks from residential customer MSAs tend to be small in comparison to other sources, with so many MSAs located within CA, the overall quantity of emissions could be significant. A field measurement study is needed to quantify methane emissions from MSAs in CA.

1 GRI/EPA. 1996. Methane Emissions from the Natural Gas Industry, Volume 9: Underground pipelines. GRI/EPA.

2 Field Measurement Program to Improve Uncertainties for Key GHG Emission Factors for Distribution Sources, OTD-10-0002, November 2009

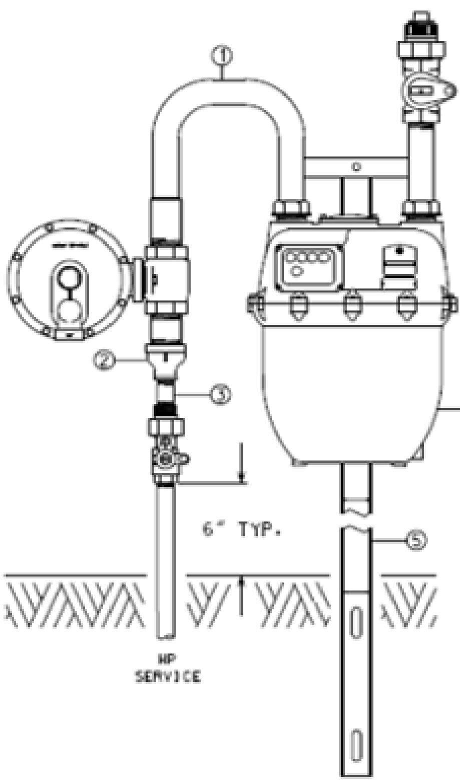
3 Farrag, Khalid, and Kristine Wiley. 2013. *Improving Methane Emission Estimates for Natural Gas Distribution Companies, Phase II - PE Pipes.* Des Plaines: Operations Technology Development.

4 Brian K. Lamb, Steven L. Edburg, Thomas W. Ferrara, Touche Howard, Matthew R. Harrison, Charles E. Kolb, Amy Townsend-Small, Wesley Dyck, Antonio Possolo, James R. Whetstone. 2015. *Direct Measurements Show Decreasing Methane Emissions from Natural Gas Local Distribution Systems in United States.* ACS Publications.

Measurements of Methane Emissions from Residential Meters-Methodology

Sampling Methodology Design

GTI designed a sampling plan that would allow for random selection of MSAs that maximized the number of samples that could be collected within the scope of the project. Initially, the plan was to select a random sample from all the residential customers of within SoCal Gas, PG&E, and SDG&E jurisdictions. After discussion with CARB and the utilities at the outset of the project, it was decided that it was best to focus the efforts on only single-family MSAs, as it would be challenging to account for the variations in the MSA for multifamily units within the budget of the project. Figure 1 shows a sketch of the typical MSA found at single family residential homes.



Legend:

1. Elbows
2. Flange
3. Treaded connections
4. Gas meter box
5. Support

Figure 1 – Typical Single-Family MSA

The target number of MSAs to include in the survey was 500 meters. GTI randomly surveyed 200 MSAs in SoCal Gas territory, 200 MSAs in PG&E's territory, and 100 MSAs in SDG&E's territory. Figure 2 below shows the location of each company's service territory.

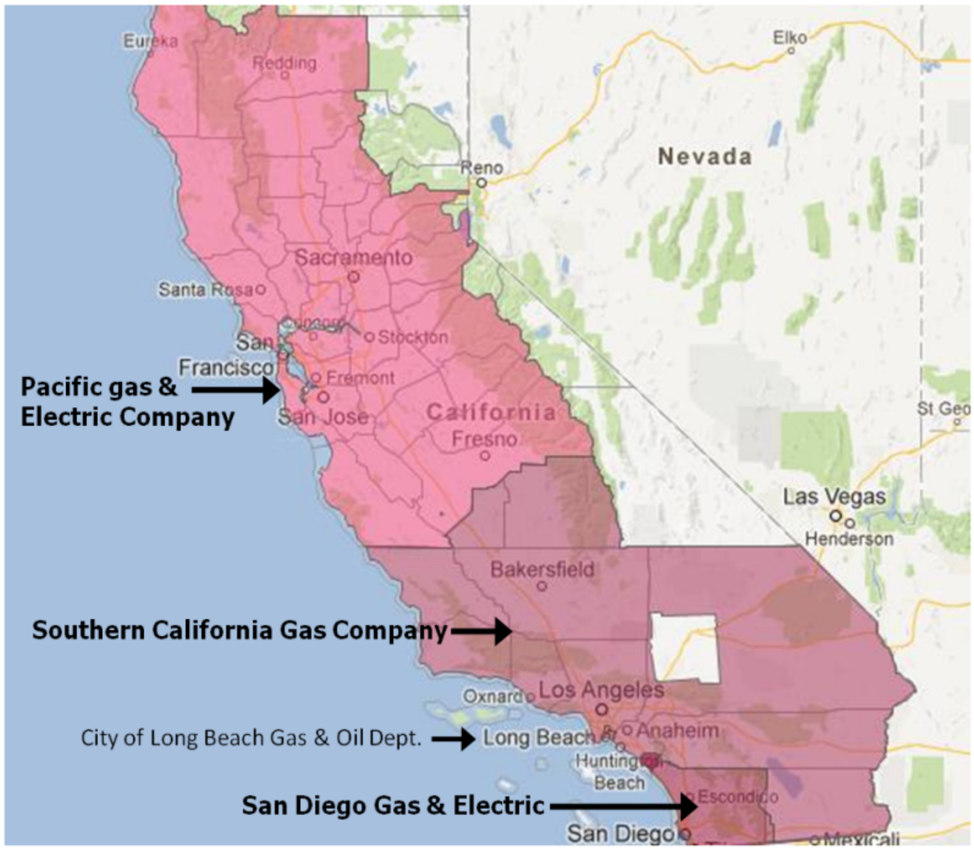


Figure 2 – CA Gas Utilities - Service Territories

GTI discussed the possibility of stratifying the sample set based on different parameters that may have an impact on the frequency or likelihood of occurrence of leaks. As such, we considered the possibility of stratifying the sample set based on age of the meter, meter manufacturer, and proximity to coastal waters. While the data may exist on the age of a meter itself, it is not necessarily indicative or representative of any maintenance that may have taken place on the meter set assembly. Over time, parts are changed out or maintained for a variety of reasons. As a result, meter age was not included in the stratification. Meter manufacturers were not included in the stratification either, as the previous 2009 OTD Study did not indicate a variation in the leakage between manufacturers from the body of the meters themselves and in fact showed no leaks from the meter bodies. As a result, it was decided to only stratify the sample set based on proximity to coastal waters. The hypothesis being that meter sets near salt water may be more prone to atmospheric corrosion and have a potentially higher leak rate. To do so, each utility company provided GTI with the percentage of meters that were located within the coastal boundary as defined by the California Coastal Commission's zoning[5]. Table 1 below shows the percentage of MSAs located within the coastal zone by utility.

Table 1 – Percentage of Coastal MSA by Company

Company	Percentage of Coastal MSAs	Target # of Coastal MSAs
PG&E	21%	42
SoCal Gas	2.39%	10
SDG&E	11.14%	11

Field data collection took place within the territory for each company. To maximize the number of MSAs surveyed, a zip code was randomly selected for each day of sampling. Within that zip code, an address was randomly selected as a starting point to begin the leak survey. The team then surveyed MSAs within proximity to each starting point.

Leak Survey and Measurement Methodology

To conduct the leak survey, a CGI device, commonly used by gas utilities for leak detection, the Sensit G2 Gold (see Figure 3) was used. This device provides readings in parts per million. GTI surveyed the entire MSA for leaks (excluding vented emissions). For this project, the MSA was only surveyed on the components that were owned by the utility company, which included all components from the top of the riser, to the first fitting beyond the outlet of the meter. The remaining components that were considered "customer owned", specifically those beyond the first fitting after the outlet of the meter, were not included in the survey. Additionally, it should also be noted that this study did not attempt to quantify or measure vented emissions from regulators. Vented emissions happen irregularly and by design. As a result, the regulator vent was never enclosed during the leak flow rate measurements. Leaks that existed at threaded connections or other locations on the regulator were captured.

Figure 3 – Sensit G2 Gold

5 California Coastal Commission, Retrieved: https://www.coastal.ca.gov/maps/czb/

GTI made component counts for each MSA. This information was collected to see what components were found to be leaking. This information included: elbows, tees, caps, plugs, meters, regulators, bushings, flanges, couplings, unions, and valves.

To conduct the leak flow rate measurements, GTI used a combination of the Hi-Flow Sampler and a cavity-based methane analyzer (Ultraportable Greenhouse Gas Analyzer, Los Gatos Research, San Jose, CA; LGR-UGGA). Each of these devices and the method in which they were used are described below.

Hi-Flow Sampler from Bacharach Inc.

The Hi-Flow Sampler (Bacharach, Inc, New Kensington, PA) is a portable, intrinsically safe, battery-powered instrument designed to determine the natural gas (CH_4) leak rate around various components such as pipe fittings, valve packings, and compressor seals found in natural gas systems. The Hi Flow Sampler samples at a high flow rate to capture all of the gas leaking from the component being examined along with surrounding air and the gas leak rate is calculated using Equation 1. The instrument automatically compensates for different specific gravity values of air and natural gas to accurately calculate methane flow rate (Bacharach 2015). For the purposes of this study, all of the samples collected were below the detection limits of the methane sensor within the device. The project team recorded the flow rate of the sample as measured by the Hi-Flow Sampler, but utilized the LGR-UGGA for the measurement of the methane concentration.

$$Leak = Flow \text{ x } (Gas\ sample - Gas\ background) \text{ x } 10^{-2} \qquad \text{Eq. 1}$$

where:

Leak = rate of gas leakage from source (scfm)

Flow = sample flow rate (scfm)

Gas sample = concentration of gas from leak source (%)

Gas background = background gas concentration (%)

Figure 4 – View of the Hi Flow Sampler device

Los Gatos Research Ultraportable Greenhouse Gas Analyzer

The recent concerns being raised about the ability of the Hi Flow sampler to properly measure CH_4 concentrations and the relatively high detection limit of the sampler has led GTI to pair sensitive analyzers with the Hi-Flow sampler to more precisely determine the concentrations for leak flow rate determination. The instrument that GTI used in-line with the Hi Flow sampler to measure concentrations is the LGR-UGGA. The LGR-UGGA is a high speed/high sensitivity instrument that uses off-axis integrated cavity output spectroscopy. The instrument is capable of parts-per-billion precision and across a wide range of concentrations (0 -100,000 ppm). The analyzer was checked using CH_4 calibration gases between 15 ppm to 2.5% volume CH_4 in the lab prior to deployment. The use of the LGR-UGGA will provide greater insight into the flow rates for very small leaks.

For leaks that were below the concentration detection limit of the Hi Flow sampler, which in this study, was all of them, the concentrations from LGR-UGGA were used to calculate the flow rate with the following equation:

$$Leak = Flow \times (Gas\ sample - Gas\ background) \times 10^{-6} \qquad Eq.\ 2$$

where:

Leak = rate of gas leakage from source (scfm)

Flow = sample flow rate (scfm)

Gas sample = concentration of gas from leak source (ppm)

Gas background = background gas concentration (ppm)

Figure 5 – LGR-UGGA Methane Analyzer and Battery Pack

Field Measurement Procedures

The field tests were performed at residential MSAs and consisted of performing the measurements as follows:

1. Leak Survey of the MSA

a) Complete a leak survey of all the components of the MSA that are owned by the utility (from top of riser to the first fitting beyond the outlet of the meter). Identify and record any leak indications on the CGI that read greater than 100 ppm. Previous field testing showed that concentrations less than 100 ppm as detected by the CGI were difficult to quantify accurately because the methane enhancement in the diluting air flow was insignificant. In addition, setting a cutoff threshold for quantifying point leaks helped to streamline the field visit process so that the most significant leaks were captured at each site.

b) below shows an example of the CGI being used to identify the leak.

c) Conduct a soap test. The MSAs that had indications on the CGI greater the 100 ppm were sprayed with a soap solution to identify the source of the leak. GTI recorded if a bubble formed or not. It is possible for gas molecules to escape through pipe and fitting connections, but not at a significant enough flow rate to form bubbles within a soap solution. If bubbles are formed, utility companies use this as the method to classify whether it is a leak. For the purposes of this study, GTI quantified a subset of leak indications greater than 100 ppm, whether a soap test formed bubbles or not.

Figure 6 – The CGI used to identify the leak

Figure 7 – Example of Soap Bubbles on Leaking Valve

2. Hi-Flow and LGR Measurements of the Leak Rate

a) The leak rate measurements were performed by enclosing the MSA with a cover/bag and measuring the methane leak rate using the Hi-Flow device and the LGR-UGGA. As mentioned previously, the regulator vent was not enclosed in the bag to ensure vented emissions were not included in the measurement.

b) Each measurement was taken for a period of 2 minutes and the test was repeated 3 times for each leak. The three leak rates were recorded and averaged.

Figure 8 – Example of meter measurements with the Hi-Flow device and LGR-UGGA

Summary of Field Tests

SoCal Field Tests

The field survey and measurements were performed in randomly selected MSAs within SoCal Gas's territory in August of 2017. Two hundred MSAs were surveyed. Ninety MSAs had leak indications (readings above 100 ppm on the CGI). Of the 90 leak indications, 33 of those leaks showed bubbles on a soap test. Ten MSAs were surveyed in the coastal region and 3 of those had leak indications. Two of the three coastal indications showed bubbles on a soap test. Table 2 provides a summary of the leaks detected in each utility. A CGI was used to indicate a leak greater than 100 ppm that was subsequently confirmed with a soap test.

SDG&E Field Tests

The field survey was conducted in SDG&E's territory in January of 2018. The measurements were performed at randomly selected locations within SDG&E's territory. The target number of MSAs for the survey was 100 and 100 MSAs were surveyed. Of the 100 MSAs surveyed, 21 leak indications were identified. Fifteen of those leaks showed bubbles on a soap test. Eleven MSAs were surveyed in the coastal zone, and no leak indications were identified on those MSAs. Table 2 provides a summary of the leaks detected in each utility. A CGI was used to indicate a leak greater than 100 ppm that was subsequently confirmed with a soap test.

PG&E Field Tests

The field survey was conducted in PG&E's territory in February of 2018. The measurements were performed at randomly selected locations with PG&E's territory. The target number of MSAs for the survey was 200 and 200 MSAs were surveyed. Of the 200 MSAs surveyed, 55 leak indications were identified. Twenty-nine of those showed bubbles on a soap test. Forty-two MSAs were surveyed in the coastal zone, and 7 leak indications were found. Of the 7 coastal zone leak indications, 6 of them showed bubbles on a soap test. Table 2 provides a summary of the leaks detected in each utility. A CGI was used to indicate a leak greater than 100 ppm that was subsequently confirmed with a soap test.

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Table 2 – MSA Leaks by Utility Company

Leak Type/Indication	SoCal Gas	SDGE	PGE	Combined	% of Total MSAs Surveyed
Bubbles	33	15	29	77	15%
No Bubbles	57	6	26	89	18%
No Leak Indications	110	79	145	334	67%
Total	**200**	**100**	**200**	**500**	**100%**

Results

This study surveyed 500 MSAs of residential single-family homes within CA. GTI worked directly with the utility companies to coordinate field measurements of randomly selected residential meters. GTI stratified the sample set to include a representative sample size of MSAs contained within the coastal zone as defined by the California Coastal Commission. The total number of leak indications (a reading of greater than 100 ppm) that were identified within the study was 166, 33% of the MSAs surveyed. Gas utility companies use a soap test to classify whether an indication is a leak. If bubbles are formed on a soap test, then they classify it as a leak. If bubbles are not formed, then it is not classified as a leak. Of the 166 leak indications identified in this study, 77 indications formed soap bubbles or 15% of the total MSAs surveyed. It was suspected that MSAs within the coastal zone may be more susceptible to leaks than those in non-coastal regions because of a potentially higher likelihood of atmospheric corrosion, however the test results do not support this. The data collected within this study showed 16% of MSAs had leak indications in coastal zones versus 36% in non-coastal zones.

GTI conducted a bootstrap analysis of the leak rates identified in this study. For all the leaks identified, both leaks that bubbled on a soap test and those indications that did not, the mean leak flow rate measured was 8.65E-05 SCFM.

The emissions from residential gas MSAs surveyed within this project were compared to the results of the 2009 OTD study. It is important to understand that this is not a direct comparison, as the 2009 study included multi-family MSAs, some vented emissions, and did not utilize the same equipment and detection thresholds as in this study. In addition, the 2009 study excluded measurement of emissions resulting from leaks with no soap bubbles. The emission factor developed in the 2009 study was 2.08 lb CH_4/meter-year. The emission factor from this study is 0.60 lb CH_4/meter-year, which represents a considerable reduction. Further studying emissions from multifamily MSAs as well as vented emissions would be needed to provide a more direct comparison.

All the components that made up the MSAs within this project were tracked, as well as those components found to be leaking. A vast majority of leaks were found on threaded connections of the MSAs. Plastic insulating bushings on threaded connections stood out as having a significantly higher likelihood of occurrence of leaks than any other component of the MSAs. Thirty-one percent of the leaks detected in the study were on plastic insulating bushings (52 leaks out of 166 total leaks detected).

Analysis and Discussion

During this study, GTI surveyed 500 single family residential MSAs within CA. One hundred and sixty-six of those MSAs had leak indications above 100 ppm. The raw leak data can be found in the Appendix to this report. The team measured flow rates on 94 of the 166 leak indications detected. Fifty of those leak rate measurements were on leaks that showed bubbles and 44 of the measurements were on leaks that did not show bubbles. A bootstrap analysis on the 94 leak rate measurements was conducted with 10,000 resamples with replacement to enable the building of a representative distribution of the population (see (Bradley Elfron 1994) for explanation of the bootstrap method). Table 3 below provides the output of the bootstrap analysis that was conducted on the 94 leak rate measurements and were also broken down by each utility. The table below also shows a 90% confidence interval (CI) with the 95% upper confidence limit (UCL) as well as the 5% lower confidence limit (LCL). The mean leak rate for the four the combined companies was 8.65E-05 SCFM with 1.24E-04 SCFM UCL and 5.46E-05 SCFM LCL.

Table 3 – Bootstrap Analysis of Leak Data

	Company	Combined (PGE, Socal, SDGE)			PGE			Socal			SDGE		
	Leak Category	Bubbles and No Bubbles	Bubbles Seen	No Bubbles Seen	Bubbles and No Bubbles	Bubbles Seen	No Bubbles Seen	Bubbles and No Bubbles	Bubbles Seen	No Bubbles Seen	Bubbles and No Bubbles	Bubbles Seen	No Bubbles Seen
Bootstrap of Mean	Number of Physical Observations	94	50	44	33	19	14	40	17	23	21	14	7
	Number of Resamples with Replacement	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
	Mean	8.65E-05	1.10E-04	5.89E-05	5.79E-05	4.79E-05	6.99E-05	5.68E-05	9.08E-05	3.02E-05	1.87E-04	2.17E-04	1.27E-04
	5% LCL of Mean	5.46E-05	6.33E-05	2.45E-05	1.81E-05	1.60E-05	7.72E-06	3.63E-05	5.93E-05	8.46E-06	7.80E-05	7.29E-05	9.57E-06
	95% UCL of Mean	1.24E-04	1.72E-04	1.00E-04	1.08E-04	9.28E-05	1.81E-04	7.92E-05	1.24E-04	5.65E-05	3.25E-04	4.23E-04	2.50E-04
	Max	2.02E-04	2.72E-04	1.78E-04	1.85E-04	1.82E-04	3.57E-04	1.18E-04	1.66E-04	1.16E-04	6.10E-04	7.86E-04	4.62E-04
	Min	2.78E-05	3.73E-05	3.64E-06	7.89E-06	7.97E-06	1.66E-06	1.66E-05	3.02E-05	2.07E-06	2.71E-05	1.72E-05	2.31E-06

Figure 9 shows a plot of the mean leak rate with the error bars representing the 90% CI. The plot shows the combined leak rates, as well as the leak rates by utility company. The bootstrap analysis properly captures the asymmetry of the CI for some of the data sets, such as the leak indications without bubbles within the SoCal sample set.

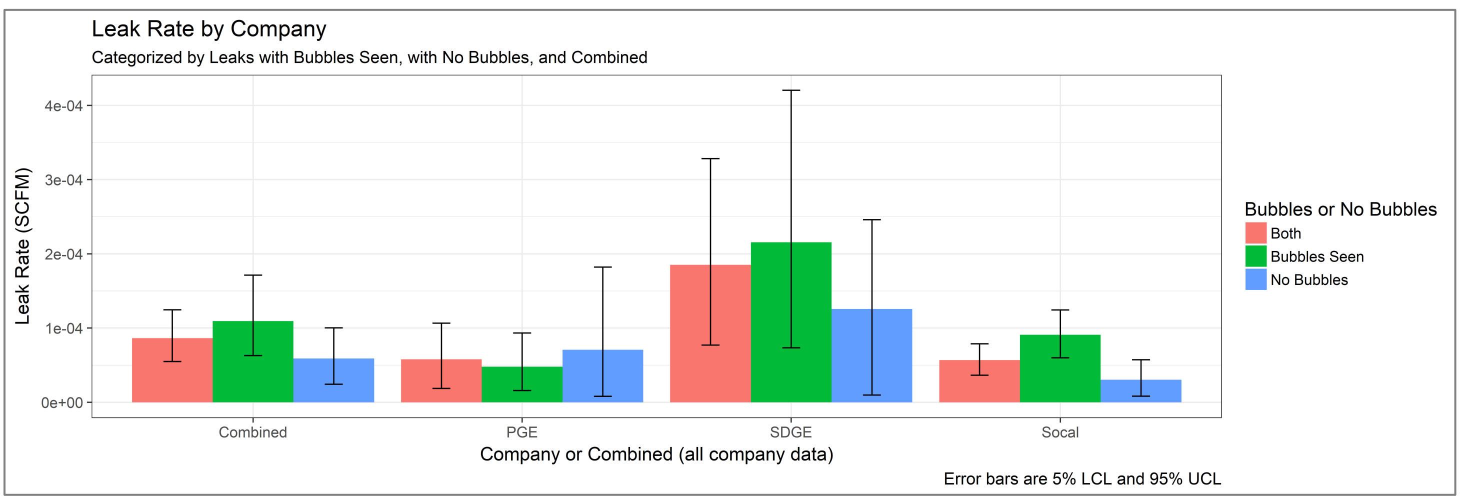


Figure 9 – Leak Rate by Utility Company – Bubbles, No Bubbles, and Combined Data

Figure 10 shows a histogram along with a density plot overlay of the mean leak rate. Similar to other methane emission measurement studies on the natural gas industry, the sample set was not normally distributed.

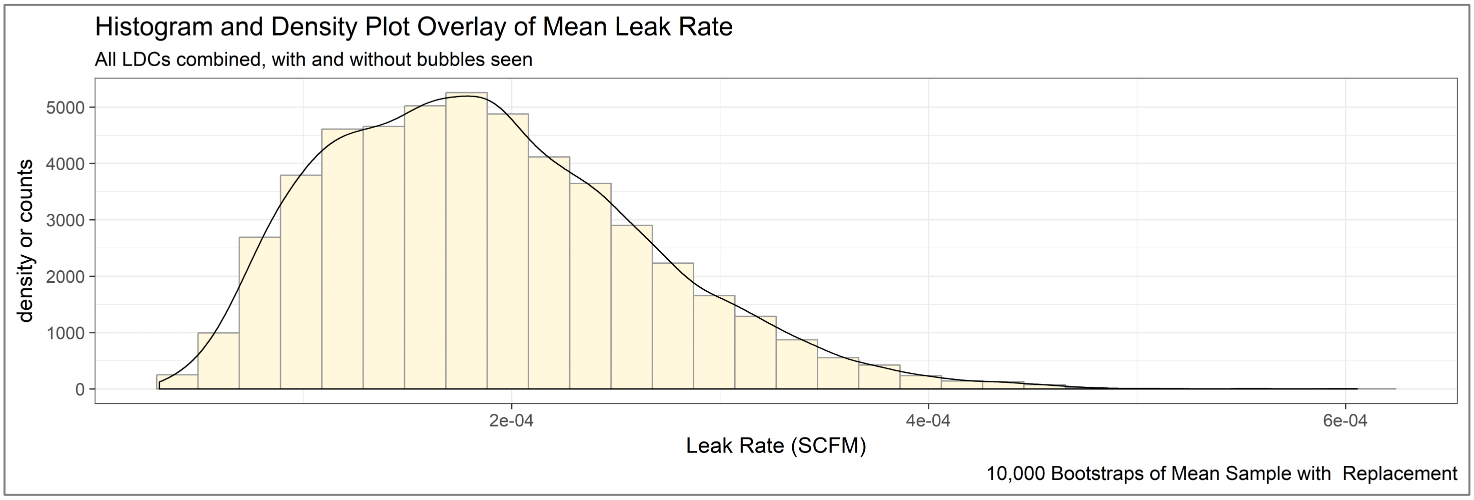


Figure 10 – Histogram and Density Plot Overlay of Mean Leak Rate

A comparison of the company specific sample sets was made to determine their difference from one another. Figure 11 shows a depiction of the analysis of variance (AOV) difference of means across the three companies. For this study, it was assumed that a p-value statistics of 5% or less would be an indication that the sample sets were statistically different. If the p-value was greater than 5%, we assume the sample sets are statistically similar. The 95% CIs for the difference of means plot tells us the likelihood of the sets of data being statistically similar. In Figure 11 below, the middle row shows the difference of means between SoCal Gas and PG&E is nearly 0, meaning the sample sets are statistically the same. That is the mean leak rates between the two utilities are practically the same. When SDG&E is compared to both PG&E and SoCal, it falls just inside, and just outside respectively of the 90% CI, indicating the sample sets are likely not statistically the same. There were fewer samples recorded in SDG&E's territory and it is possible that additional data could influence the results shown.

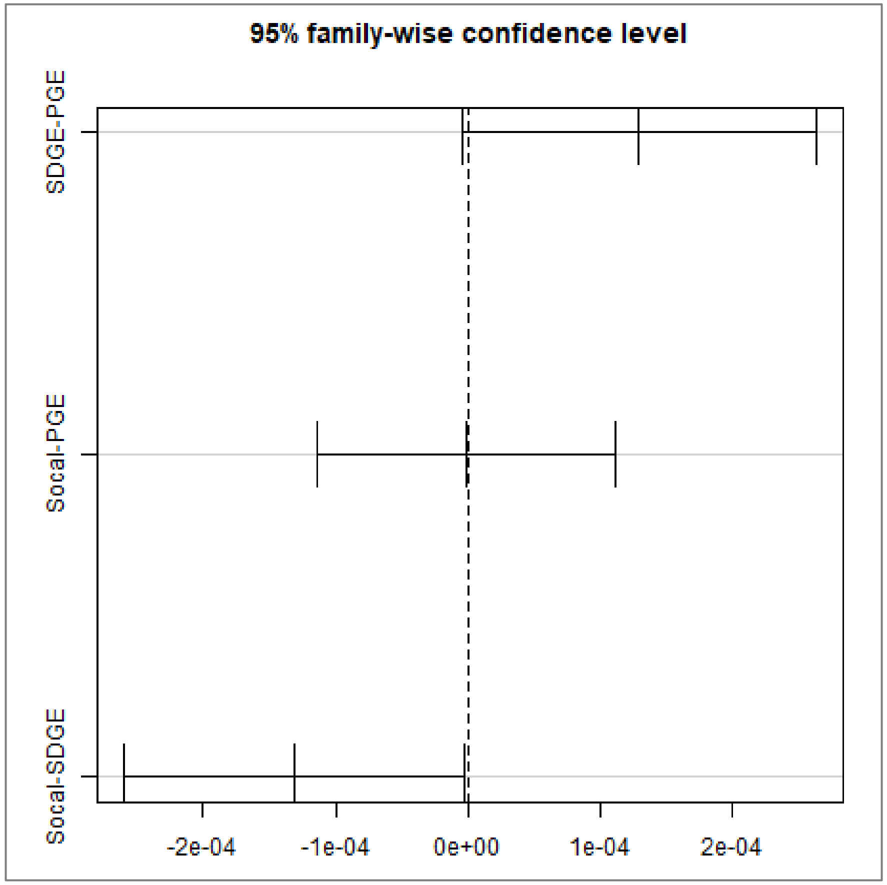


Figure 11 – AOV Difference of Means in Mean Leak Rate (SCFM) Across Company "Family"

Coastal vs. Non-Coastal MSAs

As part of this study, one mode of stratification of the sample set was to compare coastal vs. non-coastal MSAs. Coastal MSAs have greater exposure to salt in the air given the proximity to the sea. This exposure could potentially increase the likelihood of atmospheric corrosion that may cause gas leaks from the threaded components. However, Table 4 below shows that the frequency of leaks encountered in the coastal region was less than in non-coastal regions. A bootstrap analysis of the coastal and non-coastal leak rates was conducted. As shown in Figure 12 and Table 5, the leak flow rates in the coastal region were found to be lower than those in the non-coastal regions. While Figure 14 shows that the median leak rates, where 50% of the data points either below or above the value, from both locations are similar, a difference of means analysis was conducted to determine if the data sets were statistically different from one another. The percent of resampled pairs that produced means that differed by as much as 5.47E-05 (the sample set difference) was 19.66%. As discussed earlier and based on p-value statistics, this suggests that the coastal and non-coastal data sets are statistically similar. Figure 13 shows a histogram of the difference of means. A secondary analysis was performed to validate that the two data sets are not statistically different.

Table 4 – Frequency of Leak Indication – Coastal vs. Non-Coastal

Region	No Leak Indications	Leak Indications	Percentage with Leak Indications
Coastal	63	10	15.9%
Non-Coastal	437	156	35.7%
Total	**500**	**166**	**33.2%**

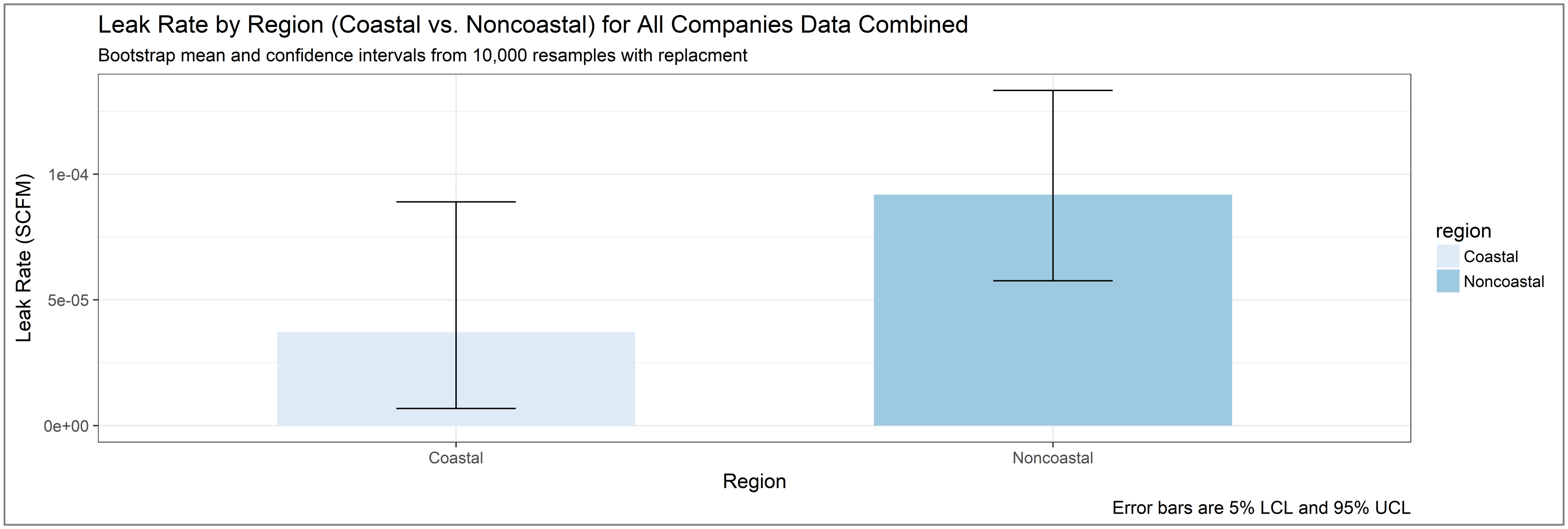


Figure 12 – Comparison of Leak Rate by Region

Table 5 –Mean Leak Rate – Coastal vs Non-Coastal MSAs

Bootstrap with all companies' data combined			
Leak Location Category	**Mean Leak Rate (scfm)**	**UCL**	**LCL**
Coastal	3.680E-05	8.900E-05	6.770E-06
Noncoastal	9.180E-05	1.330E-04	5.770E-05

Notes - 10,000 resamples with replacement

The percent of resampled pairs that produced means that differed by as much as 5.476307e-05 was **19.66 %.**
The (0.05, 0.95) confidence interval for the bootstrap sample of means of the pair: -0.0001521167, 8.423026e-05

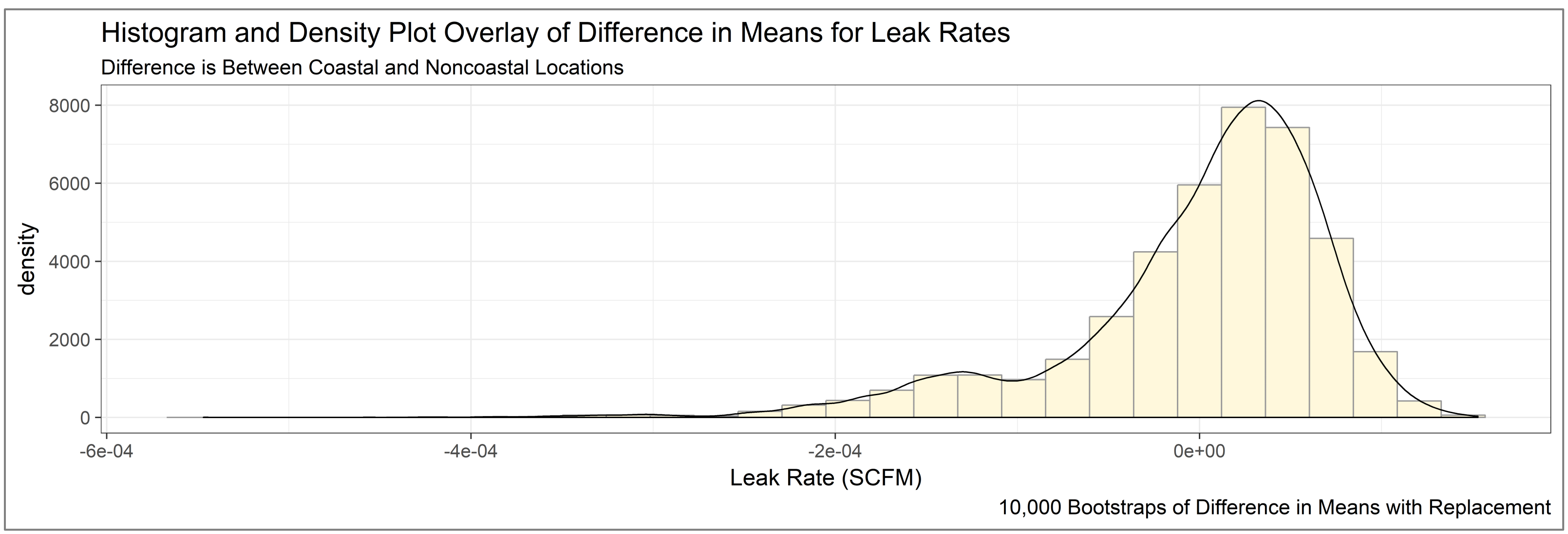


Figure 13 – Histogram and Density Plot Overlay of Difference in Means for Leak Rates

Table 6 shows the results of a Kolmogorov-Smirnov (K-S) test on the difference of means in the two sample sets which indicates that the sample sets are statistically similar. The Kolmogorov-Smirnov test is preferred for a couple reasons when performing a testing of two samples for the same distribution. First, it is a non-parametric test so one does not need to make any assumptions regarding the underlying distributions, i.e. it works for all distributions. Second, it checks the location, dispersion, and shape of the populations, based on the samples themselves. If these characteristics disagree then the test will detect that, allowing one to conclude that the underlying distributions are different.

Table 6 – K-S Test of Difference of Means – Coastal vs. Non-Coastal Leaks

statistic.D	0.25794
p.value	**0.56875**
alternative	two-sided
method	Two-sample Kolmogorov-Smirnov test

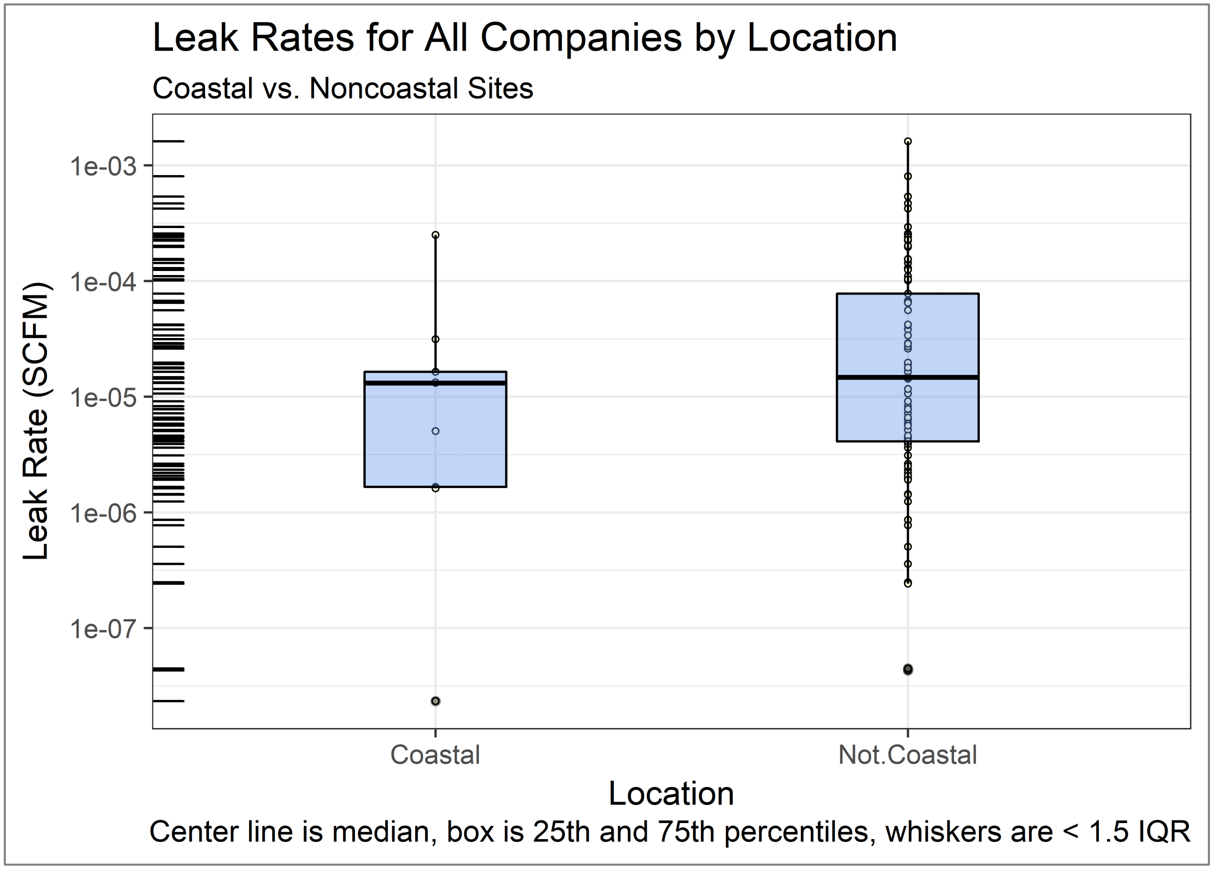


Figure 14 – Leak Rates for All Companies – Coastal vs. Non-Coastal

Soap Leak Test

As mentioned previously in this report, utility companies will identify if they have a leak by using a soap test. If bubbles form on a leak indication, companies will classify that as a leak. If they do not form from an indication, then they do not classify it as a leak. For this study, methane was measured from all leak indications with or without bubbles from a soap test. Figure 15 below shows a box and rug plot of both types of leaks. As expected, the leak rate on leaks that produced bubbles was higher than that of those leak indications that did not show a bubble.

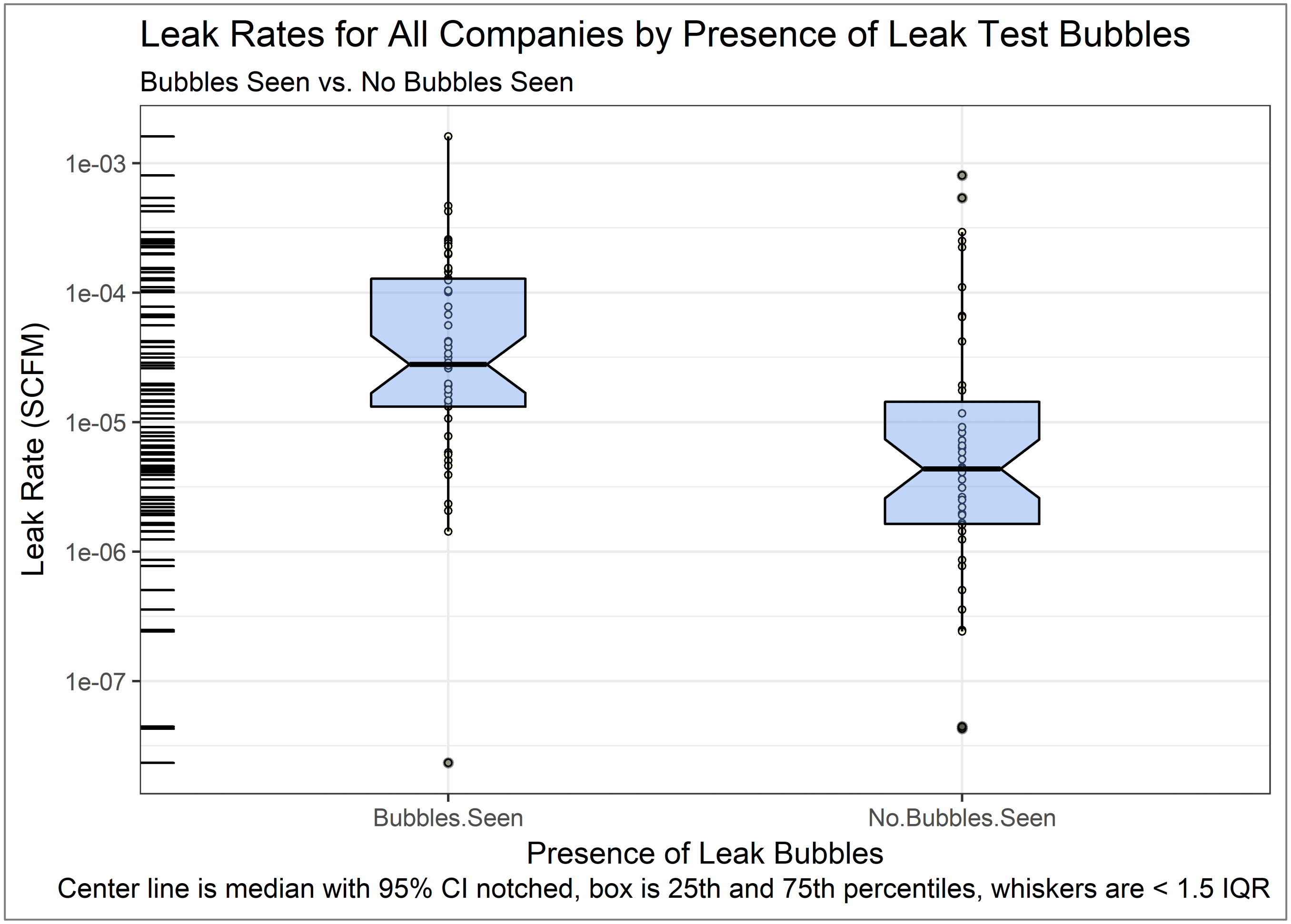


Figure 15 – Leak Rate for All Companies by Presence of Leak Test Bubbles

Table 7 above shows the contributions to the total emissions from the MSAs surveyed in this study of leaks that showed bubbles, as well as those indications that did not bubble. As can be seen in the table, leaks with bubbles accounted for 46% of the leaks and contribute to 62% of the emissions from residential meters. The leaks that did not bubble, but had indications greater than 100 ppm, accounted for 54% of the leaks, but contribute to 38% of the emissions.

Table 7 – Contribution to Measured Emissions: Bubbles vs. No Bubbles

Leak/Indication Type	Number of Leaks/Indications	% of Total Leaks/Indication	Bootstrapped Mean Leak Rate (scfm)	Emissions Per Year (lb CH_4/year)	% of Total Emissions Contribution
No Bubbles	89	54%	5.89E-05	123	38%
Bubbles	77	46%	1.10E-04	199	62%

Leak Rates by Company

The bootstrapped leak rate data for each individual company is plotted in Figure 16 which shows that the median leak rate for SoCal Gas and PG&E were very similar. SDG&E had a higher median leak flow rate than both SoCal and PG&E. The sample size for SDG&E was also smaller than that of PG&E and SoCal Gas. The data for the plot below can be seen in Table 3 – Bootstrap Analysis of Leak Data above.

Figure 17 shows a box and rug plot of the data broken out by company and by bubbles versus no bubbles. While the distribution varies, the mean leak rates for no bubbles are quite similar across the three companies.

Figure 18 shows a box and rug plot of the coastal vs non-coastal leaks, as well as bubbles vs. no bubbles. As can be seen, no coastal leaks were identified in SDG&E's territory.

While the mean leak rate of leaks that did not show bubbles were lower than those with bubbles, Figure 18 also shows there were a number of samples with no bubbles that had corresponding leak rates that were larger than even the median leak rates shown in Figure 17.

The leak rates by company for bubbles vs. no bubbles are shown in the jittered scatter plot in Figure 19. This plot reveals the variation in the data and that there is not a consistent trend with regards to samples that had no bubbles having a lower associated leak rate versus samples with bubbles having a larger associated leak rate.

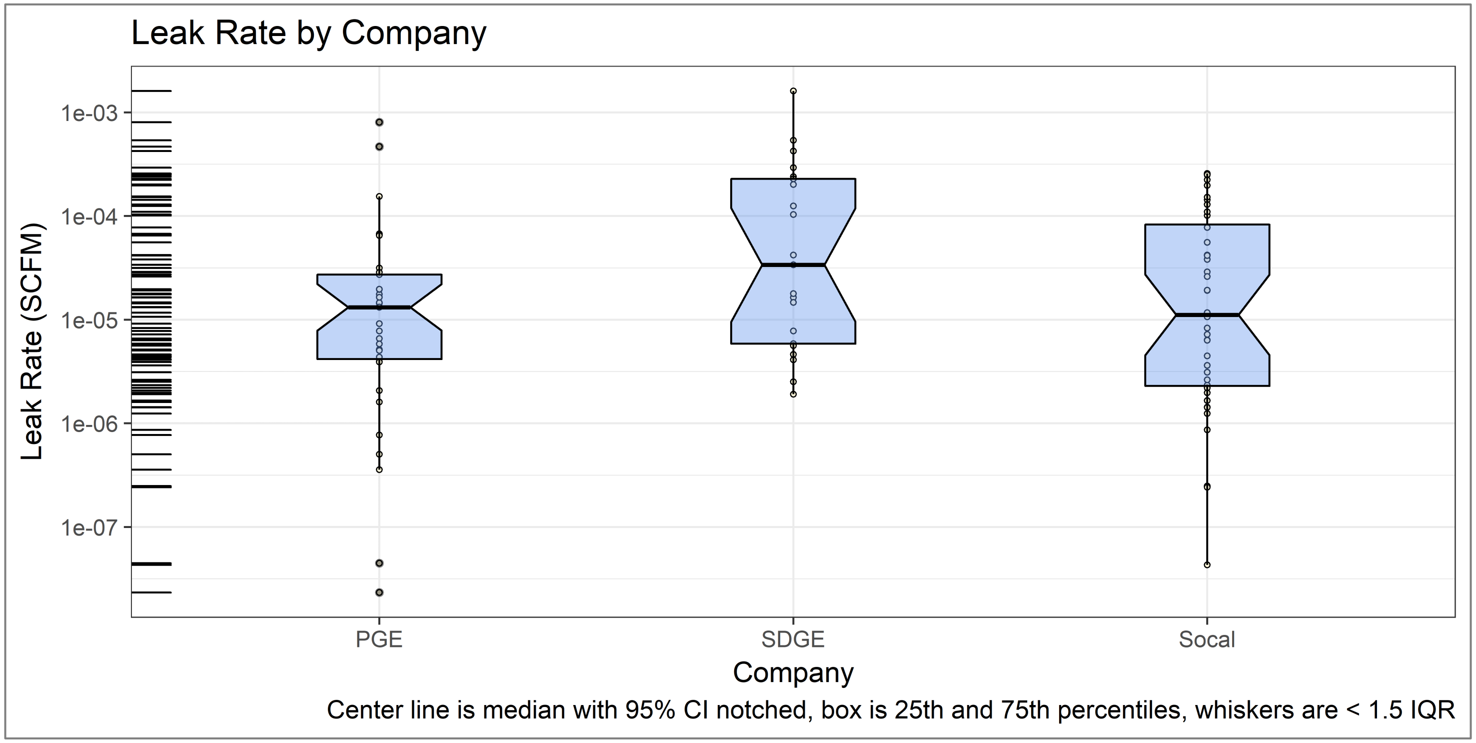


Figure 16 – Leak Rate by Company

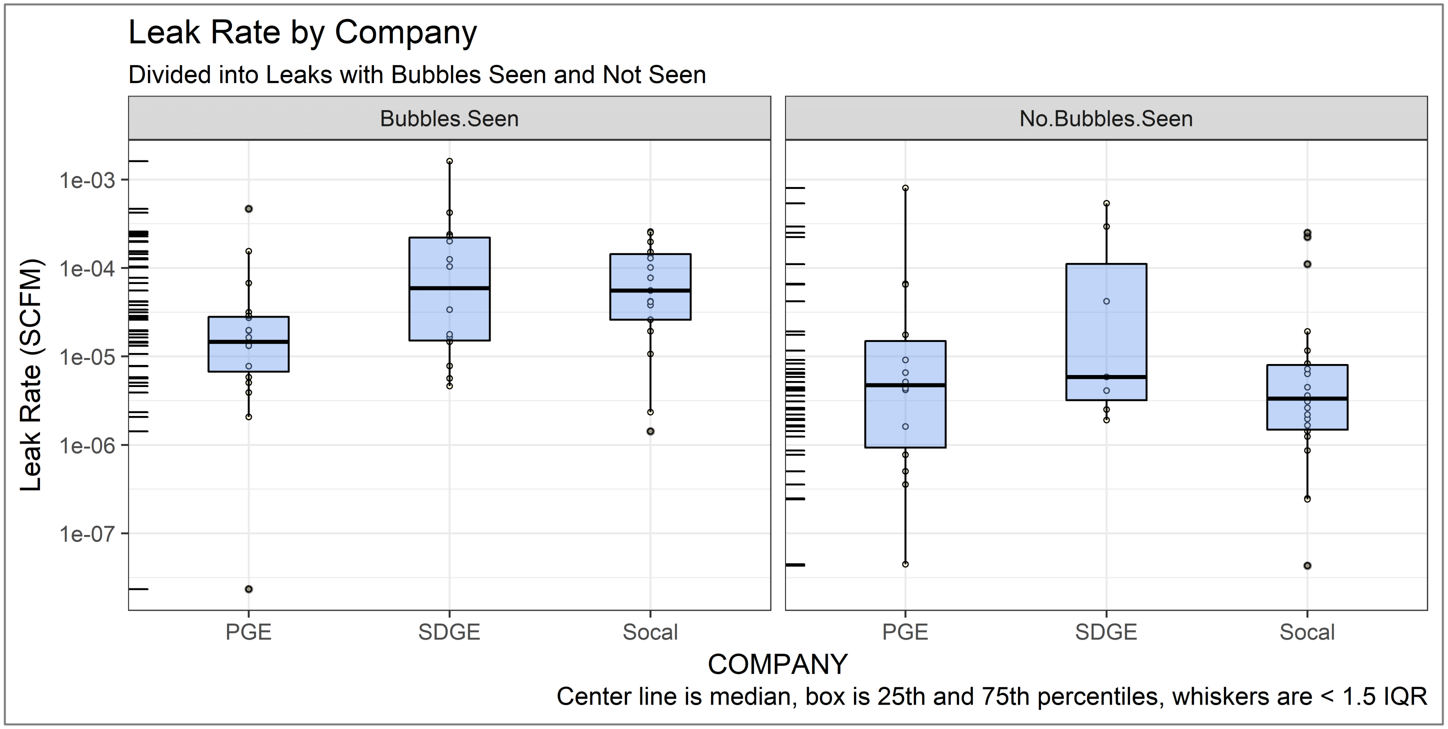


Figure 17 – Leak Rate by Company – Bubbles vs. No Bubbles

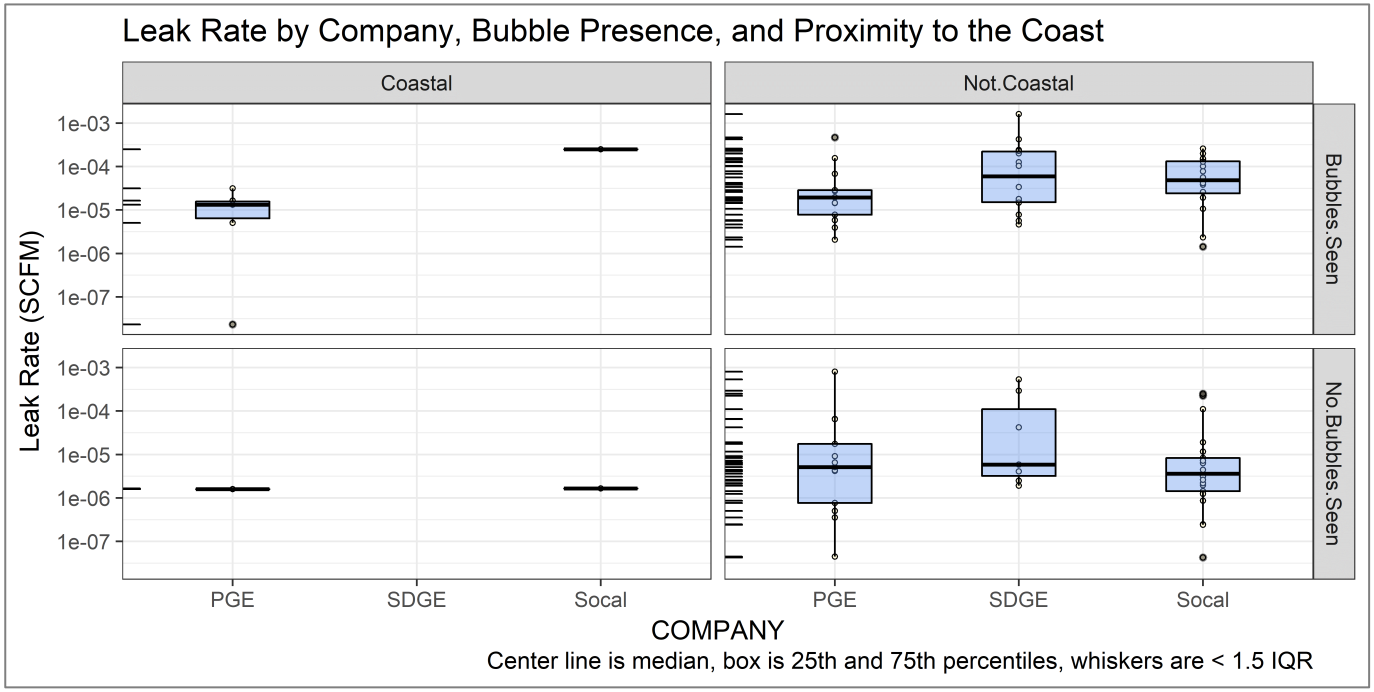


Figure 18 – Leak Rate by Company – Bubbles vs. No Bubbles – Coastal vs. Non-Coastal

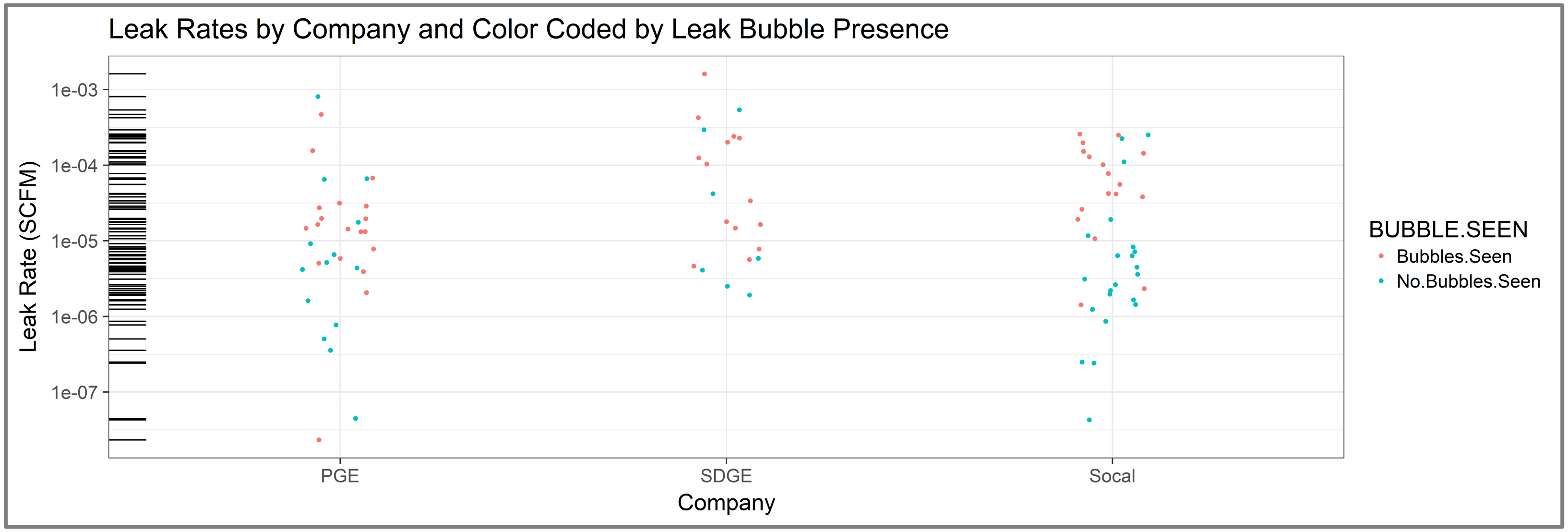
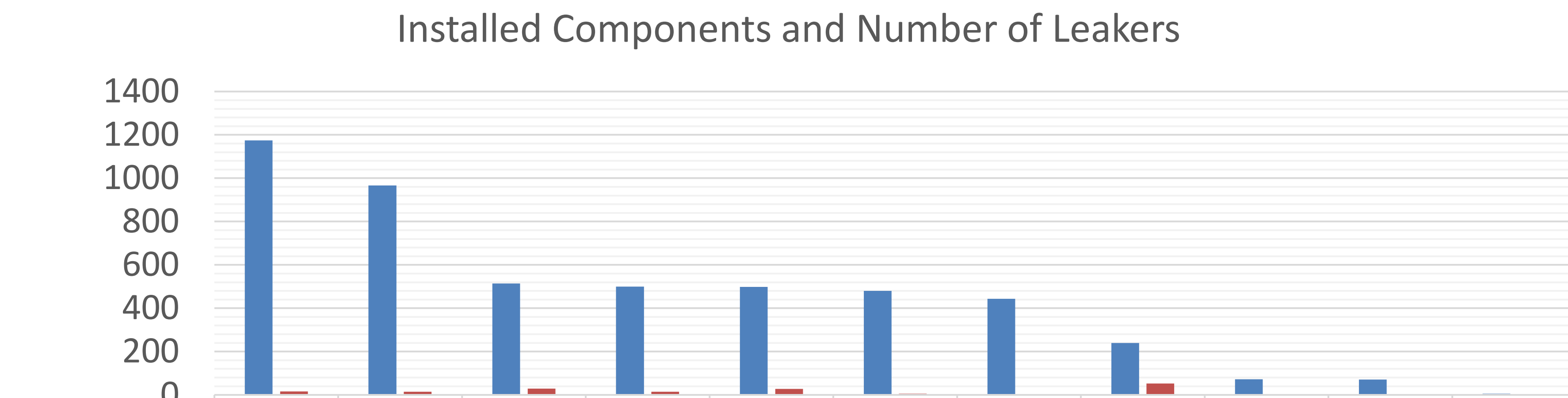


Figure 19 – Scatter Plot of Leak Rates by Company – Bubble vs. No Bubble

MSAs Component Analysis

A component count was performed on each MSA surveyed within this project as well recording the specific leaking components. Figure 20 shows the total number of installed components encountered during this study, along with the total number of leaks.



	Elbows	Tees	Valves	Meters	Regulators	Plugs	Flanges	Bushings	Couplings	Unions	Caps
Total Installed	1175	967	514	500	498	480	443	240	72	71	6
Number Leaking	16	14	29	15	28	6	0	52	3	3	0

Figure 20 – Total Number of Installed Components and Number of Leaking Components

Figure 21 shows the percentage of each component that was found to be leaking during this study. As can be seen, bushings had the highest number of leaks, as well as the highest percentage of leaks encountered. They were nearly 4 times as likely to be found leaking as any other component. It should be noted they are not necessarily found on all MSAs, and there is usually only one per MSA. Bushings are a threaded connection made of plastic material. They are commonly installed within a MSA to provide electrical isolation from the house. On steel service lines, there is commonly cathodic protection of some form in place to protect the service from corrosion. The bushings are installed to prevent any current or fault from the house from interfering with the cathodic protection of the service line. Bushings are not the only means of providing electrical isolation. There are other fittings, such as some valves, that have rubber gaskets that provide similar electrical isolation.

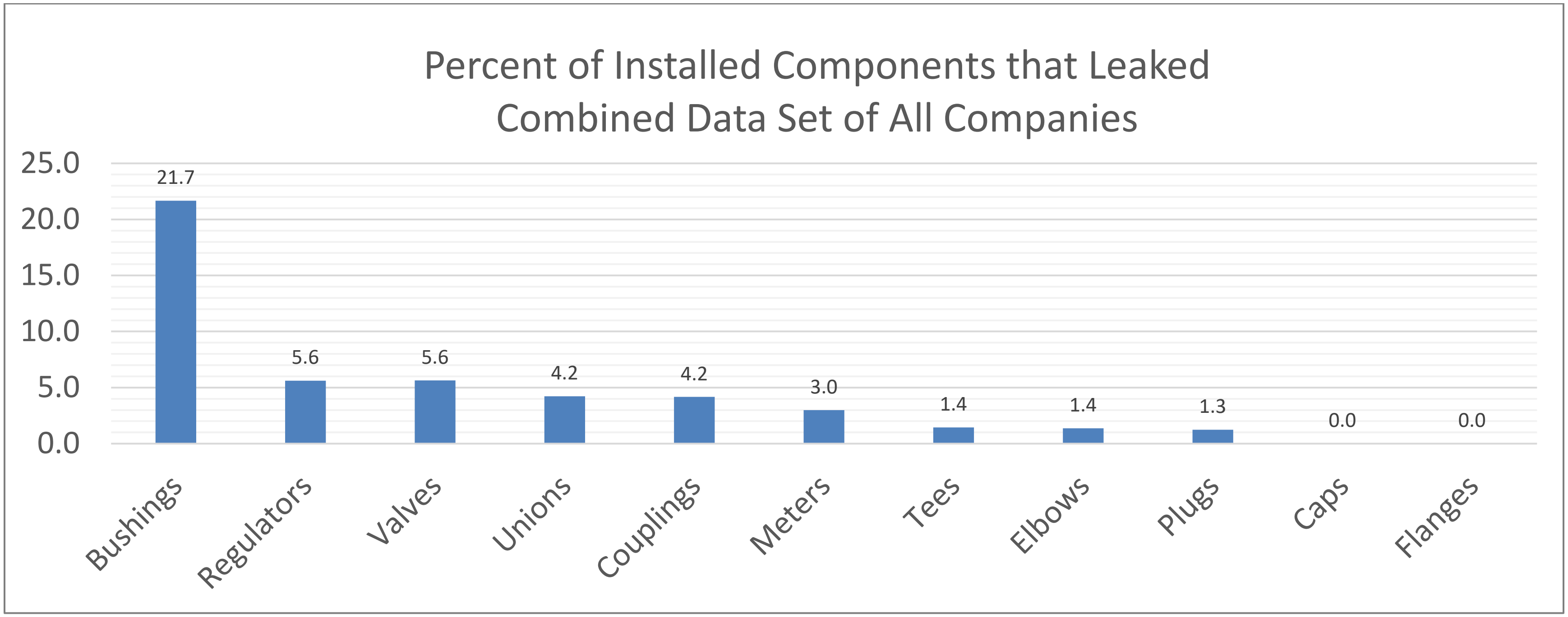


Figure 21 – Percent of Installed Components that Leaked

Comparison to the 2009 OTD Study

A national study conducted by OTD in 2009 measured methane emissions from customer MSAs which included industrial, commercial and residential MSAs. The scope of this project was focused on measuring fugitive methane emissions only from single family residential MSAs in CA. Multifamily MSAs, duplexes, townhomes, apartment buildings, etc., were not included in this study, but were included in the OTD 2009 study. Multifamily MSAs can have more connections and fittings than your typical single family MSA, although potentially fewer on a per meter basis, and as a result may have a different likelihood of a leak occurrence. The technology used for the leak detection and quantification were different as well. There were some vented emissions from a meter pressure regulator encountered in the 2009 study, which were not included in this study. It appeared vented emission were small, but no attempts were made to separate them out from the total. Recognizing that the studies differed in scope and sample design, a comparison of the derived emission factors was conducted. Table 8 below was taken from the 2009 OTD Study and shows the emission factor calculated.

Field Survey	No. Fugitive Leaks Identified	No. Vented Emissions Identified	Total Natural Gas (ft^3/year)	Total Methane Emissions (lb CH_4/year)	No. Residential Meters Surveyed	Residential Meter Emission Factor (lb CH_4/meter-yr)
Test A	5	1	34,073	1,344	288	4.67
Test B	4	2	5,950	235	637	0.37
Test C	1	0	2,637	104	201	0.52
Test D	27	0	72,927	2853	420	6.79
Test E	3	2	2,398	94	492	0.19
Test F	2	4	9,203	371	362	1.02
Total	**42**	**9**	**127,188**	**5,001**	**2,400**	**2.08**

Table 8 – Residential Meter Survey Results and Emission Factors – OTD 2009 National Study[6]

Applying the same methodology used in the OTD 2009 study Table 9 shows the CA specific residential MSA emission factor from this study.

6 Field Measurement Program to Improve Uncertainties for Key GHG Emission Factors for Distribution Sources, OTD-10-0002, November 2009

Table 9 – Residential Meter Survey Results and Emission Factor - This study

Number of Leaks Identified	Bootstrap Mean (scfm)	Total Methane (ft^3/year)	Total Methane Emissions (lb CH_4/year)	Number of Residential Meters Surveyed	Residential Meter Emission Factor (lb CH_4/meter-yr)
166	8.65E-05	7547	319	500	0.64

As can be seen, the frequency of leaks in this study (166 leak indications per 500 MSAs surveyed) was much higher than that of the 2009 study (42 leaks per 2,400 MSAs surveyed). However, the leak rate measured per leak was considerably smaller in this study. This is not a direct comparison and consideration should be given to further study of multifamily units as well as vented emissions to enable a more direct comparison.

Conclusions

The data collected from this project provide a representation of the weighted average leak rate of residential single-family customer MSAs within CA. When the data were compared between coastal and non-coastal MSAs, both frequency of leaks and leak flow rates were lower for coastal zones. A bootstrapped difference in means leak rates showed the coastal and non-coastal data sets were statistically similar.

The data when compared to the emission factors that were developed under the 2009 OTD Study, while not a direct comparison due to differences in the sample population and measurement techniques, indicates there may be a reduction in leakage rates (although the frequency of leaks was higher). The 2009 study showed a 2.08 lb CH_4/meter-year compared to a 0.64 lb CH_4/meter-year from this study. Further study into venting emissions and multifamily MSA would be required for a direct comparison.

Plastic insulating bushings surveyed in this study leaked at a frequency nearly four times higher than other fittings and connections within residential MSAs.

Recommendations

This project measured emissions from single family residential MSAs within CA. When the data within this project is compared to that of the 2009 OTD study, while it is not a direct comparison due to differences in the sample population and measurement technique, the leak rate shows a considerable reduction. However, emissions from MSA regulators were included in the 2009 study, but are not included in this study's leak rate. In addition, no multi-family residential MSAs were included in this study, but they were included in the 2009 study. Further studies to examine the emissions from multifamily MSAs, as well as vented emissions from regulators should be considered to provide additional data regarding methane emissions from residential customer meters in CA.

Appendix A – GTI Data

GTI Field Data

Table 10 – GTI Field Data – Leak Rate Measurements

LEAK RATE MEASUREMENTS - ALL LEAK SITES							
NUMBER	COMPANY	SITE ID	CITY	STATE	COASTAL LOCATION	BUBBLE SEEN	LEAK RATE AVE (SCFM)
1	SoCal	17080707	Santa.Fe.Springs	CA	Not.Coastal	No.Bubbles.Seen	2.48647E-07
2	SoCal	17080710	Santa.Fe.Springs	CA	Not.Coastal	No.Bubbles.Seen	3.61383E-06
3	SoCal	17080711	Santa.Fe.Springs	CA	Not.Coastal	No.Bubbles.Seen	4.47820E-06
4	SoCal	17080714	Santa.Fe.Springs	CA	Not.Coastal	Bubbles.Seen	1.43257E-04
5	SoCal	17080723	Santa.Fe.Springs	CA	Not.Coastal	Bubbles.Seen	2.33777E-06
6	SoCal	17080727	Santa.Fe.Springs	CA	Not.Coastal	Bubbles.Seen	1.06663E-05
7	SoCal	17080801	Los.Angeles	CA	Not.Coastal	No.Bubbles.Seen	1.16657E-05
8	SoCal	17080811	Los.Angeles	CA	Not.Coastal	No.Bubbles.Seen	6.38628E-06
9	SoCal	17080813	Los.Angeles	CA	Not.Coastal	Bubbles.Seen	1.52082E-04
10	SoCal	17080823	Los.Angeles	CA	Not.Coastal	No.Bubbles.Seen	8.29900E-06
11	SoCal	17080825	Los.Angeles	CA	Not.Coastal	No.Bubbles.Seen	2.23863E-04
12	SoCal	17080836	Los.Angeles	CA	Not.Coastal	No.Bubbles.Seen	2.89553E-05
13	SoCal	17080840	Los.Angeles	CA	Not.Coastal	Bubbles.Seen	2.58006E-04
14	SoCal	17080904	Corna.Del.Mar	CA	Coastal	No.Bubbles.Seen	1.66000E-06
15	SoCal	17080907	Corna.Del.Mar	CA	Coastal	Bubbles.Seen	2.49866E-04
16	SoCal	17080911	Orange	CA	Not.Coastal	Bubbles.Seen	2.60383E-05
17	SoCal	17080914	Orange	CA	Not.Coastal	Bubbles.Seen	5.58143E-05
18	SoCal	17080923	Orange	CA	Not.Coastal	No.Bubbles.Seen	3.11233E-06
19	SoCal	17080925	Orange	CA	Not.Coastal	No.Bubbles.Seen	2.42000E-07
20	SoCal	17080934	Orange	CA	Not.Coastal	No.Bubbles.Seen	1.91917E-05
21	SoCal	17080935	Orange	CA	Not.Coastal	No.Bubbles.Seen	6.34800E-06
22	SoCal	17081001	Anaheim	CA	Not.Coastal	No.Bubbles.Seen	1.96800E-06
23	SoCal	17081004	Anaheim	CA	Not.Coastal	No.Bubbles.Seen	2.19800E-06
24	SoCal	17081011	Anaheim	CA	Not.Coastal	No.Bubbles.Seen	1.43567E-06
25	SoCal	17081013	Anaheim	CA	Not.Coastal	No.Bubbles.Seen	2.62900E-06
26	SoCal	17081021	Anaheim	CA	Not.Coastal	Bubbles.Seen	3.80750E-05
27	SoCal	17081031	Anaheim	CA	Not.Coastal	Bubbles.Seen	1.01202E-04
28	SoCal	17081032	Anaheim	CA	Not.Coastal	Bubbles.Seen	1.42467E-06
29	SoCal	17081042	Anaheim	CA	Not.Coastal	No.Bubbles.Seen	2.50863E-04
30	SoCal	17081044	Anaheim	CA	Not.Coastal	No.Bubbles.Seen	1.24333E-06
31	SoCal	18011801	Mission.Viejo	CA	Not.Coastal	No.Bubbles.Seen	8.63333E-07
32	SoCal	18011802	Mission.Viejo	CA	Not.Coastal	Bubbles.Seen	4.21133E-05

33	SoCal	18011807	Mission.Viejo	CA	Not.Coastal	Bubbles.Seen	1.29030E-04
34	SoCal	18011808	Mission.Viejo	CA	Not.Coastal	Bubbles.Seen	1.92410E-05
35	SoCal	18011809	Mission.Viejo	CA	Not.Coastal	No.Bubbles.Seen	1.10199E-04
36	SoCal	18011812	Mission.Viejo	CA	Not.Coastal	Bubbles.Seen	1.97553E-04
37	SoCal	18011813	Mission.Viejo	CA	Not.Coastal	Bubbles.Seen	7.76547E-05
38	SoCal	18011816	Mission.Viejo	CA	Not.Coastal	Bubbles.Seen	4.15157E-05
39	SoCal	18011817	Mission.Viejo	CA	Not.Coastal	No.Bubbles.Seen	7.19833E-06
40	SoCal	18011821	Mission.Viejo	CA	Not.Coastal	No.Bubbles.Seen	4.30000E-08
41	PG&E	18020502	Fremont	CA	Not.Coastal	Bubbles.Seen	1.43333E-05
42	PG&E	18020512	Fremont	CA	Not.Coastal	No.Bubbles.Seen	1.75940E-05
43	PG&E	18020527	Fremont	CA	Not.Coastal	Bubbles.Seen	1.95300E-05
44	PG&E	18020533	Fremont	CA	Not.Coastal	Bubbles.Seen	1.55097E-04
45	PG&E	18020538	Fremont	CA	Not.Coastal	Bubbles.Seen	6.76130E-05
46	PG&E	18020540	Fremont	CA	Not.Coastal	Bubbles.Seen	4.67987E-04
47	PG&E	18020550	Fremont	CA	Not.Coastal	No.Bubbles.Seen	6.61917E-05
48	PG&E	18020601	San Ramon	CA	Not.Coastal	No.Bubbles.Seen	4.17367E-06
49	PG&E	18020603	San Ramon	CA	Not.Coastal	No.Bubbles.Seen	4.36833E-06
50	PG&E	18020604	San Ramon	CA	Not.Coastal	No.Bubbles.Seen	5.04000E-07
51	PG&E	18020605	San Ramon	CA	Not.Coastal	No.Bubbles.Seen	3.57000E-07
52	PG&E	18020606	San Ramon	CA	Not.Coastal	No.Bubbles.Seen	5.15000E-06
53	PG&E	18020607	San Ramon	CA	Not.Coastal	No.Bubbles.Seen	7.73000E-07
54	PG&E	18020611	San Ramon	CA	Not.Coastal	Bubbles.Seen	1.46330E-05
55	PG&E	18020612	San Ramon	CA	Not.Coastal	No.Bubbles.Seen	9.14500E-06
56	PG&E	18020614	San Ramon	CA	Not.Coastal	No.Bubbles.Seen	4.46667E-08
57	PG&E	18020615	San Ramon	CA	Not.Coastal	Bubbles.Seen	7.77767E-06
58	PG&E	18020705	Pacifica	CA	Coastal	Bubbles.Seen	1.31693E-05
59	PG&E	18020712	Pacifica	CA	Coastal	Bubbles.Seen	2.33333E-08
60	PG&E	18020716	Pacifica	CA	Coastal	Bubbles.Seen	1.64397E-05
61	PG&E	18020720	Pacifica	CA	Coastal	Bubbles.Seen	3.15080E-05
62	PG&E	18020734	Pacifica	CA	Coastal	No.Bubbles.Seen	1.61000E-06
63	PG&E	18020736	Pacifica	CA	Coastal	Bubbles.Seen	1.32590E-05
64	PG&E	18020737	Pacifica	CA	Coastal	Bubbles.Seen	5.04967E-06
65	PG&E	18020808	Fairfield	CA	Not.Coastal	Bubbles.Seen	3.90500E-06
66	PG&E	18020815	Fairfield	CA	Not.Coastal	Bubbles.Seen	2.72977E-05
67	PG&E	18020819	Fairfield	CA	Not.Coastal	Bubbles.Seen	2.06667E-06
68	PG&E	18020822	Fairfield	CA	Not.Coastal	Bubbles.Seen	2.86783E-05
69	PG&E	18020823	Fairfield	CA	Not.Coastal	Bubbles.Seen	1.97160E-05
70	PG&E	18020827	Fairfield	CA	Not.Coastal	No.Bubbles.Seen	6.57433E-06
71	PG&E	18020828	Fairfield	CA	Not.Coastal	No.Bubbles.Seen	6.48730E-05
72	PG&E	18020829	Fairfield	CA	Not.Coastal	Bubbles.Seen	5.82900E-06
73	PG&E	18020832	Fairfield	CA	Not.Coastal	No.Bubbles.Seen	8.05102E-04

74	SDG&E	18011601	La Mesa	CA	Not.Coastal	Bubbles.Seen	2.40197E-04
75	SDG&E	18011603	La Mesa	CA	Not.Coastal	Bubbles.Seen	4.61333E-06
76	SDG&E	18011606	La Mesa	CA	Not.Coastal	Bubbles.Seen	1.24863E-04
77	SDG&E	18011616	La Mesa	CA	Not.Coastal	Bubbles.Seen	4.23617E-04
78	SDG&E	18011627	La Mesa	CA	Not.Coastal	Bubbles.Seen	3.38030E-05
79	SDG&E	18011629	La Mesa	CA	Not.Coastal	No.Bubbles.Seen	2.93853E-04
80	SDG&E	18011635	La Mesa	CA	Not.Coastal	No.Bubbles.Seen	5.85667E-06
81	SDG&E	18011642	La Mesa	CA	Not.Coastal	Bubbles.Seen	7.80333E-06
82	SDG&E	18011644	La Mesa	CA	Not.Coastal	No.Bubbles.Seen	2.51333E-06
83	SDG&E	18011645	La Mesa	CA	Not.Coastal	Bubbles.Seen	2.01323E-04
84	SDG&E	18011703	San Diego	CA	Not.Coastal	No.Bubbles.Seen	1.91333E-06
85	SDG&E	18011710	San Diego	CA	Not.Coastal	No.Bubbles.Seen	5.38323E-04
86	SDG&E	18011717	San Diego	CA	Not.Coastal	Bubbles.Seen	1.03640E-04
87	SDG&E	18011720	San Diego	CA	Not.Coastal	No.Bubbles.Seen	4.10333E-06
88	SDG&E	18011725	San Diego	CA	Not.Coastal	Bubbles.Seen	1.61141E-03
89	SDG&E	18011731	San Diego	CA	Not.Coastal	Bubbles.Seen	5.63333E-06
90	SDG&E	18011736	San Diego	CA	Not.Coastal	No.Bubbles.Seen	4.20267E-05
91	SDG&E	18011737	San Diego	CA	Not.Coastal	Bubbles.Seen	1.64067E-05
92	SDG&E	18011738	San Diego	CA	Not.Coastal	Bubbles.Seen	1.78367E-05
93	SDG&E	18011739	San Diego	CA	Not.Coastal	Bubbles.Seen	2.28387E-04
94	SDG&E	18011743	San Diego	CA	Not.Coastal	Bubbles.Seen	1.46867E-05

List of Acronyms

AGA = American Gas Association

AOV = Analysis of Variance

CA = The state of California

CARB = California Air Resources Board

CGI = Combustible Gas Indicator

EPA = Environmental Protection Agency

EF = Emission Factor

FID = Flame Ionization Detector

GHG = Greenhouse Gas

GPTC = Gas Piping Technology Committee, AGA.

GRI = Gas Research Institute

GTI = Gas Technology Institute (formerly GRI, Gas Research Institute).

GWP = Global Warming Potential of a particular greenhouse gas for a given time period

IQR = Interquartile Range

LCL = lower confidence limit

LDCs = Local Distribution Companies

LEL = Lower Explosive Limit of gas, equals 5 percent methane.

LI = Leak Indication

MSA = Metering set assembly

MLV = Most likely value

OTD = Operations Technology Development

PG&E = Pacific Gas and Electric

ppm = Parts per million

psig = Pound per square inch, gauge pressure

psia = Pound per square inch, absolute pressure (psia = psig + atmospheric pressure)

SDG&E = San Diego Gas and Electric

SoCal Gas = Southern California Gas

UCL = Upper Confidence Limit

Gas Volume Units

scf = Standard cubic feet (Standard conditions are at 14.73 psia and 60°F)

scfh = Standard cubic feet per hour

scfm = Standard cubic feet per minute

Mscf = Thousand standard cubic feet (10^3 scf)

MMscf = Million standard cubic feet (10^6 scf)

Bscf = Billion standard cubic feet ($l0^9$ scf)

Gas Weight Units

g = gram

lb = pound

Mg (Megagram) = 10^6 g = 1 metric tonnes

Gg (Gigagram) = 10^9 g

Tg (Teragram) = 10^{12} g

MMT = Million metric tonnes = 1 Tg

MMT of CO_2 eq. = Million metric tonnes, carbon dioxide equivalent.

English to Metric Units Conversions

Volume Units

1 ft^3 = 0.02832 m^3

= 28.32 liters

1 Bscf = 28.32 million cubic meters

1 gallon = 3.785 liters

1 barrel (bbl) = 158.97 liters

1 scf methane = 19.23 g methane

1 Bscf methane = 0.01923 Tg methane

= 19,230. metric tonnes methane

Weight Units

1 lb = 0.4536 kg

1 short ton (2,000 lb) = 907.2 kg

1 long ton (2400 lb) = 1,016 kg

Pressure units

1 psig = 51.71 mm Hg

1 psi = 6.896 kPa (kN/m^2)

14.5 psi = 1 bar

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