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Characterization of Fugitive Methane Emissions from Commercial Buildings in California

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Natural Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater natural gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

Characterization of Fugitive Methane Emissions from Commercial Buildings in California is the final report for the Fugitive Methane Emissions from Commercial Buildings in California Assessment project (Contract Number PIR-15-017) conducted by ICF. The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

This project developed and validated methods for site recruitment, field testing, and estimating building-level and statewide methane emissions from commercial buildings in California. Analysis captured post-meter methane emissions data from natural gas appliances and pipe system components from a sample of buildings, then estimated total annual building-level and statewide emissions.

Although there were thousands of measurements at more than 100 buildings, there were only a few measurements for some appliance types for certain building types. Extrapolating these results to a statewide level implies a high level of uncertainty for some building and appliance type combinations. Thus, the total initial estimate should be refined through additional research. The study estimated emissions using the as-measured data and an alternative estimate that gives less weight to observed outliers.

The project team analyzed field data to characterize methane emissions from commercial buildings in California. Combining estimates of emissions from pipe joints and appliances, the team estimated total fugitive methane emissions from commercial buildings across California to be between 540 and 620 million cubic feet per year as measured or 311 to 392 million cubic feet per year for the alternative estimate designed to reduce the impact of outliers. Because of factors such as a limited number of buildings and appliances analyzed and outliers in the sample, the uncertainty associated with this analysis is very high, with a range of emissions spanning approximately 78.6 million to 1.1 billion cubic feet per year.

The study found that most gas piping and equipment in the sample of commercial buildings operated with low to no fugitive methane emissions. A small percentage of sources accounted for most emissions for both analyses. Future studies can apply techniques developed in this project to a larger, more diverse sample of buildings to refine the statewide emissions estimates.

Keywords: methane, fugitive emissions, commercial buildings, unburned methane, pipe joint fugitive emissions

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EXECUTIVE SUMMARY

Background

Methane has been identified as a greenhouse gas by the Intergovernmental Panel on Climate Change as well as a short-lived climate pollutant identified by the California Air Resources Board. As part of California's effort to address drivers of climate change, the legislature in 2006 passed Assembly Bill 32 (Nunez, Chapter 488, Statutes of 2006), which set goals for greenhouse gas reductions in the state. Senate Bill 605 (Lara, Chapter 523, Statutes of 2014), and Senate Bill 1383 (Lara, Chapter 395, Statutes of 2016), subsequently addressed directly the role of methane as a short-lived climate pollutant. Due to the relatively high climate impact of methane in the short-term, reducing methane emissions is an important strategy for reducing near-term warming.

Any reduction in emissions requires understanding baseline emissions for a given system and proper methods and measurement techniques to validate reductions in those emissions. California has initiated efforts to quantify emissions from various emission sources in the natural gas transmission and distribution system, such as pipelines. However, emissions from other sources, such as commercial buildings, have not been well characterized. While the fraction of fugitive emissions from post-meter sources is expected to be small relative to total natural gas consumed, it is nonetheless one of the less well-understood areas.

This project responds to the need for field measurements and analysis to provide an initial estimate of methane emissions from commercial buildings. Information on post-meter emissions is necessary to gain a holistic picture of the total emissions from natural gas use in the state. Additional data, measurement, and reporting tools can improve the characterization of fugitive methane emissions from natural gas supplies to California.

The project assessed the magnitude of methane emissions from appliances and pipe joints in commercial buildings in California. The analysis builds on prior work by the Lawrence Berkeley National Laboratory that assessed the magnitude of methane emissions in California's residential housing stock, and a parallel study of emissions from commercial buildings performed by the Gas Technology Institute. The residential study found that methane emissions from residential natural gas systems likely contribute a small but meaningful fraction of California's greenhouse gas emissions. The residential study also found that pilot lights were potentially significant contributors to emissions when the appliances were not actively in use. Unburned methane from residential appliances, especially from water heaters and stovetops, also contributed to emissions though only six furnaces were tested and five of these had no emissions.

Project Purpose

This project better characterized fugitive methane emissions from specific appliances and system components downstream of the customer meter in commercial buildings in California and help inform potential mitigation strategies, policies, and planning. The project also tested a methodological framework for recruiting sites for assessment and quantifying the magnitude of statewide fugitive methane emissions. The effort leveraged on-site assessment methods developed in previous analyses coupled with newly developed analytical methods to extrapolate sample results to estimate the statewide magnitude of fugitive methane emissions.

Project Approach

Methane emissions can come from various sources in commercial buildings, and broadly fall into two categories – emissions from combustion equipment and emissions from pipes. The project team at ICF developed and implemented a site recruitment effort, analyzed the site data, and then developed a method to extrapolate statewide emission results from the sample data. Gas Technology Institute supported ICF and was primarily responsible for conducting the on-site measurements and refining methods for measuring emissions at the component level.

The project included seven tasks, beginning with characterizing the California commercial building stock to serve as the population for the analysis. The project team designed and disseminated a survey to collect site-specific data. The project recruited participants for the field sampling phase of the study from the survey population. To incentivize participation in the field sampling phase of the study, potential participants were presented with a one-page summary of the study outlining the benefits of participation, a website containing similar information, and blog posts that were circulated by partner organizations. In the field sampling phase of the study, the project team collected samples from gas appliances and accessible gas pipe components at each site. The project team analyzed results of the first 40 participating sites to refine the protocol for emissions sampling and analysis. Based on this pilot study, the project team refined the recruitment approach, on-site testing protocols, and data collection techniques. Finally, the team conducted the full field sampling campaign, collecting data at more than 100 sites, analyzing results for the sample and extrapolating results to the state level.

ICF analyzed the raw site data by appliance type or joint-type of the pipe, appliance end use, building type, and region. To extrapolate site results for buildings across California, ICF weighted the appliance emissions results by nameplate and use factor and conducted statistical analysis to account for the fact that the sample results were not normally distributed. For appliance emission measurements, ICF applied logit and log-normal models. For measurements of pipe joint fugitive emissions, ICF applied a non-parametric model. Confidence intervals were estimated for pipe joint and appliance emission measurements.

A key challenge in the project was recruiting sites for analysis once the utility partners were no longer able to distribute the outreach materials via ratepayer bills as proposed in the original project plan. The project team received invaluable outreach support from more than a dozen California-based non-profit and municipal organizations with missions related to improving building-level sustainability. Furthermore, the project team received critical technical support and guidance from the California Energy Commission contract agreement manager as well as the project technical advisory committee on site recruitment, measurement techniques and data analysis.

Project Results

The project tested multiple outreach approaches to overcome challenges to site recruitment, and ultimately conducted thousands of field measurements at 103 commercial establishments across the state. The offer of free "fugitive methane testing" was found to be an effective tool for recruiting commercial establishments to participate in the study. Partnering with organizations across California that support commercial building sustainability initiatives also

proved to be a valuable approach to recruiting sites for participation, however, this likely led to a study sample that was skewed towards better-maintained buildings with newer appliances.

Although there were thousands of measurements at more than 100 buildings, there were only a few measurements for some appliance types for certain building types. Extrapolating these limited results to a statewide level implies a high level of uncertainty for some building and appliance type combinations and thus the total estimate is an initial estimate that should be refined through additional measurement studies. In a few cases, these measurements seemed to be outliers, sometimes traceable to specific operational anomalies in the equipment. Extrapolating these outliers to a statewide level could skew the estimates.

ICF applied two methods in estimating statewide appliance emissions based on field measurements:

- The "as-measured" estimate applied the results as measured in the field including three building/appliance categories that seemed to be outliers.
- The "alternative estimate" in which the measured values of unburnt methane for the three categories that appear to be outliers were replaced with the average value for the appliance category across the relevant region.

Based on ICF's analysis of pipe joint fugitive emissions and uncombusted methane from appliances, the researchers estimate that total methane emissions from commercial buildings across California are between approximately 540 and 620 million cubic feet per year for the as-measured estimate and 311 to 392 million cubic feet per year for the alternative estimate. For context, California's commercial building sector consumed approximately 216 billion cubic feet of natural gas in 2018.

These results are equivalent to 0.24 percent to 0.28 percent of total natural gas consumption in the commercial building sector across the state for the as-measured estimate and 0.14 percent to 0.18 percent for the alternative analysis. The study team found emissions from appliances to be larger than emissions from pipe joints (about 1.6 to 2.4 times larger) for the as-measured estimate. In the alternative estimate, the appliance emissions were about equal to or lower than (by about a third) the pipe emissions.

Because of factors such as a limited number of buildings and appliances analyzed and outliers in the sample, the uncertainty associated with this analysis is very high. Incorporating uncertainly analysis in the estimation indicates that total methane emissions could range from approximately 78.6 million to 1.1 billion cubic feet year

Based on thousands of field measurements, the study found that most gas piping and equipment operated with low to no fugitive methane emissions. A small percentage of sources accounted for most emissions. For example, of the 429 gas appliances measured, the top 3 percent of emitters accounted for more than 50 percent of total emissions. The same was true for piping components, with the highest 3 percent of emitters accounting for more than 50 percent of observed emissions. Other studies of methane emissions have observed this type of distribution, and the higher emitters are sometimes referred to as "superemitters".

The distribution suggests that it may be possible to significantly reduce emissions from the commercial building sector by identifying and repairing a relatively small number of faulty appliances and pipe joints. By identifying where these problem areas are most likely to be and

understanding what may be driving their poor performance, relatively quick and limited adjustments could yield sizable emissions reductions.

The data gathering and analysis techniques employed in this study provide a strong basis for developing a more robust future statewide estimate of fugitive emissions across the commercial building sector. With this foundation, further field data collection could be fed into these models to calculate emissions estimates from additional data points. ICF acknowledges that the study sample is small, and is biased towards urban areas, newer buildings, and — due to the nature of the recruitment process — establishments with engaged energy managers. At the level of building and appliance type, some categories have only a few data points. A larger, more representative field data collection effort could shed further light on whether and why these components may be the greatest contributors, including what roles age, installation practices, maintenance, cleanliness, or other factors may play. With this information, it would be possible to make more targeted recommendations about how best to reduce methane emissions behind the meter in commercial buildings.

The methodological advancements achieved by this project are important steps to overcoming barriers to meeting California's statutory energy goals. By quantifying emissions from all sources in the natural gas system, inclusive of natural gas customers such as the commercial building sector, it will be possible to characterize emission profiles that can allow for targeting of sources with the largest potential for emissions reduction to meet the state's statutory targets.

Knowledge Transfer

Given the diversity of stakeholders engaged in various stages of this effort, knowledge generated by this study will be shared and disseminated at multiple levels. The team has shared individual site reports with study participants, detailing appliance-specific emissions factors and highlighting any unusually high values for appliance inefficiencies or pipe joint fugitive emissions. These reports will enable participating establishments to better target and prioritize their gas appliance maintenance and replacement practices.

Moreover, the project team has prepared a summary snapshot of key findings from the study and shared it with all intermediary organizations that helped publicize the study. These findings will be disseminated to their memberships — including large property owners, corporate facility managers, green building associations, municipal sustainability organizations, and other related constituencies — to further enhance knowledge transfer.

The two major natural gas utility companies in California, Pacific Gas and Electric and Southern California Gas, participated in the technical advisory committee throughout this project. These utility partners will share the findings of the study internally and disseminate key findings to their customers.

Finally, the project team has worked with the California Energy Commission to ensure that findings from the study are shared with the California Air Resources Board Greenhouse Gas Inventory Group to further inform the state's approach to developing its emissions inventory, as well as with other relevant state policymakers.

Benefits to California

Post-meter methane emissions comprise natural gas that has already been purchased, so commercial properties will benefit from purchasing less natural gas if these emissions are reduced. Based on ICF's analysis, ratepayers in northern California would save up to $1.8 million per year in the aggregate, and ratepayers in southern California would save up to $3.2 million per year in the aggregate. More significant are the potential benefits to California in terms of environmental impacts.

Based on this limited study sample, ICF provided central estimates of annual fugitive methane emissions from California's commercial buildings of 0.25 to 0.29 million tonnes of carbon dioxide equivalent (MMT CO_2e) for the as-measured estimate or 0.15 to 0.18 MMT CO_2e for the alternative estimate (100-year global warming potential=25). It is important to note the uncertainty of these estimates, for which the 95 percent confidence intervals span a range from 0.038 MMT CO_2e to 0.53 MMT CO_2e.

The commercial sector natural gas combustion category of the California Air Resources Board's statewide GHG inventory currently includes only estimated combustion emissions and does not include fugitive emissions. Based on these central estimates, commercial building fugitive methane emissions make up 0.63 percent to 0.72 percent of total California methane emissions from all sectors for the as-measured estimate or 0.36 percent to 0.46 percent for the alternative estimate in 2017. On a 20-year global warming potential basis (global warming potential=72), the central estimates for as-measured emissions are 0.72 MMT CO_2e to 0.84 MMT CO_2e or 0.43 MMT CO_2e to 0.52 MMT CO_2e for the alternative estimate, with the 95 percent confidence intervals of the analyses spanning a range of 0.11 MMT CO_2e to 1.5 MMT CO_2e.

CHAPTER 1: Introduction

Background

The "Fugitive Methane Emissions from Commercial Buildings in California" study, sponsored by the California Energy Commission (CEC), aims to develop an understanding of methane emissions from commercial buildings across California. ICF worked with Gas Technology Institute (GTI) to conduct on-site methane detection tests by sampling un-combusted methane from appliances and pipe-related fugitive methane emissions from sites in northern and southern California. In addition to analyzing the appliance-, pipe joint- and building-specific emissions data, the project team also calculated statewide and regional methane emissions. The results of this study will help inform public energy sector policy and planning efforts to reduce greenhouse gas emissions that come from these methane emissions.

Methane has been identified as a greenhouse gas (GHG) by the Intergovernmental Panel on Climate Change (IPCC) and as a short-lived climate pollutant by the California Air Resources Board (CARB). As part of California's effort to address drivers of climate change, Assembly Bill 32 (Nunez, Chapter 488) was passed in 2006 and set goals for reduction of GHGs in the state. Subsequent legislation, Senate Bill 605 (Lara, Chapter 523, Statutes of 2014) and Senate Bill 1383 (Lara, Chapter 395, Statutes of 2016), directly addressed methane's role as a short-lived climate pollutant. Any reduction in emissions requires an understanding of the baseline emissions for a given system and the proper methods and measurement techniques to validate any reduction in the emissions. California has initiated efforts for quantifying emissions from various sources of emissions in the natural gas transmission and distribution system, such as pipelines. However, it has been recognized that emissions from other sources such as commercial buildings have not been well characterized. While it is expected that the relative magnitude of the emissions from post-meter sources would be small, it is arguably one of the less well-understood areas. This project was undertaken to measure and quantify methane emissions from commercial buildings. Obtaining information on post-meter emissions is needed to gain a holistic picture of the total emissions from the use of natural gas in the state. Additional data, measurement, and reporting tools can improve the characterization of fugitive methane emissions from natural gas supplies to California.

This project assessed the magnitude of methane emissions from appliances and pipe joints in commercial buildings in California. The analysis builds on prior work by the Lawrence Berkeley National Lab[1] that assessed the magnitude of methane emissions in California's residential

[1] Fischer, Marc L., Wanyu Chan, Seongeun Jeong, and Zhimin Zhu. Lawrence Berkeley National Laboratory. 2018. Natural Gas Methane Emissions From California Homes. California Energy Commission. Publication Number: CEC-500-2018-021.

housing stock and a parallel study of emissions from commercial buildings performed by GTI.[2] The residential study found that methane emissions from residential natural gas systems likely contribute a small but meaningful fraction of California's greenhouse gas emissions. The residential study found that pilot lights were potentially significant contributors to inactive emissions. Uncombusted methane from residential appliances also contributed to emissions, especially from water heaters and stovetops, though only six furnaces were tested and five of these had no emissions. Another study[3] assessed residential and commercial sector methane emissions through a correlation to seasonal atmospheric methane levels but did not include direct measurement of either unburned or fugitive pipe joint emissions.

The current study represents a significant advancement from the previous studies as it included a significantly larger sample than the two direct measurement studies. That said, it is still a small sample relative to the diversity of commercial buildings and appliance types, which limits the accuracy of the overall estimate.

Project Purpose

The purpose of this project is to better characterize fugitive methane emissions from specific appliances and system components downstream of the customer meter in commercial buildings in California and to inform energy sector policy and planning, particularly that relate to natural gas systems. Additional goals of the study are the refinement of methods for recruitment of sites and testing and analyzing fugitive emissions that can be used in the future for more comprehensive studies.

[2] Sweeney, Meredith, Daniel Ersoy, Kristine Wiley, Erin Case, Eric Stubee, Marc L Fischer. Gas Technology Institute. 2019. Assessment of Fugitive Emissions from the Natural Gas System. 2019. Commercial Buildings, California Energy Commission. Publication Number: CEC-100-2019-001-CMD.

[3] Liyin He, Zhao, Zeng, et al, Atmospheric Methane Emissions Correlate With Natural Gas Consumption From Residential and Commercial Sectors in Los Angeles, Geophysical Research Letters, 28 July 2019, https://doi.org/10.1029/2019GL083400

CHAPTER 2:
Project Approach

This chapter describes the team's method and lessons learned across three phases of the project: (1) site recruitment and selection; (2) on-site field measurement; and (3) data analysis and modeling.

Methane emissions can come from various sources in commercial buildings, but they broadly fall into two categories: unburned methane emissions from combustion equipment and fugitive emissions from piping. ICF developed and implemented a robust site recruitment effort, refined methods for measuring emissions at the component level (with support from GTI) and developed a methodology to extrapolate statewide emission results from the sample data.

At the outset of the project, ICF analyzed data to characterize California's commercial building stock. ICF compiled data from public data sources such as the Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS) and EIA state reporting to characterize commercial buildings across California in terms of industry type (NAICS code), natural gas consumption, and number of buildings by type and county. This database was later used in the statewide and regional extrapolation analyses, which is discussed further in this section.

Next, ICF designed and disseminated a building characteristics survey and recruited participants to join the study. The activities undertaken in these tasks are captured in more detail in the following discussion of the study approach to site recruitment and selection.

The project team analyzed results from the first 40 sites that participated as a pilot study. This initial analysis was used to refine the protocol for emissions sampling and analysis. The project team revised the recruitment approach, on-site testing protocols, and data collection techniques. Lastly, the team conducted the full study, collecting data at more than 100 sites, and analyzing results of the sample as well as extrapolating results to the state level.

Site Recruitment and Selection

ICF sought to collect building-level site data through two main outreach methods: (1) dissemination of a survey to collect information on building type, age, size, natural gas consumption, and appliance types; and (2) on-site fugitive methane detection and measurement tests. The purpose of the survey was to inform the site selection process and the design of the measurement protocols. ICF set out to recruit commercial buildings in California to participate in these data collection opportunities from six different building types: offices, lodging, education, food service, retail, and warehouses. The project team refined the recruitment methods employed throughout the pilot study as they determined the most effective and efficient approaches.

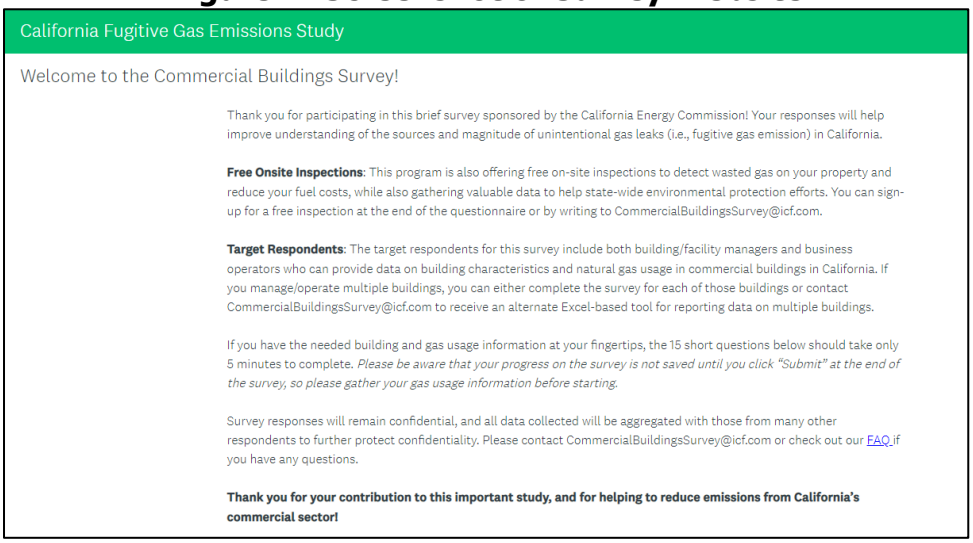
Initial Approaches

The original approach to outreach and recruitment that was envisioned for this project relied on the two largest gas utilities in California to disseminate a paper-based survey in mailed utility bills throughout the state. The survey would collect information on building

characteristics from ratepayers, while also providing information about the availability of on-site fugitive methane detection and measurement tests. Under this approach, it was anticipated that participation in the survey would help recruit sites for the on-site testing. However, due to sensitivities around gas leaks and their public perception, the utilities were unable to circulate the survey in their mailings. As a result, ICF had to explore alternative outreach methods that could be used to recruit study participants.

- Outreach Approach #1: The first approach ICF tested centered on dissemination of a web-based survey (Figure 1) via mass email. The survey website was designed to both collect information on building characteristics and recruit entities to participate in the on-site fugitive methane detection and measurement tests. ICF disseminated the survey link via email and followed-up by phone using an ICF proprietary database of email addresses and phone numbers for approximately 1,050 corporate entities across California. The database contained information for facility-related contacts within each organization. However, the response rate was poor, due to the fact that most of the email addresses were associated with general building information mailboxes or the public affairs/press contacts, rather than the sustainability-oriented staff members who would more likely be interested in the study and thus be more appropriate targets for outreach.

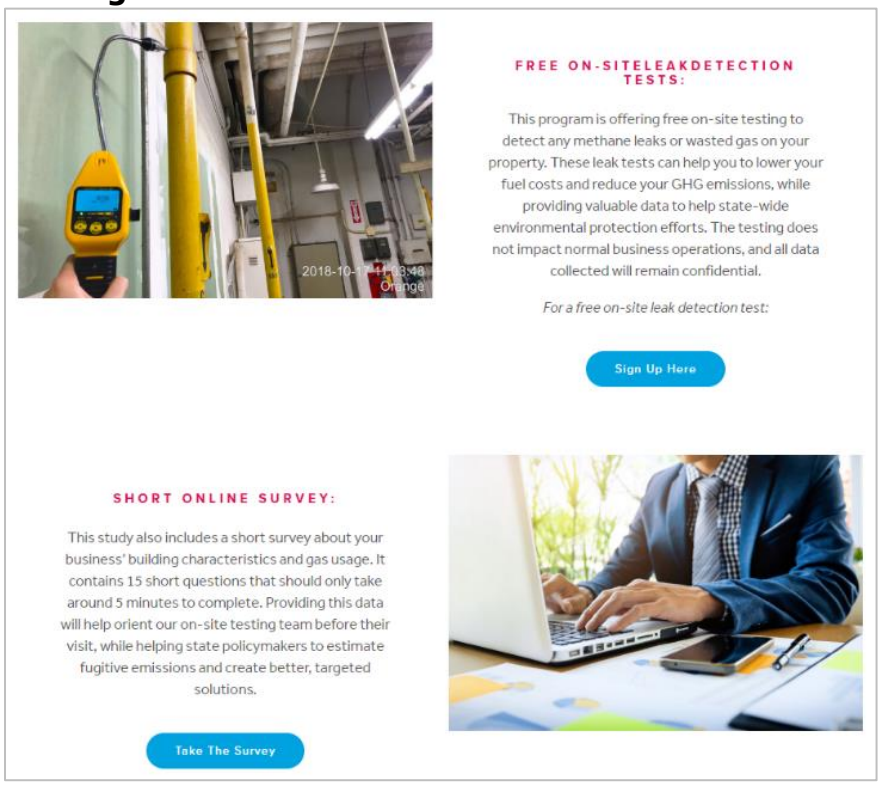
Figure 1: Screenshot of Survey Website



Source: ICF

- Outreach Approach #2: The project team went on to develop a second approach to outreach, which focused on disseminating study recruitment materials via trade associations and at industry-focused conferences. The team developed new materials for dissemination, including:
    - An updated website at www.methanestudy.org (Figure 2), which described the study's objectives and importance, highlighted benefits to participants and the low level of effort required, and included links to the online survey and FAQ;
    - Handouts, flyers, and business cards for circulation at relevant industry conferences and events.

Figure 2: Screenshot of Recruitment Website



Source: ICF

ICF then compiled a database of contact information for industry-specific trade associations in the target commercial building sectors and disseminated the website link and updated study recruitment materials. Additionally, the study team collaborated with ICF's Energy Account Managers who circulated the promotional materials at conferences related to energy efficiency in retail and commercial buildings/businesses.

Since these industry associations and conferences were better connected to the target audience of corporate sustainability professionals, this approach garnered more interest. However, follow-up was inconsistent since the project team did not have direct access to contact information for interested individuals and had to wait for them to contact ICF rather than being able to proactively follow-up. While more effective than the initial approach, this method of coordinating with industry associations and attending industry conferences ultimately did not reach the ideal target audience for site recruitment, and so a further refinement to the approach was needed.

Revised Approach

- Outreach Approach #3: The approach that ultimately succeeded in identifying, reaching, and recruiting study participants was based on extensive networking within the sustainability community and partnering with key allies that could amplify outreach and connect the project team with key decisionmakers. The project team:
    - Identified influential intermediary organizations focused on sustainability, energy, green building, and other related topics whose members might be interested in participating in the study. These organizations included the U.S. Green Building Council (USGBC), Business Council on Climate Change (BC3), Building Owners

and Managers Association (BOMA), Los Angeles Regional Collaborative (LARC), and the San Francisco Green Building Task Force, among others.

- Built relationships with staff from these organizations and worked closely with them to develop concise messaging that would resonate with their membership. These partners then leveraged their well-targeted email distribution lists, meetings, and social media outlets to circulate information about the study and promote participation.
- Reached out to city departments of the environment and sustainability and connected with municipal committees and task forces focused on green building and sustainable operations.
- Through the above networks, the project team connected with and built relationships with key managers in both corporate and public organizations that were responsible for sustainability, energy, or facilities.
- The team focused on recruiting organizations that had significant building portfolios, such as universities and large companies with multiple campuses.
- After some early high-profile recruitment successes, the team was able to leverage these early participants to further strengthen recruitment efforts.

Employing this more targeted approach, the study team successfully recruited 41 sites for participation in the Pilot Study sample (exceeding the initially proposed pilot sample of 30 sites), and ultimately recruited more than 100 sites for participation in the full study.

Lessons Learned

Initial recruitment was difficult and resulted in poor response due to low interest and perceived high level of effort for participants. But the project team learned a range of lessons that ultimately led to a successful site recruitment approach, and which can help future efforts by researchers. These lessons are described here.

- Develop Partnerships and Target Outreach: Partnerships with intermediary organizations who were trusted by their memberships – as well as targeted, consistent communication with specific individuals who were already oriented towards facility sustainability – was much more effective in recruiting participants. The project team requested personalized introductions to decision-makers. Furthermore, in each of the discussions, ICF requested referrals and introductions to other potentially interested stakeholders.
- Emphasize Free Testing Over Survey: The project team had expected the survey to be an efficient tool for gathering data, as it was quick and easy to complete. However, only 33 participants responded to the survey during the 12-month period ending on May 1, 2019, and almost all of them indicated that they also wanted to receive free on-site testing. Moreover, feedback from participants emphasized that the free fugitive methane testing was itself an effective incentive to participate in the study. Furthermore, the survey was seen as a barrier to participation rather than a recruitment tool, as it required collecting data on site-specific factors such as number of appliances and building square footage as well as procurement data related to gas usage/cost, often requiring input from multiple departments or individuals. Given the lack of participation in the survey and the fact that all needed data could be collected as part

of the on-site methane testing protocol, the project team ultimately decided to stop focusing efforts on increasing survey participation and, instead, focused on recruiting candidates directly for on-site methane testing.

- Develop Concise and Compelling Collateral: The project team honed the messaging to emphasize free fugitive methane testing, articulate the clear benefits of participating in the study, and the low level of effort required from participants. ICF developed a one-page PDF Fact Sheet (Figure 3) summarizing key study details that could be easily circulated via email by study partners.
- Target Geographic Density: To reduce travel time between sites and increase the efficiency of on-site testing, the project team targeted recruitment in key metro areas across California (such as the San Francisco Bay Area, Los Angeles, and San Diego regions) which had denser geographies, a larger number of potential participants, and robust professional networks associated with building sustainability.

Figure 3: One-Pager PDF Fact Sheet

Source: ICF

On-Site Measurement Methodology

The goal of site measurements was to quantify post-meter methane emissions from commercial buildings. The testing focused on two categories of emissions—from piping and from combustion equipment. The ICF team used the measurement method designed and implemented by GTI and Lawrence Berkeley National Laboratory in their separate assessment

of fugitive emissions from the natural gas system in commercial buildings under contact PIR-15-003. This section presents a summary of the approaches employed. For more detailed information on the measurement methodology and equipment used, please see the PIR-15-003 Final Project Report *Assessment of Fugitive Emissions from the Natural Gas System – Commercial Buildings*.

Emission Source Survey

Prior to taking measurements of emissions, all visible piping and gas-fired equipment was inventoried to understand the complete potential emission sources. Visible piping components were recorded by joint type and whether or not they were tested. This survey data was used to apportion the number of joints by type that were tested. Gas appliances were identified by category and nameplate gas input. All appliances were listed, regardless of whether they were able to be tested, to acknowledge when there were appliances that were not tested. This provided a more comprehensive picture of possible emission sources even when not all piping-related fugitive emissions or appliance emissions were quantified.

Point Identification and Measurement Methodology

The team identified piping fugitive emissions by surveying all accessible piping components with a Sensit Gold G2 single gas detector. The survey was conducted by physically touching the Sensit to the piping component and following around the circumference of each component in order to identify very small methane emissions from the piping components. While the detection limit for the Sensit was approximately 10 parts per million (ppm), only concentrations above 100 ppm as detected by the Sensit were documented and measured in order to capture the most significant emissions in the time available. For sites with many piping components and fugitive emissions, this threshold was increased to 500 ppm for the same reason. Piping was surveyed up to where it entered the equipment. Components inside the equipment itself were not surveyed.

Pipe measurements used a direct mass balance approach, diluting the pipe fugitive methane into a metered flow of background air and sequentially measuring methane in both the background and diluted pipe emissions. Testing with controlled methane releases from 0.5 to ~ 15 standard cm^3/min (sccm) during development of the method during work under PIR-15-003 confirmed that the measurement approach was accurate to within an error of ~5 percent. Field error will be greater due to variability in background concentration and methane sources being pressure dependent or having a more distributed source.

Identified piping-related fugitive emissions were measured by gathering the methane from that joint into a much larger flow of diluting ambient air using an industry standard Bacharach Hi-Flow Sampler™ to gather the methane into a calibrated flow of diluting ambient air. By pairing the Hi-Flow with the Los Gatos Research (LGR) Ultra-Portable Greenhouse Gas Analyzer (UGGA), with precision down to the parts per billion (ppb) level, very small methane enhancements in the exhaust of the Hi-Flow Sampler™ were detected. The Hi-Flow large diameter sample hose was used to take a baseline measurement of the ambient air near the pipe joint location, followed by collection of the fugitive methane, and finally an additional baseline measurement. The effective fugitive methane rate was computed by mass balance:

$$F = (C_1 - C_0) * Q/1000$$

where Q is the Hi-Flow rate in liters per minute, C_1 is the methane concentration including the fugitive methane in parts per million (ppm), C_0 is the methane concentration in ambient air in ppm, and F is the fugitive methane flow rate in sccm.

Measurements of each joint were taken two or more times to ensure repeatability. For facilities with large numbers of piping joints emitting fugitive methane, points were measured in groups using a 'leak bag' to contain multiple emission sources simultaneously, or a subset of points were quantified, starting with the largest as detected by the Sensit and continuing as long as the team had access to the site. The condition of piping and equipment varied widely between sites.

Combustion Emission Measurement Method

Methane emitted by combustion appliances is from natural gas fuel that is not combusted in the appliance and instead leaves with the exhaust. The fraction of methane emitted by operating combustion appliances was estimated by measuring the relative enhancements from background methane to CO_2 in the appliance exhaust, combined with the gas use rate. Gas-fired equipment in the commercial building types visited generally fell into one of three categories – space conditioning, water heating, and cooking – with the one common exception of clothes dryers.

This method is suitable for steady-state burner operation. Therefore, whenever possible, equipment was allowed to run for several minutes to reach steady state prior to the exhaust being measured. There is some evidence[4] that uncombusted methane can be higher during start-up and shut-down transients though the effect will depend on equipment type and duty cycle. Unfortunately, it was not possible to cycle all equipment during the measurements due to building operation requirements.

The fractional emission of methane relative to total gas consumption is determined based on the ratio of methane (CH_4) to carbon dioxide (CO_2) enhancements relative to background air, ΔCH_4: ΔCO_2. This ratio is converted to a fractional emission, which can be described as the portion of methane emitted out of the total methane supplied to the burner:

$$F = \frac{\Delta CH4 : \Delta CO2}{(1 + \Delta CH4 : \Delta CO2)}$$

where F is the fractional methane emission.

Only the LGR UGGA was used for combustion measurements. A stainless-steel probe connected to the UGGA by ¼" tubing was used to sample the ambient air to provide background air CH_4 and CO_2 concentrations, and then used to measure the concentrations in the exhaust stream, followed by an additional background measurement. Measurements were repeated two or more times for repeatability. Both pieces of equipment (HiFlow in Nov 2018 and LGR UGGA in Jan 2019) were sent back to their respective manufacturers for factory calibration prior to the field campaign.

[4] Zachary Merrin and Paul W. Francisco, Unburned Methane Emissions from Residential Natural Gas Appliances, Environmental Science and Technology, March 25, 2019, http://dx.doi.org/10.1021/acs.est.8b05323.

The probe was positioned in the exhaust stream to keep the CO_2 concentration below 20,000 ppm, which is the upper range of the UGGA documented operational range. For equipment with open exhaust, such as cooking equipment, this meant positioning the probe within a more dilute portion of the exhaust stream. For equipment with closed exhaust, such as large boilers sampled through small ports, this involved rapidly switching between pulling ambient and concentrated exhaust to keep the overall concentration within the sample chamber under the limit.

The total gas consumption was estimated from the nameplate gas input of the appliance. Whenever the actual firing rate could be determined during testing of boilers, the percent of load was documented and the gas rate scaled down accordingly.

Data Analysis

Sample Development

ICF compiled the raw data collected by GTI so that individual appliance and pipe joint measurements could be analyzed by site, appliance or joint type, building type and region.

Based on the Pilot Study results, the project team refined the building categorization techniques to better account for mixed-use facilities. Specifically, the project team defined measurements taken at dining halls on education campuses and office complexes as food service if the primary use for the building was food service, despite being operated by another type of commercial owner.

Appliance Emissions Measurements

To analyze appliance emissions from the raw appliance emission measurements collected by GTI, ICF first averaged multiple individual readings taken for the same appliances in the same operating mode in each building. For some appliances (particularly range burners), the gas detection team took measurements from different components of the appliance (such as from two individual burners out of four total burners). For these cases, ICF also took the average measurement of the burners tested and applied it to all burners to get an emission measurement for the entire appliance.

ICF also included pilot light measurements in the analysis. Continuously burning pilot lights on furnaces, water heaters, or cooking equipment utilize natural gas and emit unburned methane regardless of the appliance operating mode. The study estimated the potential methane emissions from uncombusted natural gas from pilot lights by identifying all of the pilot lights at the sites visited and applying an average pilot gas consumption estimate and an average combustion efficiency. Because the nameplate value does not reflect the pilot light consumption, ICF conducted a literature review of the average pilot light gas use for difference appliance end uses. The pilot gas consumption was determined using resources developed by two natural gas utilities as shown in Table 1.

Table 1: Pilot Light Gas Consumption Assumptions (Btu/hr)

Appliance Type	Peoples Gas Natural Gas Appliance Calculator[a]	Madison Gas and Electric[b]	Assumed Pilot Light Gas Use
Water Heating	750	750	**750**
Space Heating	1100	1000	**1050**
Cooking	350	400	**375**
Pool, Spa[c]	-	-	**400**

a: Natural Gas Appliance Calculator (People's Gas)

b: Appliance Energy Costs: Operating Costs for Major Household Appliances (Responsible Energy)

c: Natural Gas Methane Emissions from California Homes (Fischer et al.)

Source: ICF

Continuously burning pilot lights are becoming less common as new buildings are restricted from installing equipment with pilot lights according to California's Building Energy Efficiency Standards for Residential and Nonresidential buildings. This standard restricts pilot lights for fan-type central furnaces, residential household cooking appliances, pool heaters, spa heaters, or indoor or outdoor fireplaces from being installed in new buildings.[5] For older buildings or equipment not specified by the efficiency standard (that is, commercial cooking equipment), pilot lights may still be in use. For each pilot measurement in the sample, ICF replaced the nameplate value with the average pilot light gas use for the pilot light emissions calculations.

The gas detection team was unable to measure the fraction of unburnt methane or obtain nameplate information for some appliances due to a variety of reasons (for example, equipment was inaccessible, not running, and so on).

Imputation Techniques

In cases where the appliance inventory indicated that an appliance was present but was not active during the site visit (and thus not tested), the project team decided not to impute values for those inactive appliances as site coordinators indicated that those appliances may not be regularly-used and thus their inclusion might exaggerate results. However, ICF determined it was necessary to impute values for 30 measurements associated with on-site space conditioning equipment in lodging and education buildings. The project team believes that the inability to measure these appliances may have been due to the timing of the assessments (warm weather didn't warrant turning on the equipment), and it was incorrect to assume zero values for these data points.

To conduct the imputation analysis, ICF averaged the values from space conditioning appliances in the four other building sectors (food service, office, retail, and warehouse). ICF first determined 1) nameplate values, and 2) nameplate multiplied by fraction of unburnt methane values and then divided the sum of second values by the sum of first values to create a weighted average as shown in the following formula:

[5] *Building Energy Efficiency Standards for Residential and Nonresidential Buildings* (CEC). https://ww2.energy.ca.gov/2018publications/CEC-400-2018-020/CEC-400-2018-020-CMF.pdf

$$Imputation\ value\ of\ appliance\ type = \frac{\sum Nameplate\ values \times Fraction\ of\ unburnt\ methane}{\sum Nameplate\ values}$$

This result represents the weighted average of fraction of unburnt methane values for a specific space conditioning appliance type in the raw dataset. The project team then applied this value to all of that appliance type in lodging or education buildings, for which results were not available due to untested appliances, missing nameplate values, or otherwise. The team also repeated this process for all 10 space conditioning appliance types, resulting in 30 imputations.

Out of the 399 measured fractions of unburnt methane, 163 (41 percent) were too small to be detected and were originally reported as zero. The zero values were subsequently replaced by half the smallest measured fraction of unburnt methane for the purpose of statistical analysis, in which zero values were mathematically undefined. This replacement value was 8.8×10^{-7} fraction of unburned methane.

Site-Specific Analysis

To provide site-specific reports for each participating site, ICF analyzed the appliance-related emissions for each site. ICF provided information associated with each appliance tested, including its operating mode, SCFM of methane and combustion efficiency.

Sample-Level Analysis

To analyze appliance emission data for the study sample, ICF calculated descriptive statistics of the full data set and developed frequency graphs of unburnt methane to analyze trends across building type, appliance type and by region across the sample.

ICF calculated the average unburnt methane per appliance by appliance type and building type to quantify appliance-related emissions in the sample and by region. As part of this analysis, ICF developed factors for fraction of unburnt methane for each appliance end use by building type. First, ICF calculated a weighted average for each end use and building type using both appliance nameplate and appliance use factor (EOF) using the following equation:

$$Weighted\ average = \frac{\sum Fraction\ of\ unburnt\ methane\ \times\ EOF\ \times Nameplate\ value}{\sum EOF\ \times Nameplate\ value}$$

Next, ICF conducted additional statistical analysis of the data to account for the fact that the unburnt methane fractions were not normally distributed in their collected form. As noted above, because the logarithm of zero is undefined, fractions of unburnt methane that were reported as zero were replaced by half the lowest positive value to allow the logarithmic model to incorporate these values. The statistical model assumed that the logarithm of the adjusted nameplate value and the logit of the fraction of unburnt methane are normally distributed and can be correlated. The logit of a fraction F is defined as log(F/(1-F)) where log denotes the natural logarithm (base e). The adjusted nameplate value is the nameplate value multiplied by the appliance use factor (EOF).

The parameter of interest U is the weighted average of the fraction of unburnt methane, which is the expected value of the product of the adjusted nameplate and unburnt methane fraction divided by the expected value of the adjusted nameplate. The expected value is the estimated average across all appliances in California in the given region, building type, and end use category, not just the value for the sampled appliances. The logit of a fraction F is

defined as log(F/(1-F)) where log denotes the natural logarithm (base e). The parameters of this model are the means and variances of the log-adjusted nameplate and the logit of the unburnt methane fraction, together with their covariance. The logarithm of a fraction is always negative or zero. For each stratum, ICF computed an empirical estimate of U as the empirical weighted mean fraction (arithmetic mean of the adjusted nameplate x fraction unburnt divided by the arithmetic mean of the adjusted nameplate). This empirical estimate is given by the above weighted average equation, where the sums are across all appliances in the given stratum, which is defined by the region, building type, and end use category.

For the primary model, ICF also calculated an estimate of U from the fitted log adjusted nameplate and logit fraction unburnt methane statistical model. The value of U cannot be calculated as a simple function of the parameters of the fitted bivariate log-normal and logit-normal model; therefore, ICF approximated U by simulating 5,000 unburnt fraction and adjusted nameplate pairs from the fitted bivariate model and computing the weighted average of those 5,000 simulated pairs using the above weighted average equation.

To estimate the uncertainty of the lognormal/logit-normal model estimates, ICF used a parametric bootstrap method. For each of 1,000 bootstrap simulations, ICF randomly generated a data set of adjusted nameplate and fraction unburnt methane pairs for each measured appliance, using the fitted lognormal/logit-normal model. For each bootstrap simulation, ICF fitted the lognormal/logit-normal model to the simulated data set and then randomly generated 5,000 unburnt methane fraction and adjusted nameplate pairs from that statistical model. The weighted average from those 5,000 pairs is the estimated value of U from that bootstrap simulation. The bootstrapped 95 percent confidence interval for U is the 2.5th and 97.5th percentile of the 1,000 simulated weighted averages. The standard error of the estimated value of U is the sample standard deviation of the 1,000 simulated weighted averages. The results are shown in Table 2.

In some cases, the estimated variances were zero (all values equal or only one measured fraction). In these cases, or those in which there were less than 5 data points, ICF used the empirical weighted mean and—since these samples were too small and/or homogeneous to reliably fit the statistical model and support calculation of a non-zero standard error—represented uncertainty as zero. The results of the analysis showing the uncertainty ranges are summarized in APPENDIX D:
Uncertainty Graphs.

The process is summarized in Figure 4. The following equations are used in the flowcharts. They give the sample means, sample variances, sample covariance, and sample standard deviations for a sequence of N ordered pairs (X(1), Y(1)), (X(2), Y(2)), … (X(N), Y(N)).

Sample mean of X = $\overline{X} = \frac{\sum_{i=1}^{N} X(i)}{N}$

Sample mean of Y = $\overline{Y} = \frac{\sum_{i=1}^{N} Y(i)}{N}$

Sample variance of X = $S_{XX} = \frac{\sum_{i=1}^{N} (X(i) - \overline{X})^2}{N-1}$

Sample variance of Y = $S_{YY} = \frac{\sum_{i=1}^{N} (Y(i) - \overline{Y})^2}{N-1}$

Sample covariance of X and Y = $S_{XY} = \frac{\sum_{i=1}^{N}(X(i)-\bar{X})(Y(i)-\bar{Y})}{N-1}$

Sample standard deviation of X = $\sqrt{S_{XX}}$

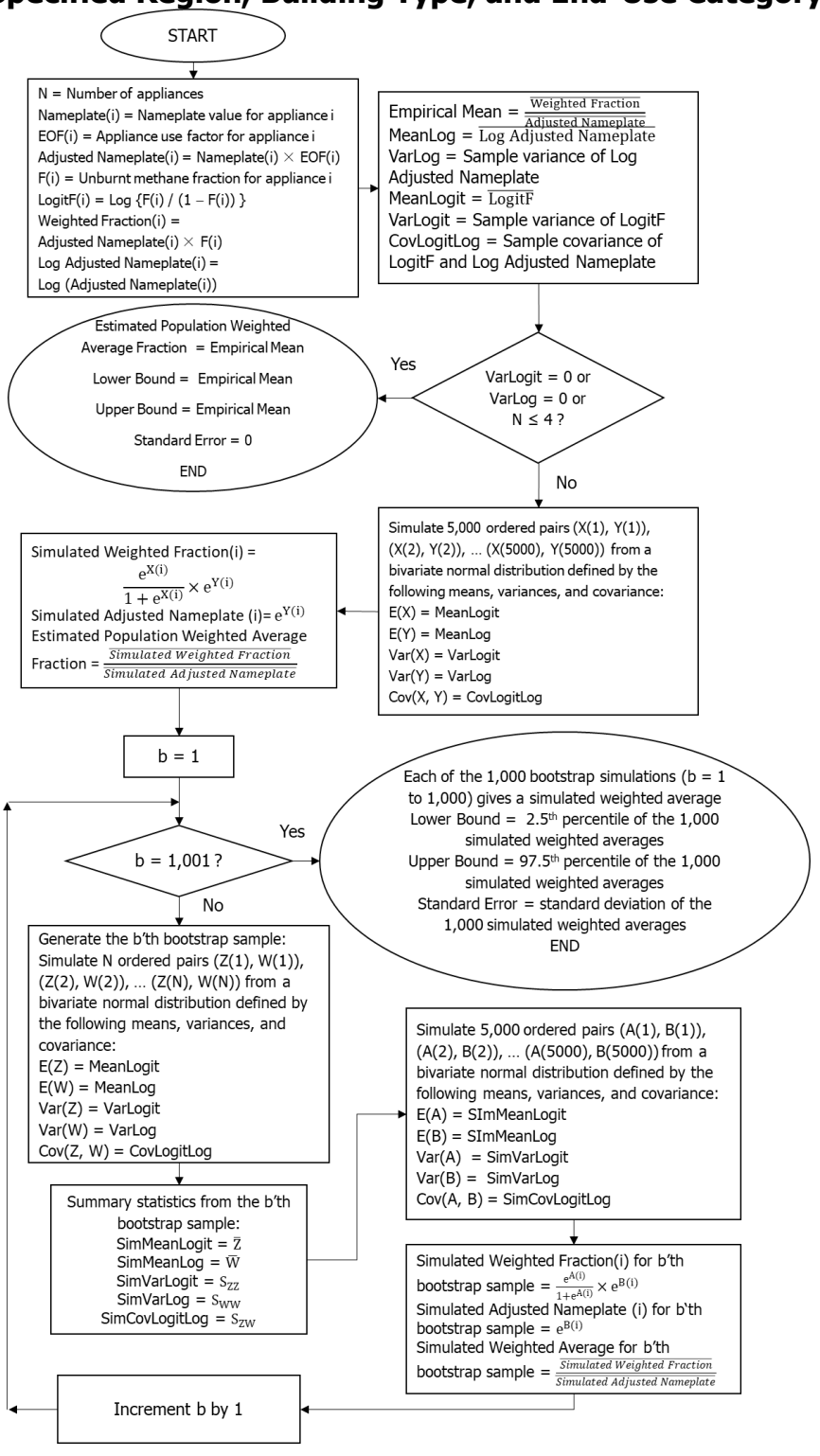
Sample standard deviation of Y = $\sqrt{S_{YY}}$

Table 2: Results of Logit-Normal/Log-Normal Model for Appliance Fraction of Unburnt Methane

Region	Building type	End use Category	Simulated Weighted Mean	Lower bound	Upper bound	Empirical mean used?
NorCal	Education	Other	4.4×10^{-7}	4.4×10^{-7}	4.4×10^{-7}	Yes
NorCal	Education	Space Conditioning	4.4×10^{-7}	4.4×10^{-7}	4.4×10^{-7}	Yes
NorCal	Education	Water Heating	9.8×10^{-6}	3.7×10^{-7}	1.7×10^{-4}	No
NorCal	Food	Cooking	6.6×10^{-4}	7.8×10^{-5}	5.7×10^{-3}	No
NorCal	Food	Other	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	Yes
NorCal	Food	Space Conditioning	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	Yes
NorCal	Food	Water Heating	3.6×10^{-3}	7.9×10^{-6}	0.17	No
NorCal	Lodging	Cooking	1.5×10^{-3}	8.3×10^{-5}	1.6×10^{-2}	No
NorCal	Lodging	Other	1.6×10^{-2}	1.6×10^{-2}	1.6×10^{-2}	Yes
NorCal	Lodging	Space Conditioning	2.4×10^{-4}	2.4×10^{-4}	2.4×10^{-4}	Yes
NorCal	Lodging	Water Heating	8.3×10^{-3}	4.6×10^{-4}	4.3×10^{-2}	No
NorCal	Office	Cooking	2.7×10^{-4}	3.0×10^{-6}	1.2×10^{-2}	No
NorCal	Office	Space Conditioning	4.4×10^{-7}	4.4×10^{-7}	4.4×10^{-7}	Yes
NorCal	Office	Water Heating	3.5×10^{-4}	1.4×10^{-5}	3.5×10^{-3}	No
NorCal	Warehouse	Space Conditioning	4.4×10^{-7}	4.4×10^{-7}	4.4×10^{-7}	Yes
NorCal	Warehouse	Water Heating	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}	Yes
SoCal	Education	Cooking	1.9×10^{-4}	1.9×10^{-4}	1.9×10^{-4}	Yes
SoCal	Education	Space Conditioning	1.2×10^{-4}	1.2×10^{-4}	1.2×10^{-4}	Yes
SoCal	Education	Water Heating	1.1×10^{-5}	9.9×10^{-8}	3.7×10^{-4}	No
SoCal	Food	Cooking	2.9×10^{-3}	3.9×10^{-4}	1.9×10^{-2}	No
SoCal	Food	Other	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	Yes
SoCal	Food	Space Conditioning	3.9×10^{-2}	2.6×10^{-3}	0.14	No
SoCal	Food	Water Heating	1.0×10^{-2}	2.3×10^{-5}	0.27	No
SoCal	Lodging	Cooking	3.2×10^{-2}	2.4×10^{-4}	0.16	No
SoCal	Lodging	Other	2.1×10^{-4}	2.3×10^{-6}	8.5×10^{-4}	No
SoCal	Lodging	Water Heating	3.2×10^{-5}	3.7×10^{-6}	5.4×10^{-4}	No
SoCal	Office	Cooking	3.1×10^{-3}	1.3×10^{-4}	3.2×10^{-2}	No
SoCal	Office	Space Conditioning	6.3×10^{-7}	3.6×10^{-7}	1.1×10^{-6}	No
SoCal	Office	Water Heating	5.4×10^{-3}	3.1×10^{-4}	3.3×10^{-2}	No
SoCal	Retail	Space Conditioning	1.1×10^{-5}	4.6×10^{-7}	3.0×10^{-4}	No
SoCal	Retail	Water Heating	2.3×10^{-5}	2.3×10^{-5}	2.3×10^{-5}	Yes
SoCal	Warehouse	Space Conditioning	2.7×10^{-3}	2.1×10^{-5}	2.0×10^{-2}	No
SoCal	Warehouse	Water Heating	7.7×10^{-4}	7.7×10^{-4}	7.7×10^{-4}	Yes

Source: ICF

Figure 4: Flowchart for Calculating Estimates and Confidence Intervals for Population-Weighted Average Fraction (U) of Unburnt Methane for Appliances from Specified Region, Building Type, and End-Use Category



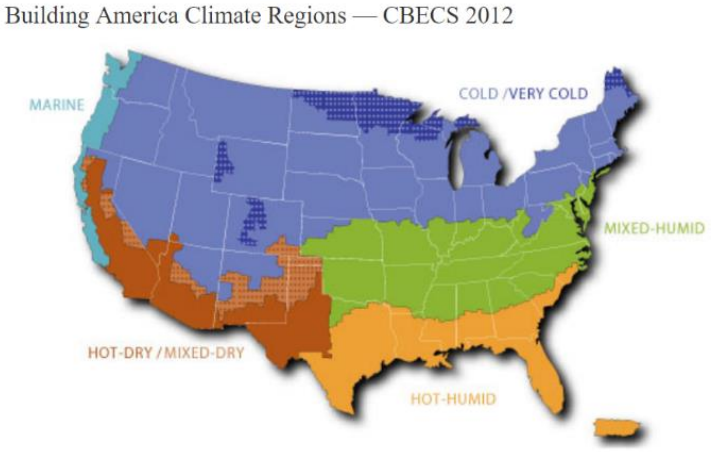
Source: ICF

Statewide and Regional Estimates

ICF estimated the California-wide appliance emissions by applying the unburned methane factors by appliance and building type to the regional and statewide gas consumption for those categories. The first step in this analysis was to develop a statewide summary profiling natural gas consumption by those categories. The team analyzed the 2012 EIA Commercial Building Energy Consumption Survey (CBECS) microdata to determine the natural gas consumption by building type, climate region, and end use within the Pacific Region (Alaska, Hawaii, California, Washington, Oregon).

- Building types: education, food service, lodging, office, retail, warehouse, other.
- Climate regions: hot-dry/mixed-dry/hot-humid, marine, very cold/cold, withheld to protect confidentiality
- Natural gas end uses: space heating, cooling, water heating, cooking, miscellaneous

Figure 5: Commercial Building Energy Consumption Survey Climate Region Map



Source: Commercial Building Energy Consumption Survey

Next, the team used EIA Form 176 data from 2012 to divide the Pacific Region total natural gas consumption into Northern California, Southern California and Other (Alaska, Hawaii, Washington, Oregon). The Northern California and Southern California regions were determined by the boundaries of Southern California Gas and Pacific Gas & Electric.

With the total Northern California and total Southern California natural gas consumption now known, the CBECS natural gas use by building type was then allocated using California's climate regions to sum to the Northern and Southern California totals. Using the CBECS Climate Regions map, the project team assumed that Southern California consists entirely of the Hot-Dry/Mixed-Dry climate while Northern California consists of Hot-Dry/Mixed Dry and Marine climates. Additionally, all of the Hot-Dry/Mixed-Dry climate from the Pacific Region was assumed to be in California. It was also assumed that the Cold/Very Cold climate in Northern California and any Marine climate in Southern California were negligible compared to the main climate regions. The climate zones were used to disaggregate the Pacific region data rather than to analyze climate impacts.

Figure 6: California Natural Gas Utility Service Area

Source: California Energy Commission

Lastly, the project team projected the 2012 Northern and Southern California data to 2016 using the natural gas data by utility in 2016 from EIA Form 176.

Statewide Appliance Emissions Estimate

California's commercial building emissions from appliances were estimated by applying the weighted average percentage of unburnt methane by building type and end use as outlined in the Sample-level Analysis to the volume of natural gas consumed by a given building type as outlined in Statewide and Regional Estimates. These values were aggregated to determine a statewide emissions estimate as shown in the following equation.

$$E_{CA} = \sum (A_{i,e,R} \times C_{i,e,R})$$

Where:

E_{CA} = California's commercial building emissions from appliances (scf)

$A_{i,e,R}$ = Unburnt methane percentage from region R (i.e., Northern California or Southern California), building type i (i.e., education, food, lodging, office, retail, warehouse, and other), end use e (i.e, space heating, water heating, cooking, miscellaneous) = Simulated Weighted Mean

$C_{i,e,R}$ = Natural gas consumption in region R for end use e within buildings of type i.

The standard deviation of the estimated statewide emissions is estimated by

$$S_{CA} = \sqrt{\sum SE(A_{i,e,R})^2 \times C_{i,e,R}{}^2}$$

Where:

S_{CA} = Estimated standard deviation of statewide commercial building emissions from appliances (scf)

$SE(A_{i,e,R})$ = Standard error of estimated unburnt methane fraction from region R, building type i, and end use e.

Using a normal approximation, a 95% confidence interval for the estimated statewide emissions is given by

$$E_{CA} \pm 1.96\, S_{CA}$$

The value 1.96 is the 97.5th percentile of a standard normal distribution.

The above summations for the statewide emissions are across all combinations of region, building type, and end use category.

If the above summations are instead across the building types and end use categories for only one of the regions, then the same formulae can be used to estimate regional emissions with 95 percent confidence intervals.

For estimating the total emissions from a specific region R, building type i, and end use e, the confidence intervals were calculated by multiplying the confidence intervals for the unburnt methane percentages, by the applicable natural gas consumption for the given region, building type, and end use. This is more accurate than using the normal approximation.

Pipe-Related Fugitive Methane Measurements

At each participating site, GTI collected three pieces of information about fugitive methane at pipe joints:

- The number of pipe joints identified/observed in the testing area
- The number of pipe joints tested to see if there was any fugitive methane
- Of the pipe joints that did have fugitive methane, the quantity of these emissions in standard cubic centimeters per minute (SCCM) of methane

During testing, the team measured each pipe joint emitting fugitive methane multiple times to create an average value for SCCM of methane. The first step in the analysis was to convert each average SCCM value to standard cubic feet per minute (SCFM) for ease of comparison with appliance-level emissions. ICF also converted values to annual emissions assuming continuous leakage and to costs to quantify the value of fugitive methane for site participants based on commercial natural gas rates. To compare pipe emissions to appliance emissions, ICF calculated the average cubic feet of methane from pipe joint leaks per building by sector in the sample and multiplied that by the total number of buildings in that sector in California using 2012 CBECS data. These figures were then projected to 2017 using the 2016 U.S. Census County Business Patterns data and then using a linear regression of the number of establishments from 2012 to 2016, the estimates were extrapolated to 2017 assuming similar growth.

Site-Specific Analysis

To prepare the site-specific report provided to each participating site, ICF analyzed site-specific results of fugitive methane from pipe values by joint type (for example threaded joint, valve, quick connect, flange, union, regulator and other) to calculate the total SCFM and the related cost equivalent of the gas.

Sample-Level Analysis

To analyze fugitive emission data in the study sample, ICF calculated descriptive statistics of the full data set and developed frequency charts to analyze the overall magnitude of 'leaking' vs 'non-leaking' pipes by joint type and building type. ICF developed graphs of average fugitive methane volumes to analyze trends across joint type and building type and graphs of total fugitive methane volumes to analyze trends across joint type and building type. ICF also calculated total emissions from fugitive methane from pipe joints in the sample as well as average annual emissions per building type.

Next, ICF used SAS to conduct additional statistical analysis to account for the fact that the fugitive methane from pipe joints is not normally distributed. The pipe analyses are stratified by region and building type. For pipes, the building fugitive methane rate (total annual SCF summed over all pipe measurements per year) was estimated as the sum of all the annual SCF measurements. Fugitive methane rates reported as zero were replaced by half the lowest positive measured value to account for non-detected emissions and to allow a logarithmic analysis of the results (logarithm of zero is undefined).

Out of the 15,490 reported measurements pipe-related fugitive methane, 260 were non-zero (specifically at or above the detection limit), and the remaining 15,230 (98.3 percent) were below the detection limit. The lowest reported positive building fugitive methane volume was 0.29 SCF per year. The building fugitive methane volumes reported as zero were replaced by 0.15 SCF per year.

For each region and building type, the sample mean (empirical mean) of the building fugitive methane volumes was used to estimate the population mean building emissions rate. To estimate the uncertainty of the estimated population mean building fugitive methane volume, ICF used a non-parametric bootstrap method. Suppose that a region and building type combination had N sampled buildings. For each of 1,000 simulations, a simple random sample of N of those buildings was selected at random with replacement. Thus, one or more of the original set of N buildings can be selected more than once to create the new simple random sample. For each simulation, the sample mean from the new simple random sample is calculated. The bootstrapped 95 percent confidence interval is the 2.5th and 97.5th percentile of the 1,000 simulated sample means. The standard error of the mean is the sample standard deviation of the 1,000 simulated sample means. The results are shown in Table 3 and the process is summarized in Figure 7.

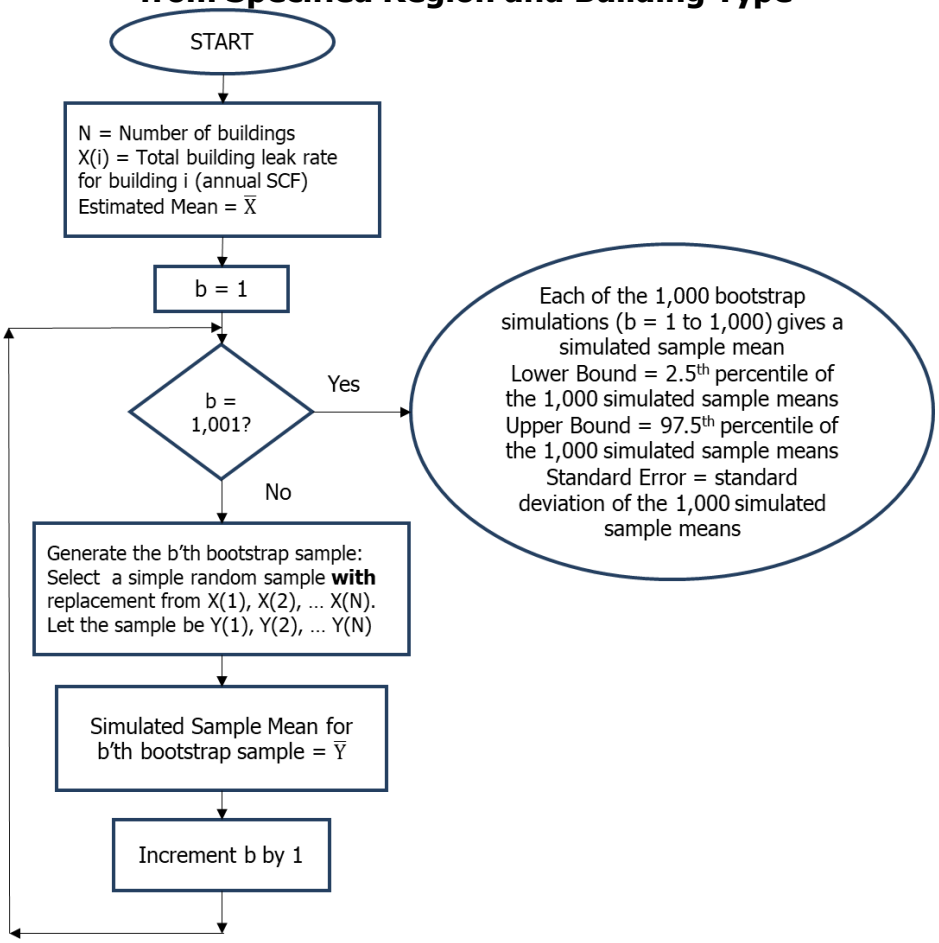
Not all pipe joints were accessible for inspection or testing during the site visit and it was determined that it was not feasible to estimate the total number of pipe joints in each building. To account for this fact on-site, the project team developed scenarios to account for inaccessible and thus unmeasured pipes. The two scenarios developed assumed that the study testing accounted for 75 percent or 50 percent of total building pipe joints. To obtain methane emission values for these scenarios, ICF divided the regional and statewide methane pipe-related fugitive methane volumes by 0.75 and 0.5 to obtain an expanded estimate of methane emission values.

Table 3: Results of Nonparametric Model for Building Total Pipe-Related Fugitive Methane (Annual Standard Cubic Feet)

Region	Building Type	Sample Size	Mean	Lower Bound	Upper Bound	Standard Error
NorCal	Education	19	243.9	80.3	474.7	100.4
NorCal	Food	7	235.6	32.6	473.8	115.8
NorCal	Lodging	22	222.8	93.0	429.7	91.8
NorCal	Office	11	395.2	81.0	932.7	239.2
NorCal	Warehouse	2	76.5	14.5	138.4	43.0
SoCal	Education	5	582.0	29.7	1146.6	312.3
SoCal	Food	7	701.4	146.9	1503.0	356.5
SoCal	Lodging	8	446.0	100.8	1063.2	276.7
SoCal	Office	11	186.2	31.6	395.4	89.5
SoCal	Retail	5	32.5	13.1	54.6	11.0
SoCal	Warehouse	3	26.4	5.3	58.9	13.4

Source: ICF

Figure 7: Flowchart for Calculating Estimates and Confidence Intervals for Population Mean Building Leak Rate for Pipes from Specified Region and Building Type



Source: ICF

Statewide and Regional Estimates

To estimate California-wide pipe joint methane emissions from the study sample analysis, the mean emissions for each building type and region were multiplied by the number of buildings in each category. The project team first needed to develop a statewide summary profiling the number of buildings by type and region. The team analyzed the 2012 CBECS microdata to determine the number of buildings using natural gas by building type and by climate region within the Pacific Region (Alaska, Hawaii, California, Washington, Oregon) as a method do disaggregate Northern and Southern California within the Pacific Region.

- Building types: education, food service, lodging, office, retail, warehouse, other
- Climate regions: hot-dry/mixed-dry/hot-humid, marine, very cold/cold, withheld to protect confidentiality

Next the number of buildings by type in the Pacific was allocated to Northern California and Southern California. This allocation followed the same methodology outlined in the Appliance Statewide and Regional Estimates section for natural gas consumption where the building counts in the Pacific region were divided into Northern California and Southern California based on percentages derived from a combination of EIA's Form 176 and CBECS Climate Regions.

The project team then projected the 2012 Northern and Southern California building counts to 2016 using the U.S. Census County Business Patterns data from 2012 and 2016. The number of business establishments for selected NAICS codes were used to project the change in the number of buildings over time. The crosswalk between the relevant NAICS codes and each building type can be found in Appendix A.

Additionally, each county was attributed to Northern or Southern California based on their location and the utility that serves that county. The counties in Northern California and Southern California were determined by the boundaries of Southern California Gas and Pacific Gas & Electric service territories. In counties where both utilities serve customers, the utility was allocated to the region that aligned with the utility that serviced more customers. Using the combination of building establishments for the relevant NAICS codes and the counties to determine Northern vs Southern, the County of Business Patterns data was able to provide a number of establishments by building type by region for 2012 and 2016. The ratio between these two numbers was then applied to the 2012 building counts to get the building counts in 2016. Lastly, using a linear regression of the number of establishments from 2012 to 2016, the estimates were extrapolated to 2017 assuming similar growth.

Statewide Pipe Emissions Estimate

Next, the team generated estimates for pipe-related fugitive emissions across California's commercial buildings. California's pipe-related fugitive emissions were estimated by applying the average methane volume per building by building type as outlined in the Sample-level Analysis to the number of buildings in California of that building type as outlined in Statewide and Regional Estimates. These values were aggregated for all building types to determine a statewide emissions estimate as shown in the equation below.

$$M_{CA} = \sum (M_{i,R} \times N_{i,R})$$

Where:

M_{CA} = Fugitive methane volume across all California's commercial buildings (scf)

$M_{i,R}$ = Average fugitive methane rate for building type i (e.g., education, office, etc.) in region R (i.e., Northern California or Southern California)

$N_{i,R}$ = Number of buildings of type i in region R

The standard deviation of the estimated statewide emissions is estimated by

$$SM_{CA} = \sqrt{\sum SE\left(M_{i,R}\right)^2 \times {N_{i,R}}^2}$$

Where:

SM_{CA} = Estimated standard deviation of region R's commercial building volume (scf)

$SE(M_{i,R})$ = Standard error of estimated average annual pipe-related fugitive methane volume from building type i and region R.

Using a normal approximation, a 95% confidence interval for the estimated emissions in region R is given by

$$M_{CA} \pm 1.96\, SM_{CA}$$

The above summations for the statewide emissions are across all combinations of region and building type.

If the above summations are instead across the building types for only one of the regions, then the same formulae can be used to estimate regional emissions with 95% confidence intervals.

For estimating the total emissions from a specific region R and building type i, the confidence intervals were calculated by multiplying the confidence intervals for the average fugitive methane rate, given in Table 3 above, by the fugitive methane volume for the given region and building type. This is more accurate than using the normal approximation.

CHAPTER 3:
Project Results

Site Level Findings

The analysis contains on-site assessment results from 101 sites[6], of which 61 are in Northern California and 40 in Southern California. The study sample includes more than 20 buildings from each of the most prevalent building types (specifically office, education, food service), 14 from lodging, six from retail, and five warehouses. Table 4 presents the breakdown of sites tested by region and building sector.

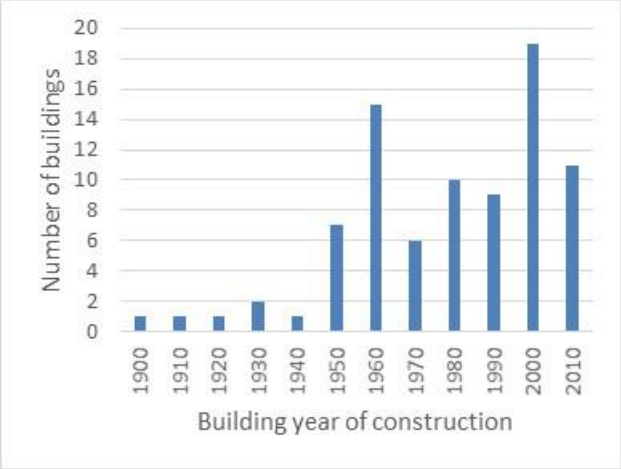
Table 4: Sites by Region and Building Sector

Building Sector	NorCal	SoCal	Total
Office	11	11	22
Lodging	7	7	14
Retail	0	6	6
Education	20	5	25
Food Service	21	8	29
Warehouse	2	3	5
Total	61	40	101

Source: ICF

Due the nature of the recruitment process and scope of the measurement effort, the sample is small and biased towards urban areas, newer buildings and, because of the nature of the recruitment process those with engaged energy managers. As can be seen in Figure 8, most buildings were not constructed until the 1950s or afterwards.

Figure 8: Distribution of Building Year of Construction by Decade



Source: ICF

6 Site measurements were collected from 103 sites; however, 2 sites were removed from the analysis sample as they did not align with the study sample's building category definitions.

Appliance Emissions

Appliances align with four end uses: space conditioning, water heating, cooking, and "other". Across the study sample buildings, there was a diversity of appliances analyzed, as shown in Table 5. The on-site testing team was not able to test every appliance within a given building due to a variety of reasons, such as inaccessible spaces or appliances that were not running during the visit. Throughout the study, 924 appliances were observed and 429 were tested.

Table 5: Appliance Data Breakdown

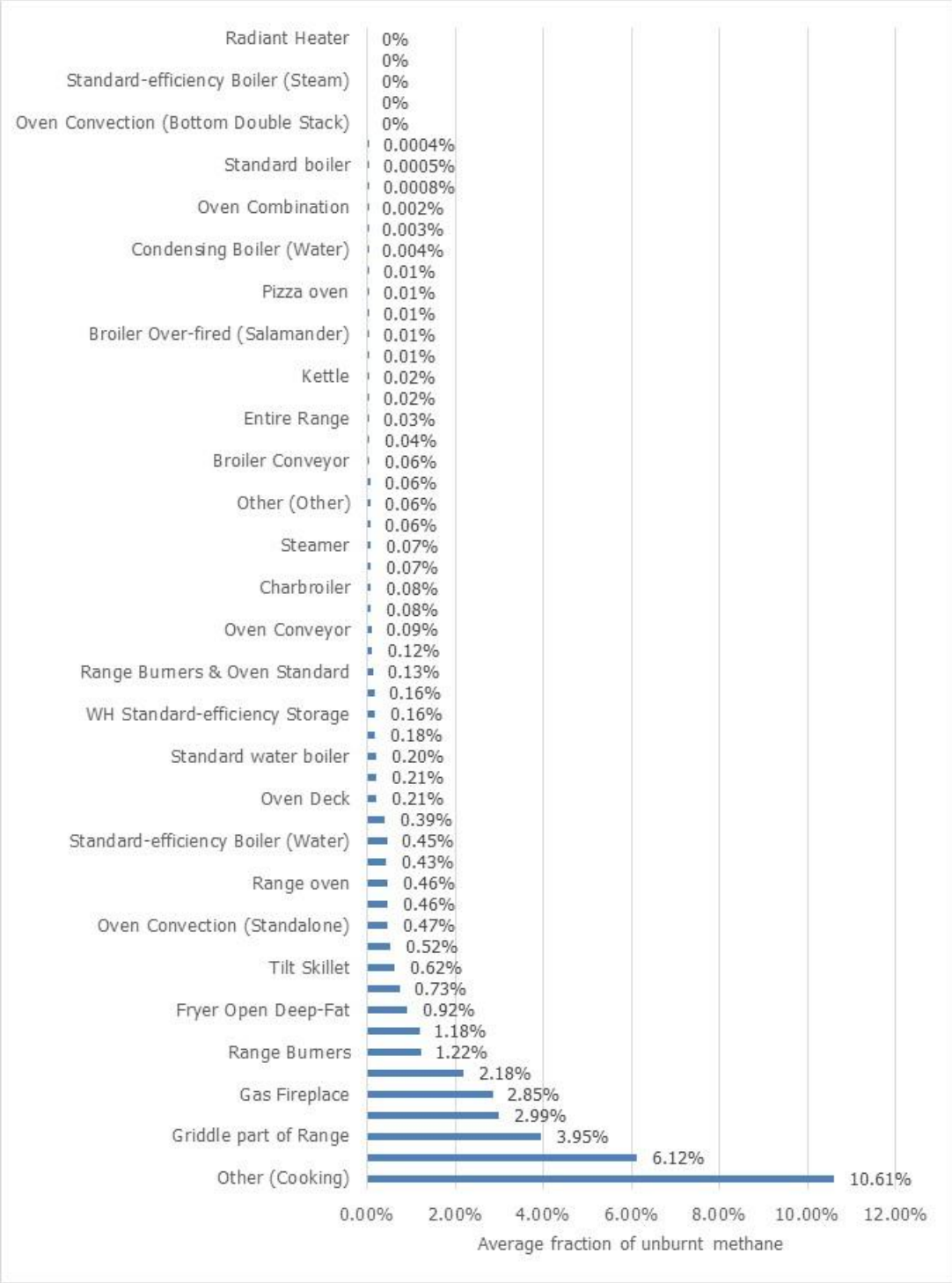
Appliance Type	# of Appliances Total	# of Appliances Tested
Space Conditioning		
Duct furnace	1	1
Duct heater	1	0
Fire pit	2	2
Furnace Standard	18	12
HVAC (Other)	1	0
HVAC (RTU)	83	36
HVAC (Swamp Cooler)	12	0
HVAC (Unknown)	6	0
Infrared Heater	62	15
Radiant Heater	7	3
Unit Heater	33	4
Water Heating		
Boiler	1	0
Condensing Boiler (Water)	44	38
Electric	1	0
Pool/Spa Heater	4	3
Standard boiler	7	6
Standard tank water heater	3	3
Standard water boiler	3	3
Standard-efficiency Boiler (Steam)	3	2
Standard-efficiency Boiler (Water)	104	64
Unknown (Water Heating)	1	0
Water heater	3	3
WH Condensing Storage	7	5
WH Standard-efficiency Storage	43	33
WH Standard-efficiency Storage & Furnace Standard	1	1
WH Standard-efficiency Tankless	10	8
Cooking		
Broiler Conveyor	2	1
Broiler Over-fired (Cheesemelter)	1	1
Broiler Over-fired (Salamander)	3	1

Appliance Type	# of Appliances Total	# of Appliances Tested
Broiler Under-fired (Charbroiler)	18	15
Charbroiler	1	1
Chinese Range	7	4
Convection Ovens, Stacked	1	1
Entire Range	1	1
Fryer Open Deep-Fat	42	20
Gas grill	8	4
Griddle part of Range	7	5
Griddle part of Range & Oven Standard (Under-Range)	1	1
Griddle Standalone	20	15
Grill	2	2
Kettle	4	2
Other (Cooking)	9	7
Oven Combination	22	13
Oven Convection (Bottom Double Stack)	8	3
Oven Convection (Standalone)	3	2
Oven Convection (Top Double Stack)	9	5
Oven Convection (Under-Range)	2	1
Oven Conveyor	6	3
Oven Deck	1	1
Oven Rack	2	1
Oven Standard (Bottom Double Stack)	1	0
Oven Standard (Under-Range)	27	11
Oven under range	1	0
Pizza oven	2	2
Range and griddle	2	2
Range Burners	34	26
Range Burners & Oven Standard	1	1
Range oven	2	1
Residential oven under range	1	1
Residential range	1	1
Smoker (Bottom of Stacked)	1	0
Smoker (Top of Stacked)	1	1
Steam Kettle	1	0
Steamer	7	2
Stock Pot Range	1	0
Tilt Skillet	13	9
Unknown (Cooking)	2	1

Source: ICF

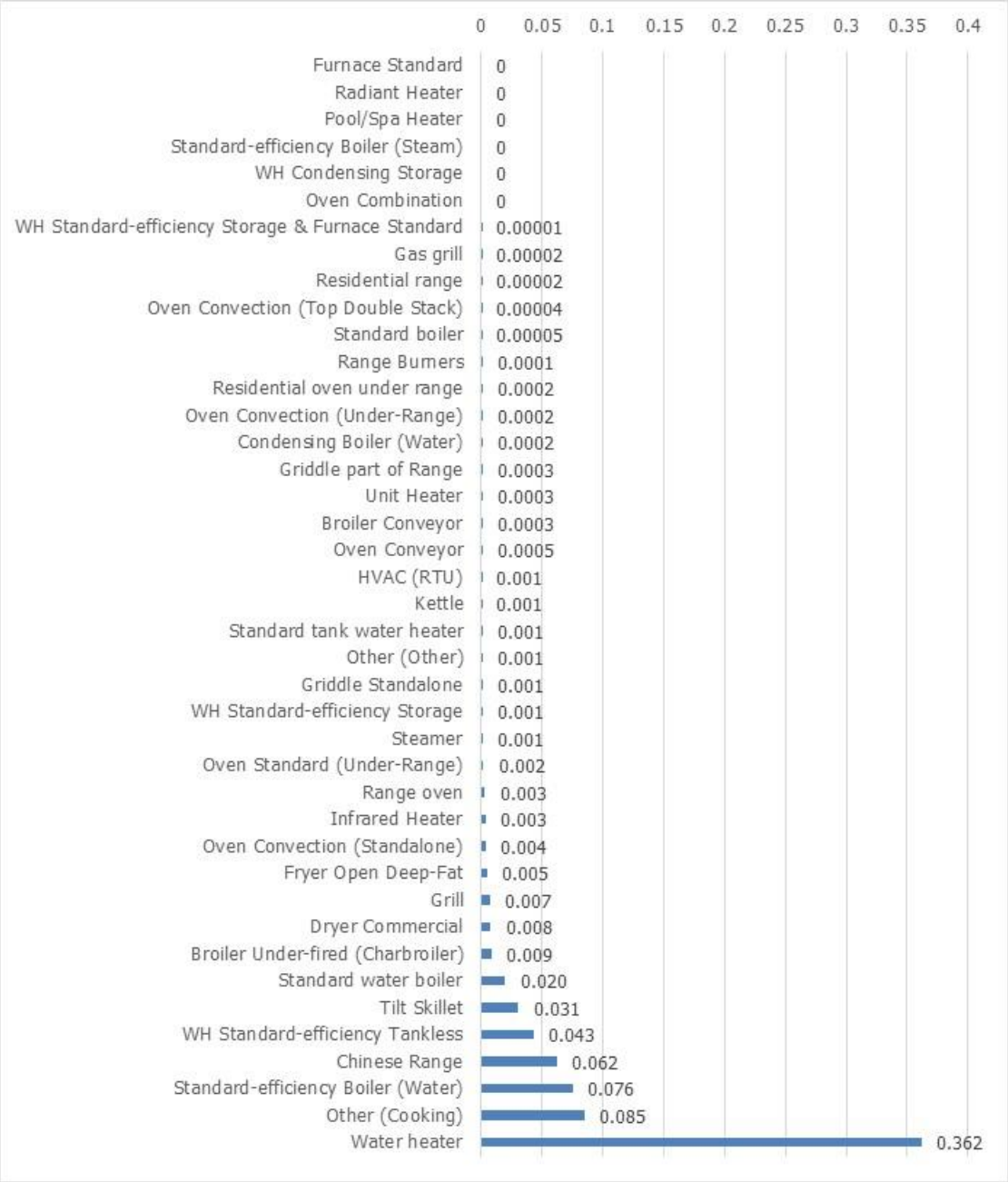
Figure 9 shows the average fraction of unburnt methane by appliance type. A poorly maintained outdoor grill at a university dormitory had the highest unburnt methane value. A commercial water heater running in an unusual configuration and control scheme had the second highest average fraction of unburnt methane values, followed by cooking appliances, such as griddles and miscellaneous cooking appliances. Figure 10 shows a similar ranking in terms of estimated SCFM emitted.

Figure 9: Average Fraction of Unburnt Methane by Appliance Type



Source: ICF

Figure 10: Average Unburnt Methane by Appliance Type (Standard Cubic Feet per Minute)



Source: ICF

Pipe-Related Fugitive Emissions

The gas detection team identified a total of 17,584 pipe joints, tested 15,288 joints for fugitive methane, and identified 330 joints where fugitive methane was present. Based on these findings, 2.2 percent of tested connections had pipe-related fugitive methane. As Table 6 shows, roughly 1–2 percent of threaded joints, valves, quick connects, and other types of joints identified had pipe-related fugitive methane, about 3 percent of flanges and regulators identified had fugitive methane, and more than 4 percent of unions identified had fugitive methane. Despite the small percentage of joints with pipe-related fugitive emissions, threaded joints were the most prevalent type of joint assessed with pipe-related fugitive emissions.

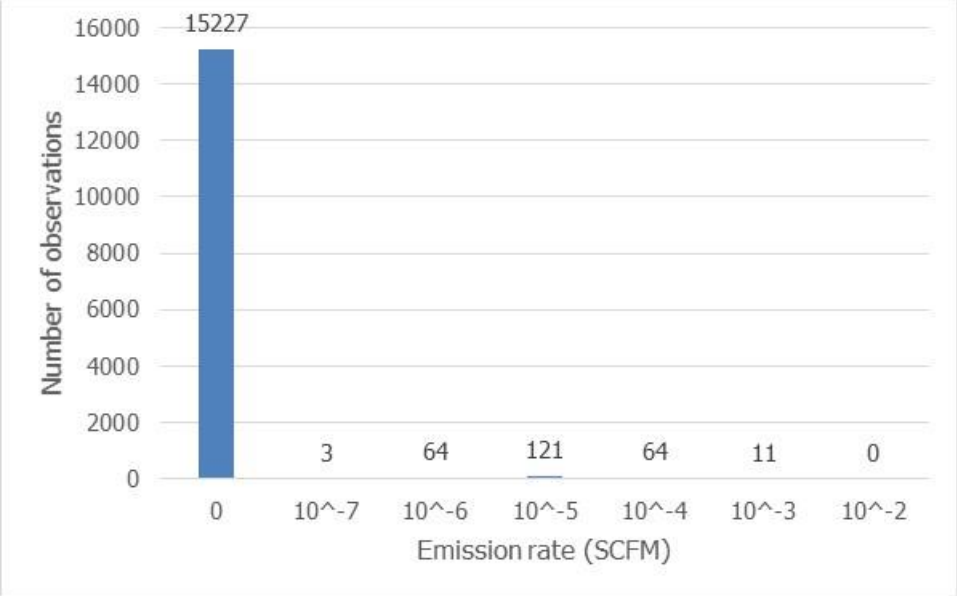
Table 6: Pipe Data Breakdown

Pipe Joint Type	Number of Joints Identified	Number of Joints Tested	Number of Joints with Methane	% of Joints with Methane
Threaded joints	14,056	12,318	253	2.1%
Valves	1,605	1,206	29	2.4%
Quick connects	177	163	2	1.2%
Flanges	212	199	6	3.0%
Unions	481	436	20	4.6%
Regulators	207	196	6	3.1%
Other	846	770	14	1.8%
Total	17,584	15,288	330	2.2%

Source: ICF

As shown in Figure 11, the vast majority of tested pipe joints (15,288) did not have any fugitive methane. Most pipe joints that did have fugitive methane emitted in the $1x10^{-5}$ SCFM range. No pipe joints emitted more than 0.01 SCFM methane.

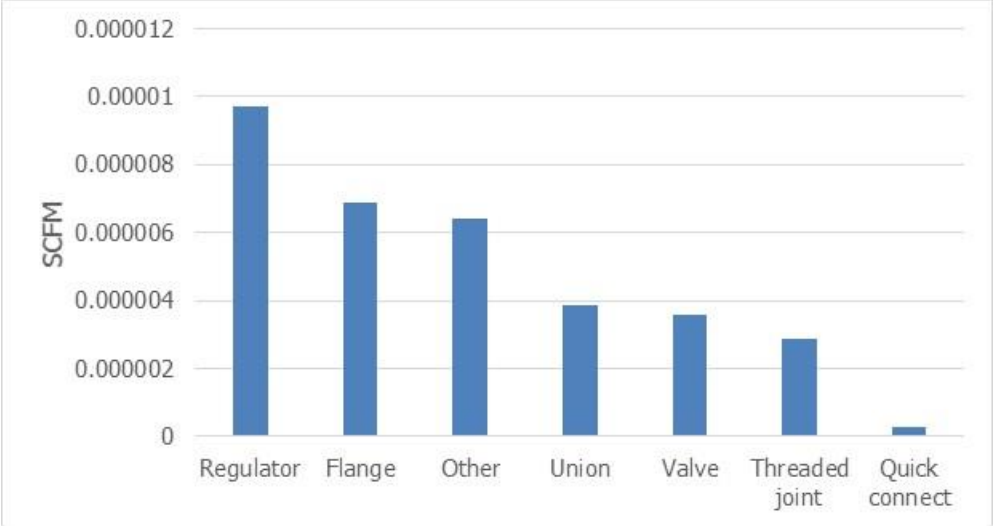
Figure 11: Distribution of Pipe Emissions (Standard Cubic Feet per Minute)



Source: ICF

Figure 12 shows the simple average SCFM methane released per pipe joint type during the study. Overall, regulators had the highest average SCFM methane values; however, average SCFM methane values per pipe joint type were similar overall.

Figure 12: Average Standard Cubic Feet per Minute Methane by Pipe Type



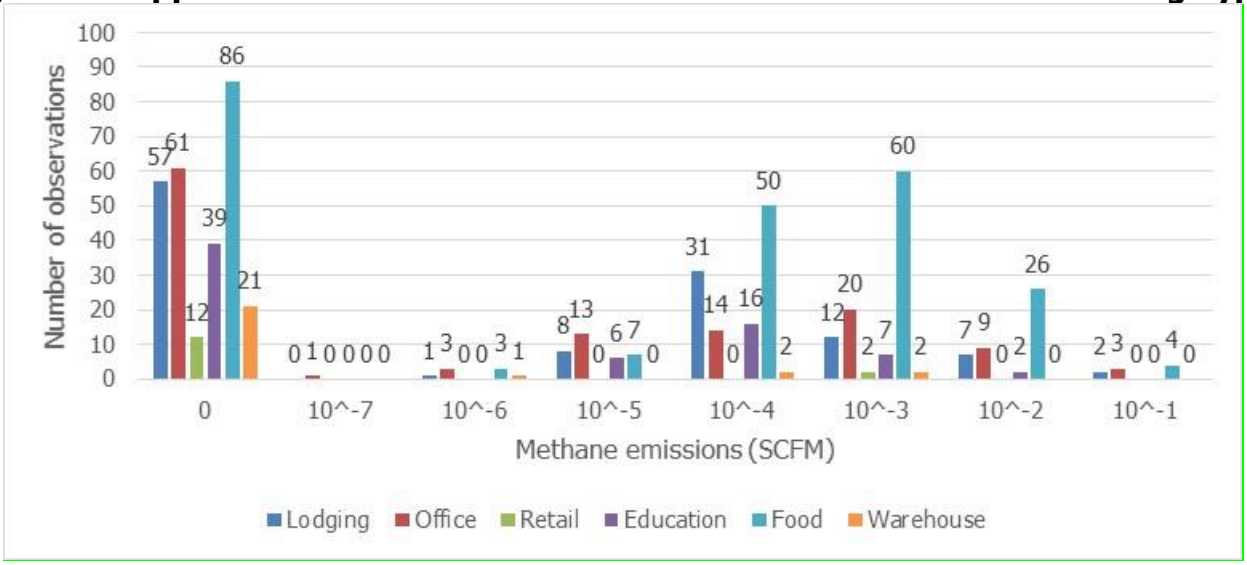
Source: ICF

Building-Type Level Findings

Appliance Emissions

Figure 13 shows the distribution of appliance emission measurements across the six different building types.[7] Food service buildings tended to have more appliances with high unburnt methane values, followed by office and lodging buildings. The distribution of emission values was lowest for retail and warehouse buildings, though there were few measurements in these two building types to begin with.

Figure 13: Appliance Unburnt Methane Emission Distribution Across Building Types



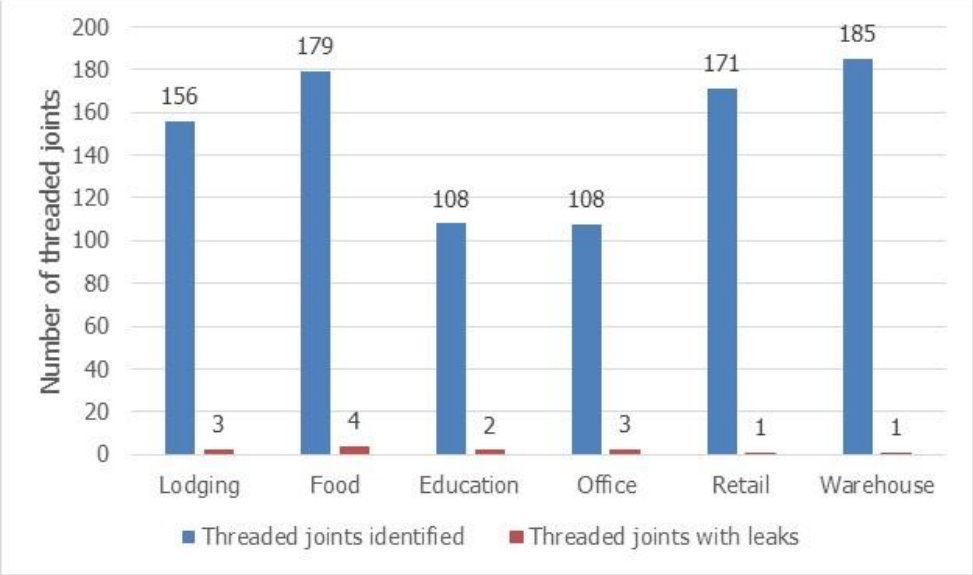
Source: ICF

[7] Of the 429 measurements, 98 percent had no or very minimal unburnt methane exhaust. Such a skewed distribution does not allow for easy interpretation of potential patterns in the data. For such distributions, the log transformation can be applied to make patterns in the data more interpretable.

Pipe-Related Fugitive Emissions

Figure 14 shows the breakdown of average number of pipe joint with fugitive methane per building by building type for threaded joints, the most common type of pipe joint. The vast majority of pipe joints tested did not have fugitive methane, and those that did exist tended to be very small. Only five pipe joints yielded more than 1,000 cubic feet of methane per year.

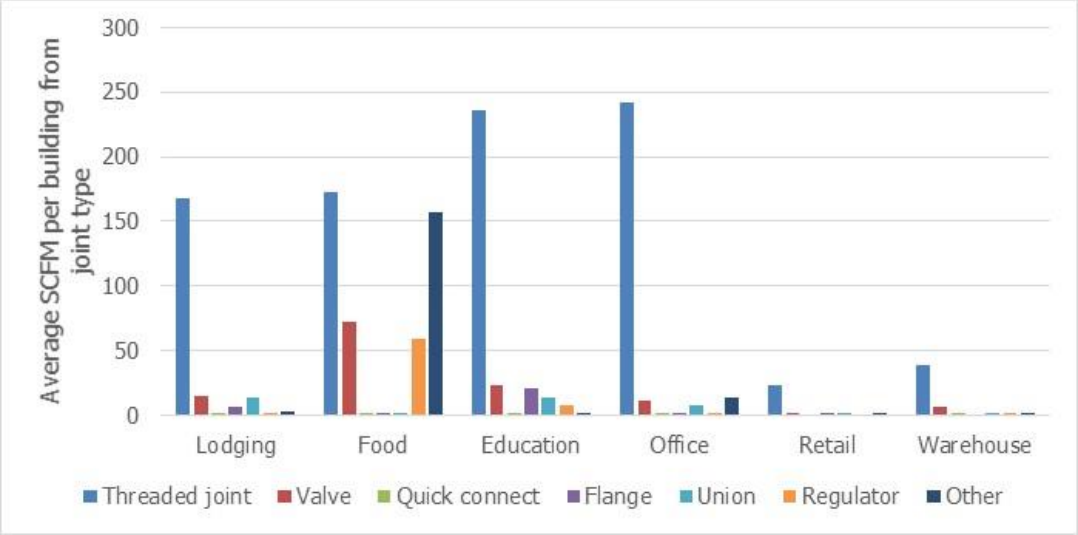
Figure 14: Average Count of Threaded Joints with Fugitive Methane per Building



Source: ICF

The project team estimated the annual magnitude of pipe-related methane tested. Figure 15 shows the average methane emissions per year that would be released from the different sampled buildings by sector based on their test results, including those joints that tested with no emissions. Overall, threaded joints produced the most annual emissions due to the higher number of these pipe joint types. In food service buildings, however, valves, regulators, and other pipe joint types also produced significant methane emissions.

Figure 15: Estimated Pipe-Related Methane Across Building Types (Standard Cubic Feet per Minute)



Source: ICF

Regional and State-Level Findings

The emission results associated with the study sample discussed in the previous two sections, were then used to analyze regional and statewide emissions. In addition to the six building types in the sample, ICF estimated the emissions from "other" buildings, to account for the commercial buildings in the state that do not align with the six categories in the study sample. To estimate the results for "other" buildings, ICF used the average of unburnt methane across the sample and applied it to the 2012 CBECS data; thus, the trends in this building type mirror trends from the other types. Because of this, the "other" category of buildings is not reflected in the following graphs but is incorporated in the statewide total for methane emissions.

Graphs with error bars to show uncertainty are located in APPENDIX D: Uncertainty Graphs.

Appliance Emissions

Although there were several hundred appliances measured across the entire study, at the building type/end use level, there are some cases that are represented by as few as one data point. If that data point is unusually high, as seems to be true in a few cases, it creates a very high result for the state-level results in that category. The state-level emissions for these categories and for the affected building types may therefore be over-estimated. Additional site measurements would be required to provide improved estimates. In the interim, an alternative analysis addressing this potential was developed.

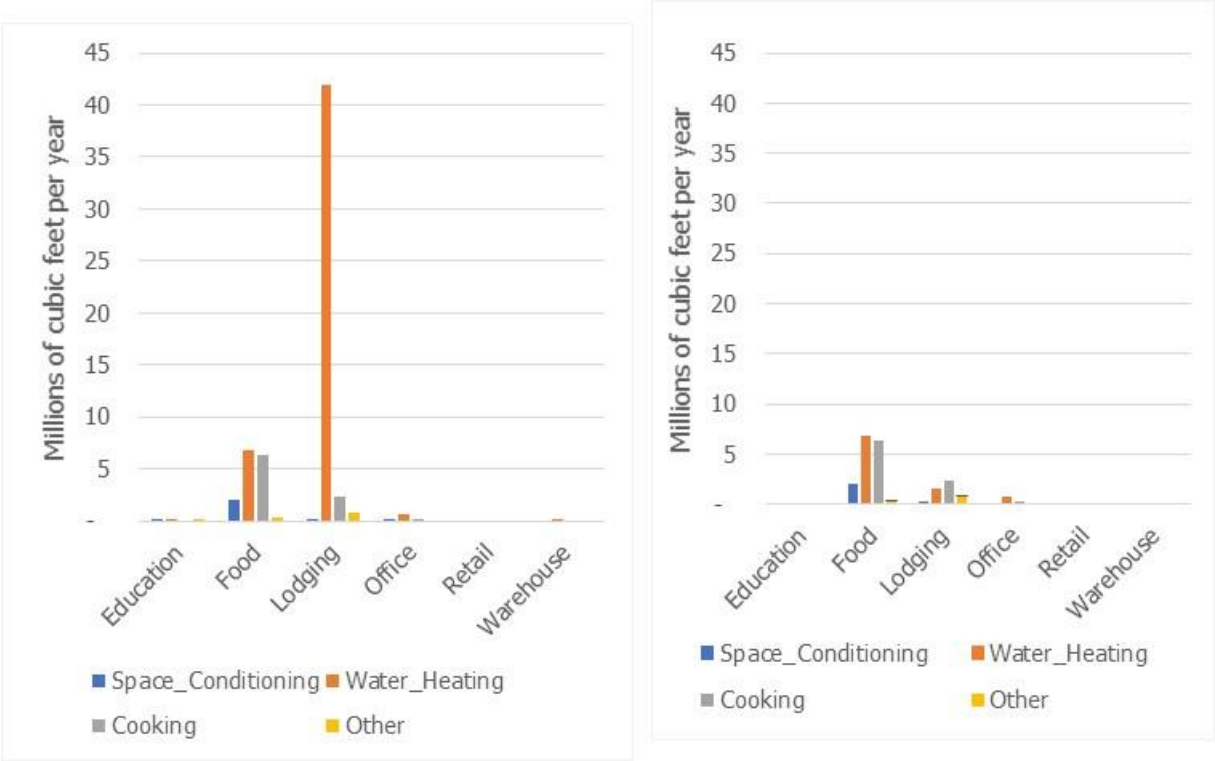
There were three categories where this issue was evident:

- Water heating in lodging in Northern California
- Cooking in lodging in Southern California
- Heating in food in Southern California

The approach for the alternative analysis was to substitute the average of the unburnt methane values across all building types for the relevant appliance type in the problematic building type. For example, the average unburnt methane value for all Southern California cooking appliances was substituted for the single anomalous measurement for cooking appliance in lodging.

The following graphs show estimated methane emissions in millions of cubic feet per year by building type in Northern and Southern California for the results as-measured and for the alternative analysis. In Northern California, almost 42 million cubic feet of methane per year is estimated from water heating appliances in lodging buildings in the as-measured estimate (Figure 16). Water heating is also a significant driver of emissions in food service buildings, contributing 6.8 million cubic feet of methane annually. Similarly, cooking appliances in food service buildings contribute about 6.3 million cubic feet of methane per year. The spike in emissions associated with water heating activity in the lodging building category as-measured is driven by two water heaters in one hotel and therefore may not be representative of the sector. The alternative analysis substituted the region-wide water heating value for the measured value in lodging, resulting in the regional value being reduced to 1.6 million cubic feet.

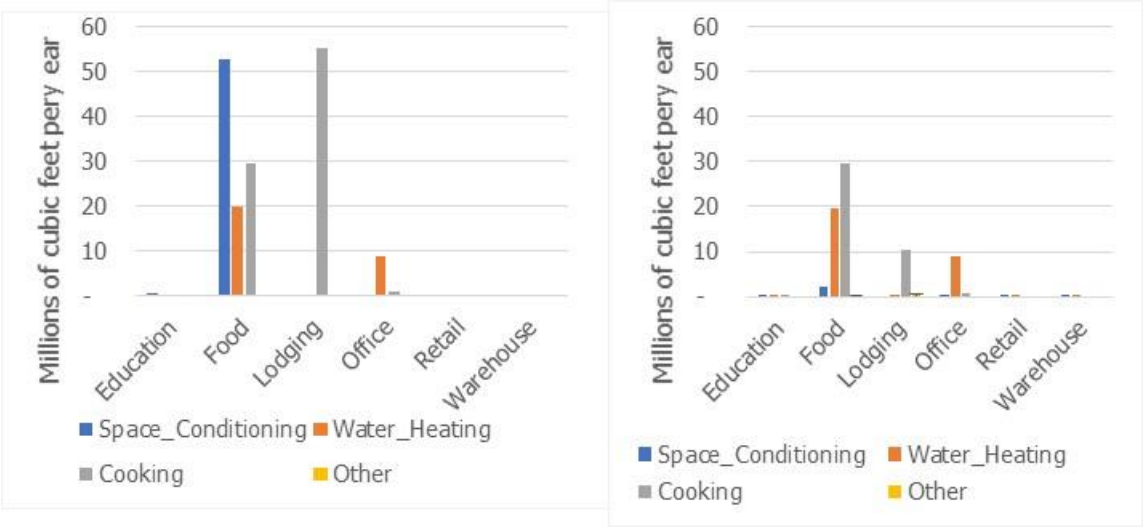
Figure 16: Northern California Estimated Appliance Methane Emissions – As Measured (left) and Alternative Estimate (right)



Source: ICF.

In Southern California, cooking appliances in lodging buildings contribute 55.1 million cubic feet methane emissions per year, followed by space conditioning appliances in food service buildings that contribute 52.6 million cubic feet of methane emissions per year in the as-measured estimate. Cooking appliances in food service buildings contribute 29.6 million cubic feet of methane emissions per year (Figure 17). In general, emission values are higher in Southern California than in Northern California, due to both higher unburnt methane from sources and move overall gas usage. The peak in emissions associated with space heating activity in food service buildings is driven by a handful of readings from a moderately inefficient appliance type (infrared heater), which was the only appliance type measured in that category, which, again, may not be representative of the category. There are a handful of inefficient cooking appliances that contribute to the peak in emissions associated with cooking activity in food service buildings. The peak in emissions associated with cooking activity in the lodging building category is driven by a single poorly maintained outdoor grill at a university dorm, again probably not representative. In the alternative analysis, the unburnt values for the questionable categories are replaced by the region-wide averages for each end use type, resulting in a significant reduction in the estimated emissions for space heating in food and cooking in lodging.

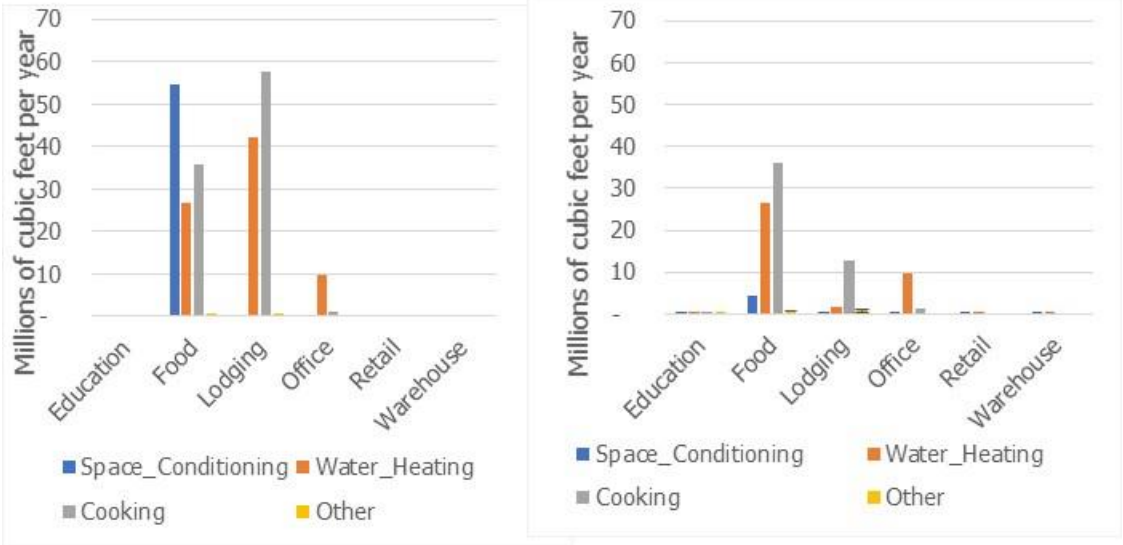
Figure 17: Southern California Estimated Appliance Methane Emissions As Measured (left) and Alternative Estimate (right)



Source: ICF

Figure 18 provides statewide results. Overall, appliances in food service buildings release the most uncombusted methane emissions, amounting to about 117 million cubic feet per year of methane, largely due to space conditioning appliances in the as-measured analysis. Water heating appliances in food service, lodging, and office building types release 78.3 million cubic feet of methane per year, while cooking appliances in food and lodging buildings release 93.4 million cubic feet of methane per year in the as-measured analysis. The alternative estimate reflects the lower emissions due to the lower average emission rates for the three categories.

Figure 18: Statewide Estimated Appliance Methane Emissions As Measured (left) and Alternative Estimate (right)



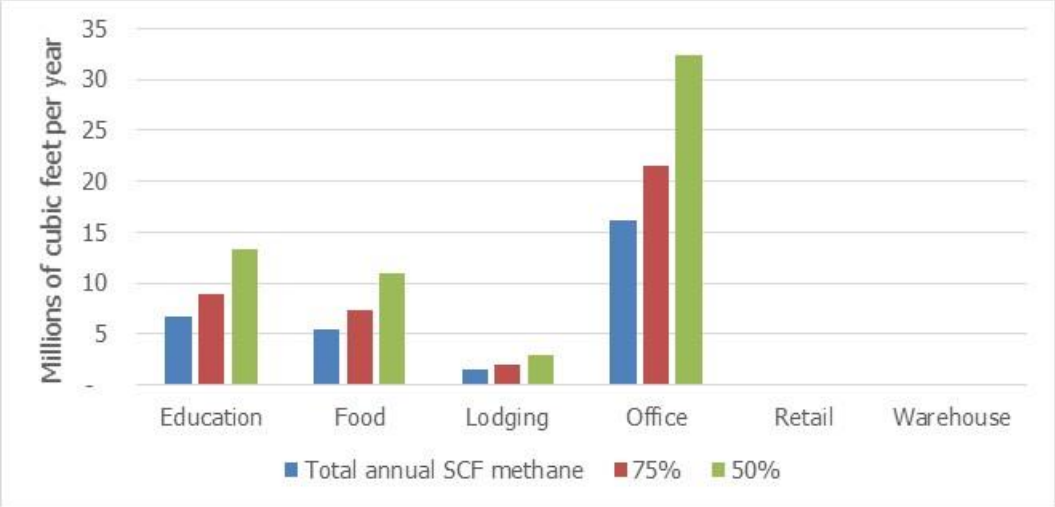
Source: ICF

Pipe-Related Fugitive Emissions

The following graphs show total methane emissions from pipe joints per year for Northern and Southern California. Blue bars indicate the total annual standard cubic feet of methane, while red and green bars show estimates assuming the gas detection team observed 75 percent or 50 percent of the total number of pipes in each building, respectively.

In Northern California, 16.2 million cubic feet of methane per year comes from pipe joints in office buildings (Figure 19). Education buildings contribute 6.7 million cubic feet per year of methane emissions, while food buildings emit 5.4 million cubic feet of methane per year and lodging buildings emit 1.5 million cubic feet of methane per year. The study results show little-to-no fugitive methane from retail and warehouse buildings at the regional level due to the poor representation from these building types in the study sample of Northern California.

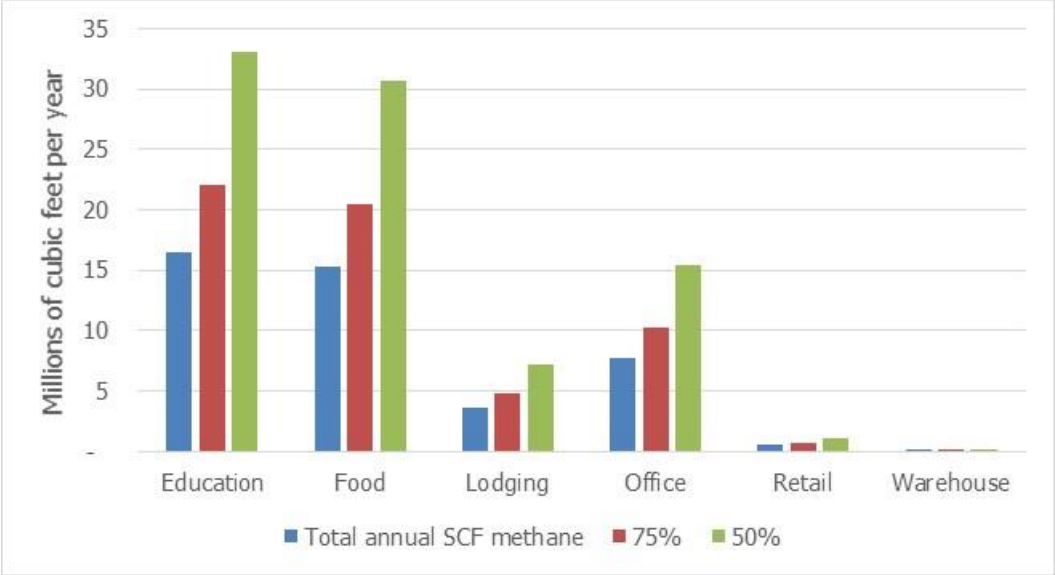
Figure 19: Northern California Estimated Pipe Joint Emissions



Source: ICF

In Southern California, the most fugitive methane from pipe joints comes from education buildings (16.5 million cubic feet per year) and food buildings (15.3 million cubic feet per year) (Figure 20). 7.7 million cubic feet of methane per year come from office buildings while 3.6 million cubic feet come from lodging buildings, and 538 thousand cubic feet per year come from retail buildings. Similar to the case in the Northern California results, the very low value of methane from pipe joints in warehouse buildings in Southern California is due to the lack of data points in the sample.

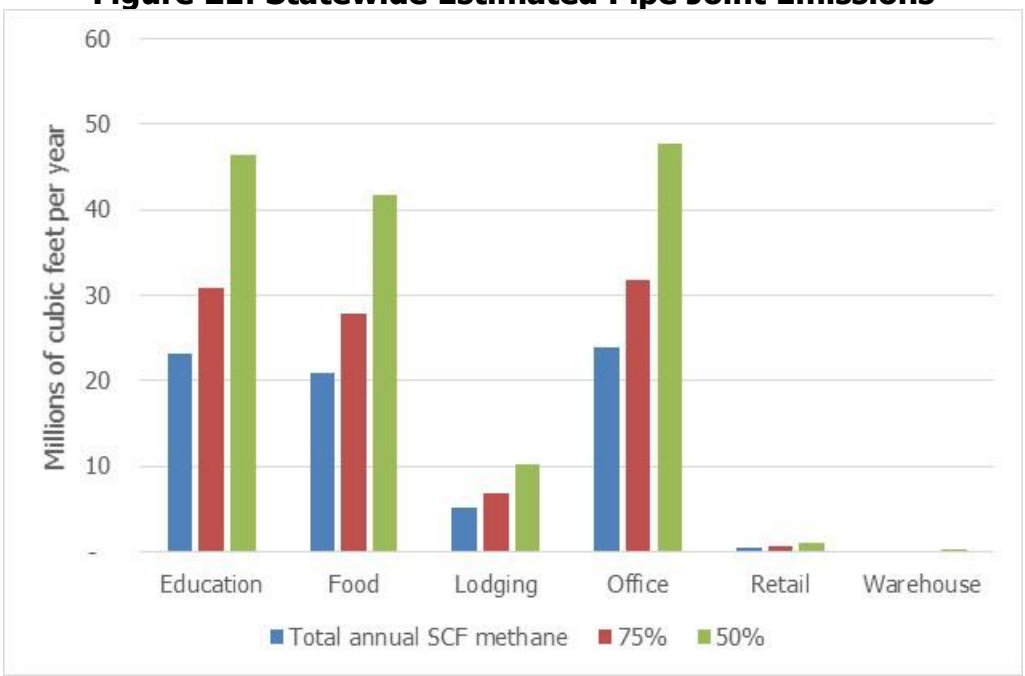
Figure 20: Southern California Estimated Pipe Joint Emissions



Source: ICF

Statewide results are presented in Figure 21. Overall, office buildings emitted the most methane emissions from pipe joints (23.9 million cubic feet per year), mostly due to Southern California office buildings, followed closely by education buildings (23.2 million cubic feet per year) and food buildings (20.8 million cubic feet per year). Lodging, retail, and warehouse buildings emitted much fewer methane emissions in comparison (5 million or fewer cubic feet per year).

Figure 21: Statewide Estimated Pipe Joint Emissions



Source: ICF

While the figures in this section show trends across building type, ICF does not believe there is a correlation between pipe joints with fugitive methane and building type and the results are more indicative of the specific sample of tested buildings.

Commercial Building Emissions

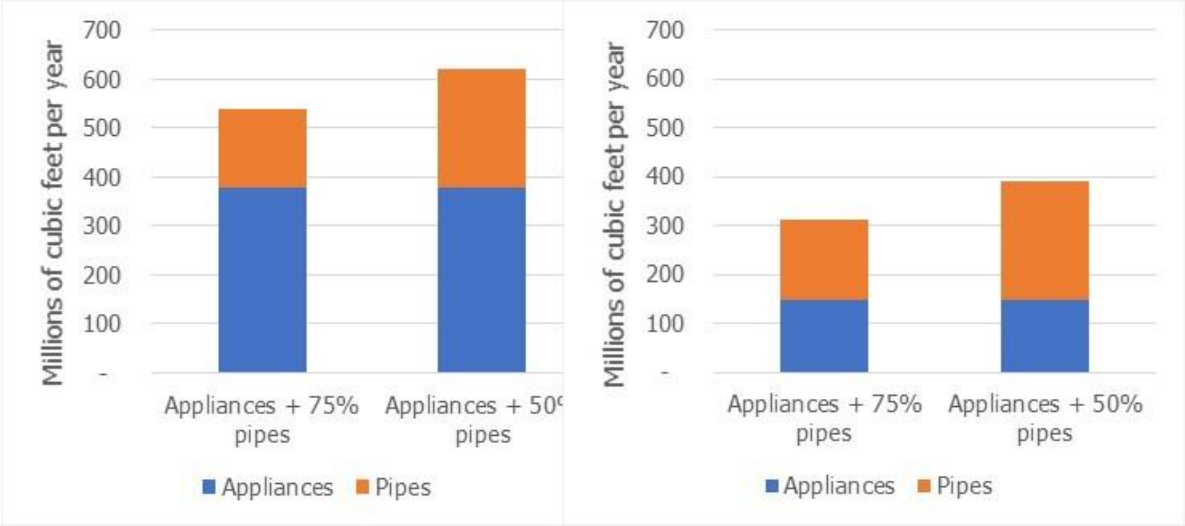
Combining the estimates of pipe joint-related fugitive methane and uncombusted methane from appliances, ICF estimated total methane emissions from commercial buildings across California at between approximately 540 and 620 million cubic feet per year for the as-measured estimate and 311 to 392 million cubic feet per year for the alternative estimate. This is equivalent to 0.24–0.28 percent of total natural gas consumption in the commercial sector across the state for the as-measured estimate and 0.14-0.18 percent for the alternative analysis (Table 7). As can be seen in Table 7 and Figure 22, emissions from appliances were found to be slightly larger than emissions from pipes (about 1.6 to 2.4 times larger) for the as-measured estimate. In the alternative estimate, the appliance emissions were about equal to the pipe emissions or about 36 percent lower.

Table 7: Estimated Methane Emissions from California Commercial Buildings as Fraction of Total Natural Gas Use

Scenario	Methane emission as % of Total Natural Gas Consumption	Methane Emission as % of Total Natural Gas Consumption
Northern California	As-Measured	Alternative
Appliances	0.10%	0.03%
Appliances w. 75% Pipe Scenario	**0.17%**	**0.10%**
Appliances w. 50% Pipe Scenario	**0.20%**	**0.13%**
Southern California		
Appliances	0.23%	0.10%
Appliances w. 75% Pipe Scenario	**0.31%**	**0.18%**
Appliances w. 50% Pipe Scenario	**0.35%**	**0.22%**
Statewide		
Appliances	0.17%	0.07%
Appliances w. 75% Pipe Scenario	**0.24%**	**0.14%**
Appliances w. 50% Pipe Scenario	**0.28%**	**0.18%**

Source: ICF

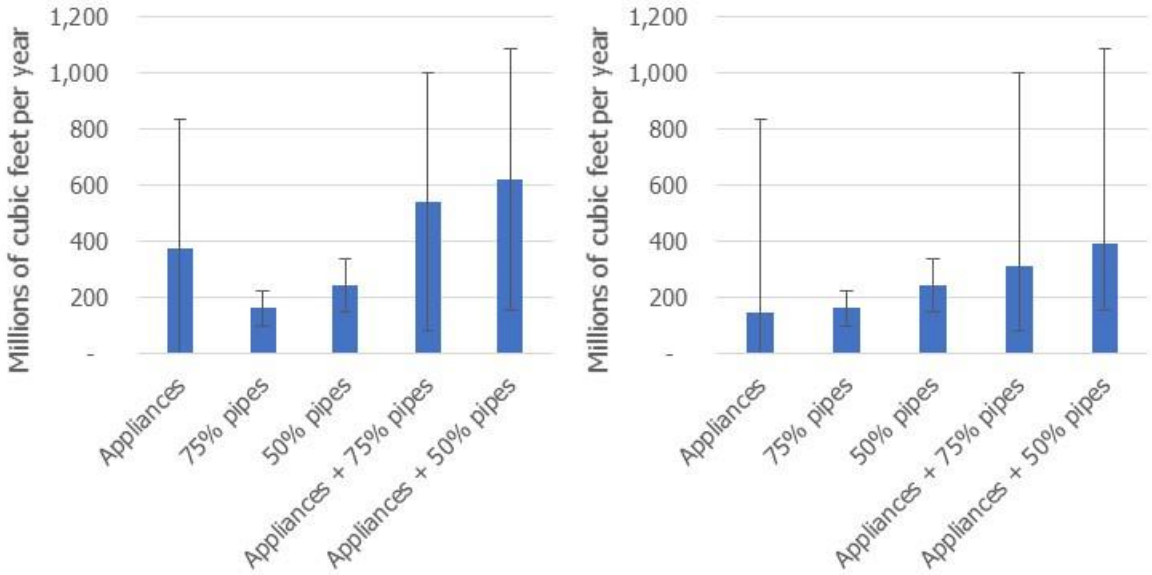
Figure 22: Statewide Estimated Total Emissions
As Measured (left) and Alternative Estimate (right)



Source: ICF

Due to multiple factors such as a limited number of buildings and appliances analyzed and outliers in the sample, the uncertainty associated with this analysis is very high. Incorporating uncertainly analysis in the estimation indicates that total methane emissions could range from approximately 78.6 million to 1.1 billion cubic feet year.

Figure 23: Statewide Estimated Total Emissions with Uncertainty
As Measured (left) and Alternative Estimate (right)



Source: ICF

Based on the limited study sample, ICF converted the volumetric estimates into their GHG equivalents (using a 100-year GWP of 25, as used by CARB) and estimated annual fugitive methane emissions from California's commercial buildings at between 0.25–0.29 MMT CO_2e for the as-measured estimate or 0.15-0.18 MMT CO_2e for the alternative estimate (Table 8).

Table 8: Estimated Methane Emissions from California Commercial Buildings as a Fraction of Other California Emissions – Different Appliance + Pipe Scenarios

Metric	As-Measured 50% scenario	As-Measured 75% scenario	Alternative 50% scenario	Alternative 75% scenario
Statewide commercial fugitive methane emissions (million cubic feet)	620	540	392	311
Statewide commercial fugitive methane emissions (MMT CO_2e) 100-year GWP=25	0.29	0.25	0.18	0.15
Statewide commercial methane emissions (MMT CO_2e) 20-year GWP=72	0.84	0.72	0.52	0.43

Source: ICF

Using a 20-year GWP of 72, the estimated emissions would be 0.72-0.84 MMT CO_2e for the as-measured estimate or 0.43-0.52 MMT CO_2e for the alternative estimate.

To date, there has not been systematic quantification of fugitive methane emissions from commercial buildings in California due to lack of data for this category. This study provides central estimates suggesting that there might be an additional 0.15 to 0.29 MMTCO2e fugitive methane emissions from commercial buildings (0.038 to 0.53 MMTCO2e, based on 95% confidence intervals of analyses) that have not yet been captured in the CARB GHG Inventory. As in prior assessments of behind-the-meter methane emissions, these results indicate small but not insignificant emissions that may account for some part of the discrepancy between bottom-up and top-down emission estimates. Most of the more than 16,000 pipe joint measurements and nearly 600 appliance measurements showed no emissions, and most of those that had measurable emissions were very small. A very small number of sources accounted for most of those emissions. This is typical of other methane measurement studies[8,9] and the high emitters are sometimes referred to as "superemitters". Determining whether the small sample assessed in this study is truly representative would require a much larger effort. That said, the results suggest that testing and repair/adjustment of a small number of sources—especially appliances—could result in material reductions in emissions from California's commercial buildings.

[8] Duren, R.M., Thorpe, A.K., Foster, K.T. et al. California's methane super-emitters. Nature 575, 180–184 (2019). https://doi.org/10.1038/s41586-019-1720-3

[9] A. R. Brandt, G. A. Heath, D. Cooley, Methane leaks from natural gas systems follow extreme distributions. Environ. Sci. Technol. 50, 12512–12520 (2016). doi:10.1021/acs.est.6b04303pmid:27740745

CHAPTER 4:
Knowledge Transfer Activities

Knowledge generated by this project can be used by commercial gas customers and public policymakers. The study's findings on the sources and magnitudes of fugitive methane will help inform individual businesses' gas appliance maintenance and replacement decisions, while also helping policymakers to more accurately estimate methane emissions from the commercial sector and target effective interventions.

As such, knowledge from the study can be shared and disseminated at multiple levels—including to study participants, intermediary organizations, industry associations, and California policy makers—and multiple tools have been developed to facilitate knowledge transfer, including site-specific emissions reports, a one-page summary of key study findings, and a slide deck summarizing the project approach and findings. The study team has pursued active knowledge transfer activities throughout the period of the current grant, after which time outreach and dissemination activities will be continued by intermediary organizations, industry associations, and relevant public organizations.

Knowledge Transfer to Commercial Users

Within the commercial sector, the target markets for knowledge dissemination include all of the building use types included in the study—namely office, lodging, education, housing, food service, retail, and warehouses. The size of this market in California includes a total of 293,000 establishments which consume 237.4 billion cubic feet (Bcf) of gas annually. Near-term targets for knowledge transfer and market adoption would include businesses that are highly interested in sustainable operations and GHG reductions; mid-term targets could include businesses with high gas consumption and older gas appliances and infrastructure that need servicing and/or replacement; and long-term markets would include all natural gas customers. The study team is employing multiple approaches to share information with these commercial gas users, detailed below.

Sharing of Customer-Specific Findings

Individual site reports have been produced detailing the results from each of the on-site assessments, with specific information about emissions factors and highlighting any unusually high values for appliance inefficiencies or pipe joint-related fugitive methane. These reports have been shared with the participating facilities throughout the project. Participants have provided feedback that these reports are helpful in targeting maintenance and prioritizing gas appliance replacements in both the tested buildings and other buildings within their portfolios, and, in some cases, helping to reinforce the value of proposed building electrification initiatives.

Dissemination by Intermediary Organizations

The project team prepared a one-page snapshot which summarizes key findings from the study that can be shared with intermediary organizations that helped publicize the study and recruit participants. These findings can be disseminated to their broad memberships—including large property owners, corporate facility managers, green building associations, municipal

sustainability entities, and other related constituencies—to further enable knowledge sharing and aid market adoption of fugitive methane mitigation opportunities within the commercial sector and the general public across the state. Preliminary outreach to intermediary organizations has indicated that their memberships are interested in receiving this information, and that they would be willing to leverage their communications platforms to aid in knowledge dissemination.

Dissemination by Industry Associations

The summary snapshot can also be shared with relevant industry associations in the sampled commercial sectors (specifically office, lodging, education, housing, food service, retail, and warehouses) to share with their members and constituencies. Presenting the high-level study findings, along with accessible and affordable opportunities to reduce fugitive methane, is expected to aid market adoption of emissions mitigation measures in these targeted industries.

Use by Policy Makers

Knowledge generated by this project will also help policy makers and public organizations to more accurately estimate methane emissions from the commercial sector in the future and to more effectively target policy interventions.

The current (2017 data) CARB greenhouse gas inventory does not include data on fugitive methane emissions from the commercial sector. This project has produced initial estimates (albeit based on a limited sample) and, more critically, helped develop, refine, and validate methods for developing those estimates in future. Further research will be needed to apply the data collection and extrapolation methods developed by this study to a larger and more representative sample of California facilities. But, ultimately, this improved understanding of the scale and significant sources of fugitive emissions from the commercial sector will help policymakers to develop more effective and targeted interventions (for example policy, regulation, permitting, and operational guidelines) to help reduce these emissions.

The project team has worked with CEC to ensure that findings from this study are shared with CARB's Greenhouse Gas Inventory Group to further inform the state's approach to inventory calculations, as well as other relevant state policymakers.

Technical Advisory Committee Dissemination

The project's technical advisory committee (TAC) includes representatives from state regulatory agencies (CEC, CARB), investor-owned gas utilities (PG&E, SoCalGas), and prominent research institutions. The study team has shared this report, as well as the summary snapshot and presentation slide deck, with members of the advisory committee, and they can, in turn, distributed these findings to their colleagues and other relevant networks. It is hoped that the utility members of the TAC will share the findings of this study internally and also disseminate key findings to their customers.

CHAPTER 5:
Conclusions and Future Work

This project was critical to rigorously estimating fugitive methane emissions from California's commercial building sector. Assessing more than 100 sites, with more than 500 appliance measurements and 16,500 pipe joint measurements, allowed for meaningful trend analysis from the sample. Furthermore, the project tested the framework for recruiting commercial sites for assessment and quantifying the magnitude of statewide fugitive methane emissions. The effort also further developed a previous onsite assessment methodology developed by GTI

Project field data collected paired with statistical analyses indicates methane emissions from commercial buildings at roughly 0.24–0.28 percent of natural gas consumption in the commercial building sector in the as-measured estimate and 0.14–0.18 percent for the alternative analysis. For context, the *2019 Integrated Energy Policy Report* estimates that commercial buildings in California consumed around 216 billion cubic feet of natural gas in 2018.

Based on the over 17,000 measurements taken in the field, it was found that most gas piping and equipment operates with low to no methane emissions. Combustion efficiency is more than 99 percent for the vast majority of appliances, and less than 2 percent of pipe joints had detectable fugitive methane and detected volumes were very small. The volume of unburned methane from appliance combustion exhaust is about 1.6 to 2.4 times larger than leakage from pipe joints for the as-measured estimate. In the alternative estimate, the appliance emissions were about equal to or somewhat (about a third) lower than the pipe emissions. Based on these initial estimated values, commercial fugitive methane emissions make up 0.63–0.72 percent of total California methane emissions (from all sectors) for the as-measured estimate and 0.36-0.46 percent for the alternative estimate in 2017.

Of the 499 gas appliances measured, the top 3 percent of highest emitting sources accounted for more than 50 percent of total fugitive emissions. For piping components, the same observation was made; the highest 3 percent of pipe joints emitting fugitive methane accounted for more than 50 percent of fugitive methane from pipe joints observed. This suggests it may be possible to greatly reduce fugitive emissions from the commercial sector by identifying and repairing a relatively small number of problem areas. By identifying where these problem areas are most likely to be and understanding what may be driving their poor performance, relatively quick and limited adjustments could be made to yield sizable savings.

The recruitment techniques, technical on-site data collection and analysis approaches developed by the ICF team for this project provide a solid foundation for future work. Leveraging the recruitment techniques that were refined, further field data collection data points could be applied to these statewide estimation approaches to calculate even more robust component-based factors. A larger, unbiased field data collection effort could shed further light on why certain components are more significant contributors, including what roles age, installation practices, maintenance, cleanliness, and other factors may play. With these details in hand, it will be possible to make targeted recommendations to the appropriate stakeholders about how best to reduce fugitive methane emissions behind the meter in California's commercial buildings.

CHAPTER 6:
Benefits to Ratepayers

Post-meter methane emissions comprise natural gas that has already been purchased, so commercial properties will benefit from purchasing less natural gas if these emissions are reduced. Based on ICF's analysis, rate payers in northern California would save up to $1.8 million per year in the aggregate, and rate payers in southern California would save up to $3.2 million per year in the aggregate. More significant are the potential benefits to California in terms of environmental impacts.

Based on this limited study sample, ICF provided central estimates of annual fugitive methane emissions from California's commercial buildings of 0.25 to 0.29 MMT CO_2e for the as-measured estimate or 0.15 to 0.18 MMT CO_2e for the alternative estimate (100-year GWP=25). It is important to note the uncertainty of these estimates, for which the 95 percent confidence intervals span a range from 0.038 MMT CO_2e to 0.53 MMT CO_2e.

The commercial sector natural gas combustion category of the CARB statewide GHG inventory currently includes only estimated emissions from well-functioning combustion processes; it does not include fugitive emissions. Based on these initial central estimates, commercial building fugitive methane emissions make up 0.63 to 0.72 percent of total California methane emissions (from all sectors) for the as-measured estimate or 0.36 to 0.46 percent for the alternative estimate in 2017. On a 20-year GWP basis (GWP=72), the central estimates for as-measured emissions are 0.72 to 0.84 MMT CO_2e or 0.43 to 0.52 MMT CO_2e for the alternative estimate, with the 95 percent confidence intervals of the analyses spanning a range of 0.11 MMT CO_2e to 1.5 MMT CO_2e.

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LIST OF ACRONYMS

Term	Definition
BCF	Billion cubic feet
CARB	California Air Resources Board
CBECS	Commercial Building Energy Consumption Survey
SCCM	Standard cubic centimeters per minute
CEC	California Energy Commission
SCFM	Standard cubic feet per minute
EIA	Energy Information Administration
EOF	Appliance use factor
EPA	Environmental Protection Agency
GHG	Greenhouse gas(es)
GRI	Gas Research Institute
GTI	Gas Technology Institute
GWP	Global Warming Potential
HVAC	Heating, ventilation, and air conditioning
LBNL	Lawrence Berkeley National Laboratories
LGR	Los Gatos Research
LEL	Lower explosive limit
MMT	Million metric tonnes
NA	Not applicable
PPB	Parts per billion
PPM	Parts per million
PG&E	Pacific Gas and Electric Company
SCF	Standard cubic feet
SCCM	cm^3/min
SoCal Gas	Southern California Gas Company
TAC	Technical advisory committee
UGGA	Ultra-Portable Greenhouse Gas Analyzer

APPENDIX A:
Approach Supporting Data

Project Approach Details

Table A-1: Selected NAICS Codes

Building Type	NAICs Code	NAICs Code Description
Education	611	Educational services
Food Service	445	Food and beverage stores
Food Service	722	Food services and drinking places
Lodging	623	Nursing and residential care facilities
Lodging	721	Accommodation
Office	454	Non-store retailers
Office	486	Pipeline transportation
Office	511	Publishing industries (except internet)
Office	517	Telecommunications
Office	518	Data processing, hosting, and related services
Office	519	Other information services
Office	521	Monetary authorities - central bank
Office	522	Credit intermediation and related activities
Office	523	Securities, commodity contracts, and other financial investments and related activities
Office	524	Insurance carriers and related activities
Office	525	Funds, trusts, and other financial vehicles
Office	531	Real estate
Office	533	Lessors of nonfinancial intangible assets (except copyrighted works)
Office	541	Professional, scientific, and technical services
Office	551	Management of companies and enterprises
Office	561	Administrative and support services
Office	624	Social assistance
Retail	446	Health and personal care stores
Retail	448	Clothing and clothing accessories stores
Warehouse	423	Merchant wholesalers, durable goods
Warehouse	424	Merchant wholesalers, nondurable goods
Warehouse	493	Warehousing and storage
Other	Many	All Other NAICs Codes 400 and Above

Source: Commercial Buildings Energy Consumption Survey (CBECS) (U.S. Energy Information Administration)

APPENDIX B:
Raw Site Data

.

Table B-1: Appliance Data

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Stage 1&2	1.29E-01	1.75E+00
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Stage 3	8.16E-02	1.11E+00
NorCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer Commercial	Heating	1.72E-02	7.03E-02
NorCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Pool/Spa Heater	Heating	0	0
NorCal	Lodging	Water_Heating	Pool/Spa Heater	Heating	0	0
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
NorCal	Lodging	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	1.10E-02	2.00E-02
NorCal	Lodging	Cooking	Range Burners	Burners on HIGH	0	0
NorCal	Lodging	Cooking	Oven Standard (Under-Range)	Heating to 350F	2.46E-03	1.68E-03
NorCal	Lodging	Cooking	Oven Standard (Under-Range)	Heating to 350F	5.55E-04	3.78E-04
NorCal	Lodging	Cooking	Griddle part of Range	Burners on HIGH	4.58E-04	4.44E-04
NorCal	Lodging	Cooking	Fryer Open Deep-Fat	Heating to 350F	1.52E-04	2.53E-04
NorCal	Lodging	Other	Gas Meter	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Stage 1&2	2.21E-03	2.26E-02
NorCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Pool/Spa Heater	Heating	0	0

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Lodging	Water_Heating	Pool/Spa Heater	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
NorCal	Lodging	Other	Gas Meter	N/A	N/A	N/A
NorCal	Lodging	Cooking	Grill	Burners on HIGH	5.44E-03	7.25E-03
NorCal	Lodging	Cooking	Grill	Burners on HIGH	5.06E-03	6.73E-03
NorCal	Lodging	Other	Gas Fireplace	On	5.10E-02	N/A
NorCal	Lodging	Other	Gas Fireplace	On	5.92E-03	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Lodging	Other	Gas Fireplace	N/A	N/A	N/A
SoCal	Retail	Water_Heating	WH Standard-efficiency storage	Heating	0	0
SoCal	Retail	Other	Generator	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Other	Gas Meter	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Other)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Other	Gas Meter	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Radiant Heater	Heating	0	0
SoCal	Retail	Water_Heating	WH Standard-efficiency Storage	Pilot Only	7.17E-03	N/A
SoCal	Retail	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
SoCal	Retail	Other	Gas Meter	N/A	N/A	N/A
SoCal	Retail	Other	Generator	N/A	N/A	N/A
SoCal	Retail	Other	Gas Meter	N/A	N/A	N/A
SoCal	Retail	Other	Gas Meter	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	Heating	0	0
SoCal	Retail	Space_Conditioning	Unit Heater	Heating	1.72E-03	6.51E-04

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Retail	Other	Gas Meter	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	Heating	0	0
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Unknown)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Unknown)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Unknown)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Radiant Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Radiant Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Radiant Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Radiant Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Other	Gas Meter	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	Running	0	0
SoCal	Retail	Space_Conditioning	HVAC (RTU)	Running	0	0
SoCal	Retail	Space_Conditioning	HVAC (RTU)	Running	0	0

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Retail	Space_Conditioning	HVAC (RTU)	Running	0	0
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Unknown)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Unknown)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Unknown)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	HVAC (Swamp Cooler)	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	Running	0	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Unit Heater	N/A	N/A	N/A
SoCal	Retail	Space_Conditioning	Radiant Heater	On	0	N/A
SoCal	Retail	Space_Conditioning	Radiant Heater	On	0	N/A
NorCal	Office	Water_Heating	Condensing Boiler (Water)	35% firing	0	0
NorCal	Office	Water_Heating	Condensing Boiler (Water)	30% firing	0	0
NorCal	Office	Water_Heating	Condensing Boiler (Water)	35% firing	0	0
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	On	0	0
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Running	0	0
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Running	0	0
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	12-15.5% firing	0	0
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Steam)	25%-33% firing	0	0
NorCal	Education	Other	Other (Other)	100% firing	0	0
NorCal	Education	Water_Heating	Condensing Boiler (Water)	N/A	N/A	N/A
NorCal	Education	Water_Heating	Condensing Boiler (Water)	Running	0	0

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Education	Water_Heating	Condensing Boiler (Water)	Running	0	0
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Pilot Only	N/A	N/A
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	1.02E-03	N/A
NorCal	Food	Cooking	Griddle Standalone	Burners on LOW	7.71E-02	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	9.34E-03	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	On	0	0
NorCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	7.85E-02	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	On	0	0
NorCal	Food	Cooking	Range Burners	Burners on HIGH	1.71E-03	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	1.08E-03	N/A
NorCal	Food	Cooking	Range Burners	Average - Burners on HIGH	1.40E-03	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	7.74E-04	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	3.96E-04	N/A
NorCal	Food	Cooking	Range Burners	Average - Pilot Only	5.85E-04	N/A
NorCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	2.15E-01	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	1.02E-01	N/A
NorCal	Food	Cooking	Range Burners	Average - Burners on HIGH	1.58E-01	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	1.89E-03	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	1.16E-04	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Range Burners	Average - Pilot Only	1.00E-03	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	8.05E-05	N/A
NorCal	Food	Cooking	Griddle part of Range	Pilot Only	2.23E-01	N/A
NorCal	Food	Cooking	Griddle part of Range	Burners on HIGH	3.13E-02	N/A
NorCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Top Double Stack)	Heating	N/A	N/A
NorCal	Food	Cooking	Convection Ovens, Stacked	Off	N/A	N/A
NorCal	Food	Cooking	Convection Ovens, Stacked	Off	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Bottom Double Stack)	Heating	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Bottom Double Stack)	Off	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Top Double Stack)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Bottom Double Stack)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Combination	Heating	0	0
NorCal	Food	Cooking	Oven Combination	N/A	N/A	N/A
NorCal	Food	Cooking	Tilt Skillet	Heating	0	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Running	4.40E-04	3.99E-03
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Running	0	0
NorCal	Lodging	Space_Conditioning	Furnace Standard	N/A	0	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Running	0	0
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Running	7.90E-04	9.56E-03
NorCal	Lodging	Space_Conditioning	Furnace Standard	N/A	0	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Running	2.77E-04	4.19E-03
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Running	N/A	N/A
NorCal	Lodging	Space_Conditioning	Furnace Standard	N/A	0	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Running	0	0
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Running	3.42E-04	3.11E-03
NorCal	Lodging	Space_Conditioning	Furnace Standard	Running	6.67E-05	N/A
NorCal	Education	Space_Conditioning	Furnace standard	Heating	0	0
NorCal	Education	Space_Conditioning	Furnace standard	N/A	0	N/A
NorCal	Education	Water_Heating	Condensing Boiler (Water)	Heating	2.07E-05	1.25E-04
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Pilot Only	4.16E-03	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	4.28E-05	2.07E-05
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
NorCal	Office	Space_Conditioning	Furnace standard	Heating	0	0
NorCal	Office	Space_Conditioning	Furnace standard	Heating	0	0
NorCal	Office	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
NorCal	Office	Other	Other (Other)	N/A	N/A	N/A
NorCal	Lodging	Space_Conditioning	Furnace Standard	N/A	0	N/A
NorCal	Lodging	Space_Conditioning	Furnace Standard	N/A	0	N/A
NorCal	Lodging	Cooking	Range Burners	Burners on HIGH	1.61E-04	9.77E-05
NorCal	Lodging	Cooking	Oven Standard (Under-Range)	Pilot Only	3.73E-03	N/A
NorCal	Lodging	Cooking	Oven Standard (Under-Range)	Heating to 350F	3.97E-05	2.10E-05
NorCal	Lodging	Cooking	Oven Standard (Under-Range)	Pilot Only	3.99E-03	N/A
NorCal	Lodging	Cooking	Oven Standard (Under-Range)	Heating to 500F	2.41E-05	7.29E-06
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Heating	0	0
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Pilot Only	4.32E-03	N/A
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
NorCal	Food	Cooking	Griddle part of Range	Burners on HIGH	8.84E-04	N/A
NorCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	4.16E-03	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Fryer Open Deep-Fat	On	N/A	N/A
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	3.72E-03	6.42E-03
NorCal	Food	Cooking	Oven Standard (Under-Range)	Heating	1.73E-02	1.05E-02
NorCal	Food	Cooking	Range Burners	Burners on HIGH	7.30E-04	5.86E-04
NorCal	Food	Cooking	Range Burners	Burners on HIGH	6.27E-04	8.54E-04
NorCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	2.13E-02	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Heating	1.15E-04	1.74E-04
NorCal	Food	Cooking	Griddle Standalone	Pilot Only	1.16E-03	N/A
NorCal	Food	Cooking	Griddle Standalone	Burners on HIGH	1.41E-04	1.92E-04
NorCal	Food	Cooking	Oven Conveyor	Heating to Low	3.77E-04	1.88E-04
NorCal	Food	Cooking	Oven Conveyor	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Cycling	N/A	N/A
NorCal	Lodging	Water_Heating	Condensing Boiler (Water)	Running	0	0
NorCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Cycling	N/A	N/A
NorCal	Lodging	Water_Heating	Condensing Boiler (Water)	Running	0	0
NorCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer Commercial	Running	2.53E-05	9.21E-06
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Cycling	N/A	N/A
NorCal	Lodging	Water_Heating	Condensing Boiler (Water)	20%-91% firing	7.03E-06	1.08E-05
NorCal	Lodging	Water_Heating	Condensing Boiler (Water)	Running	0	0
NorCal	Lodging	Other	Dryer Commercial	Running	N/A	N/A
NorCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Office	Water_Heating	Standard boiler	40% firing	0	0
SoCal	Office	Water_Heating	Standard boiler	40% firing	0	0

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Office	Water_Heating	Standard boiler	40% firing	0	0
SoCal	Office	Water_Heating	Standard boiler	40% firing	0	0
SoCal	Office	Water_Heating	Standard boiler	N/A	N/A	N/A
SoCal	Office	Water_Heating	Water heater	Running	9.26E-02	5.47E-01
SoCal	Office	Water_Heating	Water heater	Running	7.56E-06	4.47E-05
SoCal	Office	Water_Heating	Water heater	Running	9.11E-02	5.38E-01
SoCal	Office	Cooking	Pizza oven	On	1.21E-05	N/A
SoCal	Office	Cooking	Charbroiler	Pilot only	1.11E-03	N/A
SoCal	Office	Cooking	Charbroiler	Burners on HIGH	4.46E-04	N/A
SoCal	Office	Cooking	Griddle Standalone	Heating to 400F	4.44E-02	N/A
SoCal	Office	Cooking	Griddle Standalone	Pilot only	1.19E-02	N/A
SoCal	Office	Cooking	Griddle Standalone	Heating to 400F	1.11E-01	N/A
SoCal	Office	Cooking	Griddle Standalone	Pilot only	8.46E-03	N/A
SoCal	Office	Cooking	Griddle Standalone	Heating to 400F	1.17E-01	N/A
SoCal	Office	Cooking	Oven Combination	Convection	N/A	N/A
SoCal	Office	Cooking	Oven Combination	N/A	N/A	N/A
SoCal	Office	Cooking	Range burners	Pilot Only	N/A	N/A
SoCal	Office	Cooking	Range burners	Pilot Only	N/A	N/A
SoCal	Office	Cooking	Range burners	Average - Pilot Only	N/A	N/A
SoCal	Office	Cooking	Range burners	Burners on HIGH	6.41E-05	1.92E-04
SoCal	Office	Cooking	Range burners	Burners on HIGH	0	0
SoCal	Office	Cooking	Range burners	Average - Burners on HIGH	3.20E-05	9.60E-05

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Office	Cooking	Range oven	Heating to 400F-500F	N/A	N/A
SoCal	Office	Cooking	Range burners	Pilot Only	1.79E-03	N/A
SoCal	Office	Cooking	Range burners	Pilot Only	2.29E-04	N/A
SoCal	Office	Cooking	Range burners	Average - Pilot Only	1.01E-03	N/A
SoCal	Office	Cooking	Range burners	Burners on HIGH	0	0
SoCal	Office	Cooking	Range burners	Burners on HIGH	0	0
SoCal	Office	Cooking	Range burners	Average - Burners on HIGH	0	0
SoCal	Office	Cooking	Range oven	Heating to 400F-500F	4.58E-03	3.12E-03
SoCal	Office	Cooking	Oven Combination	Convection	0	0
SoCal	Office	Cooking	Oven Combination	N/A	N/A	N/A
SoCal	Office	Cooking	Tilt Skillet	Heating to 400F	8.92E-03	1.94E-02
SoCal	Office	Cooking	Tilt Skillet	Heating to 400F	5.86E-02	1.28E-01
SoCal	Office	Cooking	Chinese Range	Pilot only	3.53E-03	N/A
SoCal	Office	Cooking	Chinese Range	Burners on HIGH	1.60E-03	N/A
SoCal	Office	Cooking	Kettle	Heating to High	2.57E-04	5.83E-04
SoCal	Office	Water_Heating	WH Condensing Storage	Running	0	0
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Running	0	N/A
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Running	0	N/A
SoCal	Office	Cooking	Range Burners	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Office	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	5.31E-03	N/A
SoCal	Office	Cooking	Griddle Standalone	Heating to High	8.00E-03	8.47E-03
SoCal	Office	Cooking	Griddle Standalone	Pilot only	3.92E-01	N/A
SoCal	Office	Cooking	Oven Convection (Top Double Stack)	Heating to 500F	1.09E-04	4.44E-05
SoCal	Office	Cooking	Oven Standard (Bottom Double Stack)	N/A	N/A	N/A
SoCal	Office	Cooking	Pizza oven	Heating to 596F	9.79E-05	N/A
SoCal	Office	Cooking	Tilt Skillet	Heating to 300F	1.44E-03	3.15E-03
SoCal	Office	Cooking	Oven Combination	Convection	0	N/A
SoCal	Office	Cooking	Oven Combination	Steam mode	2.68E-04	N/A
SoCal	Office	Cooking	Range Burners	Burners on HIGH	1.71E-03	N/A
SoCal	Office	Cooking	Range Burners	Burners on HIGH	1.43E-03	N/A
SoCal	Office	Cooking	Range Burners	Average - Burners on HIGH	1.57E-03	N/A
SoCal	Office	Cooking	Range Burners	Pilot only	3.13E-04	N/A
SoCal	Office	Cooking	Range Burners	Pilot only	4.96E-03	N/A
SoCal	Office	Cooking	Range Burners	Average - Pilot Only	2.63E-03	N/A
SoCal	Office	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
SoCal	Office	Cooking	Oven Combination	N/A	N/A	N/A
SoCal	Office	Cooking	Oven Combination	N/A	N/A	N/A
SoCal	Office	Cooking	Smoker (Top of Stacked)	Running	1.57E-03	N/A
SoCal	Office	Cooking	Smoker (Bottom of Stacked)	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Office	Cooking	Chinese Range	Burners on HIGH	2.39E-02	N/A
SoCal	Office	Water_Heating	WH Standard-efficiency Tankless	Running	3.67E-04	1.11E-03
SoCal	Office	Water_Heating	WH Standard-efficiency Tankless	Running	1.25E-03	3.78E-03
SoCal	Office	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Office	Water_Heating	Condensing Boiler (Water)	Unknown	4.93E-05	7.47E-04
SoCal	Office	Water_Heating	WH Standard-efficiency Storage	Running	8.80E-07	5.33E-07
SoCal	Office	Space_Conditioning	HVAC (RTU)	Running	0	0
SoCal	Office	Space_Conditioning	HVAC (RTU)	Running	0	0
SoCal	Office	Space_Conditioning	HVAC (RTU)	Running	0	0
SoCal	Office	Space_Conditioning	HVAC (RTU)	Running	0	0
SoCal	Office	Space_Conditioning	HVAC (RTU)	Running	0	0
SoCal	Office	Space_Conditioning	HVAC (RTU)	Running	0	0
NorCal	Office	Water_Heating	Condensing Boiler (Water)	92-96% firing	0	0
NorCal	Office	Water_Heating	Condensing Boiler (Water)	100% firing	0	0
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Running	6.55E-05	1.53E-04
NorCal	Office	Cooking	Griddle Standalone	Off	N/A	N/A
NorCal	Office	Cooking	Griddle Standalone	Heating to 350F	2.85E-04	4.27E-04
NorCal	Office	Cooking	Griddle Standalone	Heating to 350F	2.32E-04	3.47E-04
NorCal	Office	Cooking	Griddle Standalone	Heating to 350F	1.28E-05	1.92E-05
NorCal	Office	Cooking	Griddle Standalone	Average - Heating to 350F	1.76E-04	2.64E-04
NorCal	Office	Cooking	Range Burners	Pilot only	3.20E-04	N/A
NorCal	Office	Cooking	Range Burners	Pilot only	2.61E-04	N/A
NorCal	Office	Cooking	Range Burners	Average - Pilot Only	2.90E-04	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Office	Cooking	Range Burners	Burners on MEDIUM	3.92E-05	1.66E-04
NorCal	Office	Cooking	Range Burners	Burners on HIGH	0	0
NorCal	Office	Cooking	Range Burners	Burners on HIGH	0	0
NorCal	Office	Cooking	Range Burners	Average - Burners on HIGH	0	0
NorCal	Office	Cooking	Oven under range	N/A	N/A	N/A
NorCal	Office	Cooking	Tilt Skillet	Heating	3.64E-03	5.73E-03
NorCal	Office	Cooking	Oven Combination	Steam mode	N/A	N/A
NorCal	Office	Cooking	Oven Combination	Convection	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 1&2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	Stage 2	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
NorCal	Warehouse	Water_Heating	WH Standard-efficiency Storage	On	N/A	N/A
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	On	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	On	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	On	0	0
NorCal	Warehouse	Space_Conditioning	HVAC (RTU)	On	0	0
NorCal	Warehouse	Water_Heating	WH Standard-efficiency Storage & Furnace Standard	On	1.55E-05	9.36E-06
NorCal	Warehouse	Space_Conditioning	Unit Heater	N/A	N/A	N/A
NorCal	Warehouse	Space_Conditioning	Unit Heater	N/A	N/A	N/A
NorCal	Food	Space_Conditioning	HVAC (RTU)	Stage 2	6.05E-05	2.75E-04
NorCal	Food	Space_Conditioning	HVAC (RTU)	Stage 2	2.85E-05	1.29E-04
NorCal	Food	Space_Conditioning	HVAC (RTU)	Stage 2	3.24E-04	1.47E-03
NorCal	Food	Space_Conditioning	HVAC (RTU)	Stage 1	3.92E-03	1.78E-02
NorCal	Food	Space_Conditioning	Duct furnace	Stage 2	1.89E-04	N/A
NorCal	Food	Water_Heating	Electric	N/A	N/A	N/A
NorCal	Food	Cooking	Range Burners & Oven Standard	Burners on HIGH	1.95E-03	N/A
NorCal	Food	Cooking	Range Burners & Oven Standard	Pilot Only	3.14E-03	N/A
NorCal	Food	Cooking	Range Burners	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Combination	On	0	0
NorCal	Food	Cooking	Oven Combination	N/A	N/A	N/A
NorCal	Food	Cooking	Tilt Skillet	Off	N/A	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	9.74E-04	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	1.59E-04	N/A
NorCal	Food	Cooking	Range Burners	Average - Burners on HIGH	5.66E-04	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Range Burners	Pilot Only	N/A	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	1.02E-04	N/A
NorCal	Food	Cooking	Range Burners	Average - Pilot Only	1.02E-04	N/A
NorCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	On	1.17E-03	N/A
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Pilot Only	1.75E-03	N/A
NorCal	Food	Cooking	Oven Convection (Top Double Stack)	On	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Bottom Double Stack)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Condensing Boiler (Water)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Condensing Boiler (Water)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Condensing Boiler (Water)	Heating	3.16E-05	9.58E-04
NorCal	Office	Water_Heating	Condensing Boiler (Water)	Burners on MEDIUM	0	0
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	On	7.50E-05	2.27E-03
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Condensing Boiler (Water)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Condensing Boiler (Water)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Condensing Boiler (Water)	On	0	0
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	On	0	0
NorCal	Office	Cooking	Unknown (Cooking)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Unknown (Water Heating)	N/A	N/A	N/A
SoCal	Food	Water_Heating	WH Standard-efficiency Tankless	Cycling	1.64E-04	2.69E-04
SoCal	Food	Water_Heating	WH Standard-efficiency Tankless	N/A	N/A	N/A
SoCal	Food	Water_Heating	WH Standard-efficiency Tankless	Cycling	1.37E-04	2.24E-04
SoCal	Food	Water_Heating	WH Standard-efficiency Tankless	N/A	N/A	N/A
SoCal	Food	Water_Heating	WH Standard-efficiency Tankless	Cycling	1.01E-03	1.65E-03

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Food	Cooking	Range Burners	Burners on HIGH	1.98E-04	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	4.43E-05	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	4.70E-06	N/A
SoCal	Food	Cooking	Range Burners	Average - Burners on HIGH	8.23E-05	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	8.40E-05	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	0	N/A
SoCal	Food	Cooking	Range Burners	Average - Pilot Only	4.20E-05	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	Heating to 500F	7.38E-04	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	Heating to 500F	3.42E-04	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	Pilot Only	8.57E-03	N/A
SoCal	Food	Cooking	Other (Cooking)	Burners on HIGH	3.87E-02	5.27E-02
SoCal	Food	Cooking	Other (Cooking)	Heating	4.21E-04	6.69E-04
SoCal	Food	Cooking	Other (Cooking)	Pilot Only	N/A	N/A
SoCal	Food	Cooking	Chinese Range	Burners on HIGH	2.80E-02	1.19E-01
SoCal	Food	Cooking	Chinese Range	Burners on MEDIUM	1.24E-03	5.25E-03
SoCal	Food	Cooking	Chinese Range	Pilot Only	6.18E-03	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	4.16E-03	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	Heating	2.33E-04	3.87E-04
SoCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	8.51E-03	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Food	Cooking	Oven Combination	Convection	0	0
SoCal	Food	Cooking	Griddle Standalone	Burners on HIGH	4.25E-06	3.86E-06
SoCal	Food	Cooking	Griddle Standalone	Pilot Only	9.34E-04	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	0	0
SoCal	Food	Cooking	Range Burners	Pilot Only	1.41E-04	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	1.80E-05	N/A
SoCal	Food	Cooking	Range Burners	Average - Pilot Only	7.94E-05	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	Pilot Only	5.96E-03	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	Heating	9.05E-05	1.37E-04
SoCal	Food	Cooking	Fryer Open Deep-Fat	Heating	4.22E-05	6.38E-05
SoCal	Food	Cooking	Fryer Open Deep-Fat	Average - Heating	6.63E-05	1.00E-04
SoCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	1.25E-02	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	Heating	9.01E-04	1.36E-03
SoCal	Food	Cooking	Fryer Open Deep-Fat	Heating	1.95E-04	2.96E-04
SoCal	Food	Cooking	Fryer Open Deep-Fat	Average - Heating	5.48E-04	8.30E-04
SoCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	5.88E-02	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	On	6.03E-03	4.56E-03
SoCal	Food	Space_Conditioning	Infrared Heater	On	4.73E-03	3.58E-03
SoCal	Food	Space_Conditioning	Infrared Heater	On	1.36E-02	1.03E-02
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	On	2.71E-03	2.05E-03
SoCal	Food	Space_Conditioning	Infrared Heater	On	4.49E-04	3.39E-04
SoCal	Food	Space_Conditioning	Infrared Heater	On	9.20E-04	6.96E-04
SoCal	Food	Space_Conditioning	Infrared Heater	On	8.93E-06	6.76E-06
SoCal	Food	Space_Conditioning	Infrared Heater	On	0	0

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Office	Water_Heating	Standard Boiler	On	3.20E-05	2.78E-04
SoCal	Office	Water_Heating	Standard tank water heater	On	0	0
SoCal	Office	Water_Heating	Standard tank water heater	Pilot Only	3.79E-03	N/A
SoCal	Office	Water_Heating	Standard water boiler	Running	5.74E-05	2.61E-04
SoCal	Office	Water_Heating	Standard water boiler	Stage 1	3.38E-04	3.33E-03
SoCal	Office	Water_Heating	Standard water boiler	Stage 1	5.65E-03	5.56E-02
SoCal	Office	Cooking	Residential range	Burners on HIGH	3.46E-05	2.06E-05
SoCal	Office	Cooking	Residential oven under range	Heating to 450F-500F	6.14E-04	1.67E-04
SoCal	Lodging	Cooking	Range and griddle	Burners on HIGH	1.02E-04	N/A
SoCal	Lodging	Cooking	Range and griddle	Burners on HIGH	1.09E-03	N/A
SoCal	Lodging	Cooking	Gas grill	Burners on HIGH	4.20E-04	N/A
SoCal	Lodging	Other	Industrial dryer	High Heat	N/A	N/A
SoCal	Lodging	Space_Conditioning	Fire pit	Medium	2.74E-02	N/A
SoCal	Lodging	Other	Commercial dryer	N/A	N/A	N/A
SoCal	Lodging	Water_Heating	Standard boiler	On	0	0
SoCal	Education	Water_Heating	Standard tank water heater	Pilot Only	5.05E-03	3.06E-03
SoCal	Education	Water_Heating	Standard tank water heater	Heating	0	0
SoCal	Education	Water_Heating	Standard tank water heater	Pilot Only	N/A	N/A
SoCal	Education	Water_Heating	Standard tank water heater	Heating	0	0
SoCal	Education	Cooking	Range Burners	Burners on HIGH	1.21E-04	3.31E-04
SoCal	Education	Cooking	Range Burners	Pilot Only	1.51E-03	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Education	Cooking	Oven Standard (Under-Range)	Heating to 450F	8.42E-04	4.46E-04
SoCal	Education	Cooking	Oven Combination	Heating to 325F	0	0
SoCal	Education	Cooking	Gas grill	N/A	N/A	N/A
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Running	1.69E-04	9.23E-03
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Running	0	0
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Average - Running	8.47E-05	4.61E-03
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Running	0	0
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Running	0	0
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Average - Running	0	0
NorCal	Lodging	Cooking	Range Burners	Burners on HIGH	0	0
NorCal	Lodging	Cooking	Range Burners	Burners on HIGH	0	0
NorCal	Lodging	Cooking	Range Burners	Average - Burners on HIGH	0	0
NorCal	Lodging	Cooking	Range Burners	Burners on MEDIUM	N/A	N/A
NorCal	Lodging	Cooking	Range Burners	Pilot Only	8.58E-04	N/A
NorCal	Lodging	Cooking	Entire Range	Pilot Only	1.15E-03	N/A
NorCal	Lodging	Cooking	Griddle part of Range	Burners on HIGH	5.19E-05	3.77E-05
NorCal	Lodging	Cooking	Griddle part of Range	Burners on LOW	3.88E-04	2.82E-04
NorCal	Lodging	Cooking	Griddle part of Range & Oven Standard (Under-Range)	Pilot Only	1.43E-03	N/A
NorCal	Lodging	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Lodging	Cooking	Oven Standard (Under-Range)	Heating	0	0
NorCal	Lodging	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
NorCal	Lodging	Space_Conditioning	Duct heater	N/A	N/A	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Lodging	Space_Conditioning	Unit Heater	N/A	8.61E-04	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Pilot Only	6.93E-03	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
NorCal	Education	Water_Heating	Condensing Boiler (Water)	Running	0	0
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Pilot Only	8.43E-03	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	9.93E-05	6.01E-05
NorCal	Education	Space_Conditioning	Furnace Standard	On	0	N/A
NorCal	Education	Space_Conditioning	Furnace Standard	On	0	N/A
NorCal	Education	Space_Conditioning	Furnace Standard	On	0	N/A
NorCal	Education	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Pilot Only	1.37E-02	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Running	0	0
NorCal	Education	Space_Conditioning	Furnace Standard	Running	0	0
NorCal	Education	Space_Conditioning	Furnace Standard	Running	0	0
NorCal	Education	Space_Conditioning	Furnace Standard	Running	0	0
NorCal	Education	Space_Conditioning	Furnace Standard	Running	0	0
NorCal	Education	Space_Conditioning	Furnace Standard	Running	0	0
NorCal	Education	Other	Gas Fireplace	N/A	N/A	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Tankless	Cycling	N/A	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Tankless	Running	6.95E-03	3.79E-01

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Education	Water_Heating	Condensing Boiler (Water)	On	0	0
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	3.90E-03	N/A
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Pilot Only	N/A	N/A
SoCal	Food	Cooking	Griddle Standalone	Burners on LOW	1.98E-02	N/A
SoCal	Food	Cooking	Griddle Standalone	Heating to 450F	2.87E-02	N/A
SoCal	Food	Cooking	Griddle Standalone	Pilot Only	5.33E-04	N/A
SoCal	Food	Cooking	Broiler Over-fired (Cheesemelter)	High	4.30E-03	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	2.38E-02	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	N/A	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	Pilot Only	6.48E-03	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	Heating to 500F	7.85E-03	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	9.70E-03	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	1.59E-02	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	4.98E-03	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	Heating to 375	8.64E-04	1.36E-03
SoCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	6.07E-03	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	High	6.15E-03	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	3.66E-03	N/A
SoCal	Food	Cooking	Griddle part of Range	Heating	2.04E-02	N/A
SoCal	Food	Cooking	Broiler Over-fired (Salamander)	High	1.19E-04	N/A
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	N/A	N/A	N/A
SoCal	Food	Cooking	Griddle Standalone	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Food	Cooking	Range Burners	N/A	N/A	N/A
SoCal	Food	Cooking	Broiler Over-fired (Salamander)	N/A	N/A	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
SoCal	Food	Cooking	Tilt Skillet	On	1.63E-02	2.56E-02
SoCal	Food	Cooking	Kettle	On	0	N/A
SoCal	Food	Cooking	Stock Pot Range	N/A	N/A	N/A
SoCal	Food	Cooking	Range Burners	N/A	N/A	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Oven Convection (Top Double Stack)	Heating	N/A	N/A
SoCal	Food	Cooking	Oven Convection (Bottom Double Stack)	Heating	N/A	N/A
SoCal	Food	Cooking	Oven Combination	N/A	N/A	N/A
SoCal	Food	Cooking	Oven Rack	Heating to 300F	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	On	0	0
SoCal	Food	Space_Conditioning	Infrared Heater	On	0	0
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	On	1.77E-04	1.34E-04
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	On	3.62E-02	2.74E-02
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	On	2.86E-02	4.66E-01
SoCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	On	0	N/A
SoCal	Food	Water_Heating	WH Standard-efficiency Storage	Pilot Only	3.18E-03	N/A
SoCal	Food	Water_Heating	WH Standard-efficiency Storage	On	0	0
SoCal	Food	Other	Dryer Commercial	Cycling	N/A	N/A
SoCal	Food	Other	Other (Other)	On	1.22E-03	1.94E-03
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	On	0	0
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Unit Heater	On	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	On	2.53E-03	9.57E-04
SoCal	Warehouse	Space_Conditioning	Infrared Heater	On	1.23E-03	4.65E-04
SoCal	Warehouse	Space_Conditioning	Infrared Heater	On	6.80E-04	2.57E-04
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Warehouse	Space_Conditioning	Infrared Heater	N/A	N/A	N/A
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	On	N/A	N/A
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	On	N/A	N/A
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	On	0	0
SoCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	0	0
SoCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	0	0
SoCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	0	0
SoCal	Lodging	Space_Conditioning	Fire Pit	On	1.62E-02	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	Running	0	0
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	Running	0	0
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	Running	4.09E-04	1.49E-04
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	50% firing	1.18E-03	4.48E-03
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	50% firing	0	0
SoCal	Lodging	Cooking	Other (Cooking)	Burners on HIGH	2.71E-02	1.31E-02
SoCal	Lodging	Cooking	Other (Cooking)	Burners on HIGH	5.67E-01	2.75E-01
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	60% firing	0	0
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	Unknown	0	0
SoCal	Lodging	Cooking	Gas Grill	Burners on HIGH	3.46E-05	1.68E-05
SoCal	Lodging	Cooking	Gas Grill	N/A	N/A	N/A
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	0.5	0	0
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	Unknown	0	0
SoCal	Lodging	Cooking	Gas Grill	Burners on HIGH	0	0
SoCal	Lodging	Cooking	Gas Grill	N/A	N/A	N/A
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	50% Firing	0	0
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	70% firing	0	0
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	Running	0	0
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	Running	3.81E-05	1.44E-05
SoCal	Lodging	Cooking	Gas Grill	N/A	N/A	N/A
SoCal	Lodging	Cooking	Gas Grill	Burners on HIGH	6.60E-05	3.20E-05
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	N/A	N/A	N/A
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	Heating	0	0
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	Heating, 14%	2.04E-04	1.76E-03
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	Cycling	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	Cycling	N/A	N/A
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	1	0	0
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	1	0	0
SoCal	Lodging	Water_Heating	Condensing Boiler (Water)	14-16%	1.41E-04	1.82E-04
SoCal	Lodging	Other	Dryer Commercial	Burners on HIGH	0	0
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Lodging	Other	Dryer Commercial	N/A	N/A	N/A
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Stage 1	1.74E-03	1.52E-02
SoCal	Office	Water_Heating	WH Standard-efficiency Storage	Heating	0	0

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Office	Space_Conditioning	HVAC (RTU)	Heating	0	0
SoCal	Education	Water_Heating	WH Standard-efficiency Storage	Pilot Only	3.39E-03	N/A
SoCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
SoCal	Education	Water_Heating	WH Standard-efficiency Storage	Pilot Only	9.35E-04	N/A
SoCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
SoCal	Education	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
SoCal	Education	Space_Conditioning	HVAC (RTU)	Heating	0	0
SoCal	Education	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
SoCal	Education	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
SoCal	Education	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
SoCal	Education	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
SoCal	Education	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
SoCal	Education	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
SoCal	Education	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
SoCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	Stage 1	9.02E-04	1.17E-02
SoCal	Warehouse	Space_Conditioning	HVAC (RTU)	Heating	0	0
SoCal	Warehouse	Space_Conditioning	HVAC (RTU)	Heating	0	0
SoCal	Warehouse	Space_Conditioning	HVAC (RTU)	Heating	0	0
SoCal	Warehouse	Space_Conditioning	HVAC (RTU)	Heating	0	0
SoCal	Warehouse	Water_Heating	WH Standard-efficiency Tankless	Heating	1.35E-03	2.16E-03
SoCal	Warehouse	Water_Heating	WH Standard-efficiency Tankless	Heating	2.01E-04	3.22E-04
SoCal	Warehouse	Water_Heating	WH Standard-efficiency Tankless	Average - Heating	7.75E-04	1.24E-03
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	Heating	6.97E-04	9.49E-03
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Office	Water_Heating	Boiler	N/A	N/A	N/A
NorCal	Education	Water_Heating	Condensing Boiler (Water)	8% firing	2.66E-05	4.58E-05
NorCal	Education	Water_Heating	Condensing Boiler (Water)	14% down to 9% firing	0	0
NorCal	Education	Water_Heating	WH Condensing Storage	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Griddle Standalone	Heating to 350F	0	0
NorCal	Food	Cooking	Griddle Standalone	Pilot Only	2.16E-03	N/A
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	4.33E-03	5.90E-03
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Pilot Only	7.18E-03	N/A
NorCal	Food	Cooking	Range Burners	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	9.49E-03	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Heating to 360F	5.26E-04	8.76E-04
NorCal	Food	Cooking	Chinese Range	Pilot Only	3.57E-04	N/A
NorCal	Food	Cooking	Chinese Range	Pilot Only	6.19E-05	N/A
NorCal	Food	Cooking	Chinese Range	Pilot Only	2.10E-04	N/A
NorCal	Food	Cooking	Chinese Range	Burners on HIGH	2.64E-04	N/A
NorCal	Food	Cooking	Oven Convection (Standalone)	Heating to 350F	0	N/A
NorCal	Food	Cooking	Steam Kettle	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Combination	Convection	0	0
NorCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	1.83E-02	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Heating to 340F	1.06E-03	1.77E-03
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	1.12E-02	1.02E-02
NorCal	Food	Cooking	Griddle Standalone	Pilot Only	9.05E-04	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	3.26E-05	8.88E-05
NorCal	Food	Cooking	Range Burners	Burners on HIGH	1.12E-04	3.06E-04

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Range Burners	Average - Burners on HIGH	7.24E-05	1.97E-04
NorCal	Food	Cooking	Range Burners	Pilot Only	6.90E-04	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	1.02E-03	N/A
NorCal	Food	Cooking	Range Burners	Average - Pilot Only	8.57E-04	N/A
NorCal	Food	Cooking	Broiler Over-fired (Salamander)	N/A	N/A	N/A
NorCal	Food	Water_Heating	WH Condensing Storage	Heating to 135F	0	0
NorCal	Food	Water_Heating	WH Condensing Storage	Heating to 135F	0	0
NorCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Food	Cooking	Unknown (Cooking)	Unknown	N/A	N/A
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	5.89E-04	2.41E-03
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	Heating	1.27E-04	3.84E-03
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	Heating	0	0
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	Heating	0	0
NorCal	Office	Water_Heating	Condensing Boiler (Water)	14-15% operation	1.84E-05	3.45E-05
NorCal	Office	Water_Heating	Condensing Boiler (Water)	15%-24% operation	0	0
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	Heating	N/A	N/A
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Education	Water_Heating	Condensing Boiler (Water)	Heating	N/A	N/A
NorCal	Education	Water_Heating	Condensing Boiler (Water)	Burner at 14%	1.15E-05	2.09E-05
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	Heating	3.98E-05	1.21E-03
NorCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	Heating	5.40E-04	1.63E-02
NorCal	Education	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Education	Water_Heating	Condensing Boiler (Water)	Heating	0	0
NorCal	Education	Other	Oil Heater	N/A	N/A	N/A
NorCal	Education	Other	Water compressor	N/A	N/A	N/A
NorCal	Education	Other	Water compressor	N/A	N/A	N/A
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Heating	1.35E-02	5.10E-02
NorCal	Office	Water_Heating	WH Standard-efficiency Storage	Heating	8.07E-04	9.77E-03
NorCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Heating	2.49E-05	N/A
NorCal	Office	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
NorCal	Office	Water_Heating	Condensing Boiler (Water)	60-90% firing	0	0
NorCal	Office	Water_Heating	WH Condensing Storage	N/A	N/A	N/A
NorCal	Office	Cooking	Range Burners	Burners on HIGH	3.29E-04	1.25E-04
NorCal	Office	Cooking	Oven Convection (Under-Range)	Heating	3.71E-04	1.69E-04
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	2.55E-03	3.86E-02
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	8.04E-03	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Running	1.82E-04	2.76E-03
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Unknown	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Running	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Running	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Running	N/A	N/A
NorCal	Lodging	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	0	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	0	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	0	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	0	N/A
NorCal	Lodging	Space_Conditioning	HVAC (RTU)	N/A	2.45E-04	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Lodging	Other	Dryer	N/A	N/A	N/A
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
NorCal	Food	Cooking	Steamer	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Standalone)	N/A	N/A	N/A
NorCal	Food	Cooking	Chinese Range	N/A	N/A	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	0	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	0	N/A
NorCal	Food	Cooking	Range Burners	Average - Pilot Only	0	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	0	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	0	N/A
NorCal	Food	Cooking	Range Burners	Average - Burners on HIGH	0	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Range Burners	N/A	N/A	N/A
NorCal	Food	Cooking	Griddle part of Range	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Under-Range)	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Other (Cooking)	Heating	9.65E-05	N/A
NorCal	Food	Cooking	Oven Convection (Top Double Stack)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Bottom Double Stack)	Heating to 320F	0	N/A
NorCal	Food	Cooking	Oven Convection (Top Double Stack)	Heating	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Top Double Stack)	Heating to 460F or 500F	0	N/A
NorCal	Food	Cooking	Oven Convection (Bottom Double Stack)	N/A	N/A	N/A
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	2.83E-04	N/A
NorCal	Food	Cooking	Griddle Standalone	Heating to 425F	8.29E-04	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	1.16E-04	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	7.74E-04	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	6.96E-04	N/A
NorCal	Food	Cooking	Range Burners	Average - Pilot Only	7.35E-04	N/A
NorCal	Food	Cooking	Tilt Skillet	Heating to 250F	3.27E-03	N/A
NorCal	Food	Cooking	Tilt Skillet	Pilot Only	3.05E-04	N/A
NorCal	Food	Cooking	Tilt Skillet	Pilot Only	8.29E-04	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Tilt Skillet	Average - Pilot Only	5.67E-04	N/A
NorCal	Food	Cooking	Tilt Skillet	Pilot Only	1.41E-03	N/A
NorCal	Food	Cooking	Tilt Skillet	Pilot Only	2.41E-03	N/A
NorCal	Food	Cooking	Tilt Skillet	Average - Pilot Only	1.91E-03	N/A
NorCal	Food	Cooking	Tilt Skillet	Heating to 250F	2.83E-03	N/A
NorCal	Food	Cooking	Steamer	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Heating to 370	0	0
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Heating to 350	0	0
NorCal	Food	Cooking	Steamer	Running	2.10E-04	3.97E-04
NorCal	Food	Cooking	Steamer	Running	1.15E-03	2.18E-03
NorCal	Food	Water_Heating	Standard-efficiency Boiler (Steam)	Running	0	0
NorCal	Food	Water_Heating	Standard-efficiency Boiler (Steam)	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	Heating	1.43E-03	5.40E-04
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	Heating	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Running	0	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Running	0	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Running	0	0
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Heating	0	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Off	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Heating	0	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Heating	0	0
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	On	0	0
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Heating	0	0
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	Heating	0	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Lodging	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
NorCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	Heating	3.12E-04	1.42E-02
NorCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	Heating	4.97E-04	2.40E-03
NorCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	Heating	1.96E-05	2.30E-04
NorCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	Off	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A
NorCal	Food	Other	Dryer Commercial	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Range Burners	Burners on HIGH	3.77E-03	N/A
NorCal	Food	Cooking	Range Burners	Burners on HIGH	3.84E-03	N/A
NorCal	Food	Cooking	Range Burners	Average - Burners on HIGH	3.80E-03	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	2.28E-05	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	3.19E-03	N/A
NorCal	Food	Cooking	Range Burners	Average - Pilot Only	1.61E-03	N/A
NorCal	Food	Cooking	Griddle Standalone	N/A	N/A	N/A
NorCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	9.37E-04	1.25E-03
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Heating	3.62E-06	4.38E-06
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Conveyor	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Conveyor	Unknown	2.20E-03	8.32E-04
NorCal	Food	Cooking	Range Burners	Burners on HIGH	1.71E-04	3.36E-04
NorCal	Food	Cooking	Range Burners	Burners on HIGH	6.87E-05	1.35E-04
NorCal	Food	Cooking	Range Burners	Average - Burners on HIGH	1.20E-04	2.36E-04
NorCal	Food	Cooking	Range Burners	Pilot Only	6.15E-03	N/A
NorCal	Food	Cooking	Range Burners	Pilot Only	8.47E-05	N/A
NorCal	Food	Cooking	Range Burners	Average - Pilot Only	3.12E-03	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
NorCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Fryer Open Deep-Fat	Heating	6.85E-04	7.26E-04
NorCal	Food	Cooking	Fryer Open Deep-Fat	Heating	1.45E-04	1.53E-04
NorCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
NorCal	Food	Cooking	Tilt Skillet	Heating	7.83E-05	N/A
NorCal	Food	Cooking	Tilt Skillet	N/A	N/A	N/A
NorCal	Food	Cooking	Steamer	N/A	N/A	N/A
NorCal	Food	Cooking	Steamer	N/A	N/A	N/A
NorCal	Food	Cooking	Kettle	Heating	2.77E-04	N/A
NorCal	Food	Cooking	Oven Convection (Top Double Stack)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Bottom Double Stack)	N/A	N/A	N/A
NorCal	Food	Cooking	Other (Cooking)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Top Double Stack)	N/A	N/A	N/A
NorCal	Food	Cooking	Oven Convection (Bottom Double Stack)	N/A	N/A	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	5.74E-03	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	1.14E-03	N/A
SoCal	Food	Cooking	Range Burners	Average - Pilot Only	3.44E-03	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	2.49E-04	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	1.90E-03	N/A
SoCal	Food	Cooking	Range Burners	Average - Burners on HIGH	1.08E-03	N/A
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Pilot Only	9.92E-03	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	1.88E-03	N/A
SoCal	Food	Cooking	Oven Deck	Pilot Only	4.30E-03	N/A
SoCal	Food	Cooking	Oven Deck	Heating	0	N/A
SoCal	Food	Cooking	Oven Conveyor	Heating	1.86E-04	3.80E-04
SoCal	Food	Cooking	Oven Conveyor	Cycling	N/A	N/A
SoCal	Food	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
SoCal	Food	Cooking	Range Burners	Burners on HIGH	2.38E-04	2.81E-04
SoCal	Food	Cooking	Range Burners	Burners on HIGH	0	0
SoCal	Food	Cooking	Range Burners	Average - Burners on HIGH	1.19E-04	1.40E-04
SoCal	Food	Cooking	Range Burners	Pilot Only	1.60E-03	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	1.96E-03	N/A
SoCal	Food	Cooking	Range Burners	Pilot Only	1.97E-04	N/A
SoCal	Food	Cooking	Range Burners	Average - Pilot Only	1.25E-03	N/A
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	1.55E-04	6.59E-05
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Pilot Only	8.12E-04	N/A
SoCal	Food	Cooking	Griddle Standalone	Burners on HIGH	0	0
SoCal	Food	Cooking	Griddle Standalone	Pilot Only	7.84E-03	N/A
SoCal	Food	Water_Heating	WH Standard-efficiency Storage	On	1.29E-03	3.90E-03
SoCal	Office	Water_Heating	WH Standard-efficiency Storage	Heating	1.33E-04	1.51E-04
SoCal	Office	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
SoCal	Office	Other	Dryer Domestic	Heating	N/A	N/A
SoCal	Office	Other	Dryer Domestic	N/A	N/A	N/A
SoCal	Office	Cooking	Range Burners	Pilot Only	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Office	Cooking	Range Burners	Burners on HIGH	0	0
SoCal	Office	Cooking	Oven Standard (Under-Range)	On	3.47E-03	1.84E-03
SoCal	Office	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
SoCal	Office	Cooking	Griddle part of Range	N/A	N/A	N/A
SoCal	Office	Cooking	Other (Cooking)	Burners on HIGH	3.16E-02	3.83E-02
SoCal	Office	Space_Conditioning	HVAC (RTU)	Heating	3.76E-06	2.28E-06
SoCal	Office	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Office	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Office	Space_Conditioning	HVAC (RTU)	N/A	N/A	N/A
SoCal	Education	Water_Heating	WH Condensing Storage	Heating	0	0
SoCal	Education	Water_Heating	WH Condensing Storage	Heating	0	0
SoCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	2.21E-02	2.68E-02
SoCal	Food	Cooking	Griddle Standalone	Heating	0	0
SoCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	1.01E-03	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	Pilot Only	6.79E-04	N/A
SoCal	Food	Cooking	Oven Convection (Standalone)	Heating	9.32E-03	3.88E-03
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	High Fire	3.98E-06	1.17E-04
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	High Fire	0	0
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	High Fire	3.27E-04	9.64E-03
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Stage 1&2	0	0
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Stage 1	1.72E-03	1.30E-02
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	Stage 1&2	0	0
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
SoCal	Office	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
SoCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	1	0	0
SoCal	Education	Water_Heating	Standard-efficiency Boiler (Water)	0.2-10%	0	0

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
SoCal	Education	Water_Heating	WH Standard-efficiency Storage	Pilot Only	1.11E-02	N/A
SoCal	Education	Water_Heating	WH Standard-efficiency Storage	N/A	N/A	N/A
SoCal	Education	Water_Heating	WH Standard-efficiency Storage	Heating	0	0
SoCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	100% firing	0	0
SoCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	Stages 1 - 4, varying per test	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Tilt Skillet	Heating	N/A	N/A
SoCal	Food	Cooking	Broiler Under-fired (Charbroiler)	Burners on HIGH	2.54E-04	4.38E-04
SoCal	Food	Cooking	Griddle Standalone	Heating	8.21E-04	N/A
SoCal	Food	Cooking	Griddle Standalone	Pilot Only	1.81E-03	N/A
SoCal	Food	Cooking	Other (Cooking)	Pilot Only	1.01E-02	N/A
SoCal	Food	Cooking	Other (Cooking)	Burners on HIGH	1.73E-01	1.31E-01
SoCal	Food	Cooking	Oven Combination	Convection	N/A	N/A
SoCal	Food	Cooking	Oven Combination	Convection	N/A	N/A
SoCal	Food	Cooking	Oven Combination	Convection	0	0
SoCal	Food	Cooking	Oven Rack	N/A	N/A	N/A
SoCal	Food	Cooking	Broiler Conveyor	Burners on	5.51E-04	3.34E-04
SoCal	Food	Cooking	Oven Combination	Convection	0	0
SoCal	Food	Cooking	Oven Combination	N/A	N/A	N/A
SoCal	Food	Cooking	Tilt Skillet	Heating	8.64E-04	1.88E-03
SoCal	Food	Cooking	Fryer Open Deep-Fat	Cycling	7.01E-02	8.49E-02
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Griddle Standalone	N/A	N/A	N/A

Region	Building type	End use	Appliance type	Operating mode	Fraction unburnt	SCFM
SoCal	Food	Cooking	Griddle Standalone	N/A	N/A	N/A
SoCal	Food	Cooking	Oven Conveyor	N/A	N/A	N/A
SoCal	Food	Cooking	Broiler Conveyor	N/A	N/A	N/A
SoCal	Food	Cooking	Griddle Standalone	N/A	N/A	N/A
SoCal	Food	Cooking	Range Burners	N/A	N/A	N/A
SoCal	Food	Cooking	Oven Standard (Under-Range)	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Other (Cooking)	N/A	N/A	N/A
SoCal	Food	Cooking	Kettle	N/A	N/A	N/A
SoCal	Food	Cooking	Steamer	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Fryer Open Deep-Fat	N/A	N/A	N/A
SoCal	Food	Cooking	Chinese Range	N/A	N/A	N/A
SoCal	Food	Cooking	Chinese Range	N/A	N/A	N/A
SoCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A
SoCal	Food	Water_Heating	Standard-efficiency Boiler (Water)	N/A	N/A	N/A

Source: ICF

Table B-2: Appliance Data Summary

Building type	Cooking	Other	Space_Conditioning	Water_Heating	Total
Education	5	6	19	62	92
Food	310	23	41	25	399
Lodging	35	145	22	91	293
Office	80	3	14	71	168
Retail		9	75	3	87
Warehouse			56	5	61
Total	**430**	**186**	**227**	**257**	**1100**

Source: ICF

Table B-3: Pipe-Related Fugitive Methane Data

Building type	Region	Joint type	# of points identified	# of points measured	Average SCFM measured
Lodging	NorCal	Threaded joint	1	1	1.92E-04
Lodging	NorCal	Threaded joint and union	1	1	7.39E-05
Lodging	NorCal	Threaded joint	1	1	7.40E-06
Lodging	NorCal	Union	1	1	3.01E-05
Retail	SoCal	Threaded joint	1	1	2.45E-05
Retail	SoCal	Threaded joint	1	0	N/A
Retail	SoCal	Valve	1	0	N/A
Retail	SoCal	Threaded joint	1	1	6.76E-06
Retail	SoCal	Threaded joint	1	1	5.58E-07
Retail	SoCal	Threaded joint	1	1	1.49E-06
Education	NorCal	Regulator	1	1	2.54E-04
Education	NorCal	Regulator	1	1	9.93E-05
Education	NorCal	Union	1	1	2.22E-04
Education	NorCal	Union	1	1	1.91E-04
Education	NorCal	Threaded joint	1	1	6.52E-05
Education	NorCal	Threaded joint	1	1	4.71E-05
Education	NorCal	Threaded joint	1	1	3.34E-06
Education	NorCal	Threaded joint	1	0	N/A
Education	NorCal	Threaded joint	1	1	1.44E-04
Education	NorCal	Threaded joint	1	1	4.88E-04
Education	NorCal	Threaded joint	1	1	2.88E-06
Education	NorCal	Flange	1	1	1.69E-04
Lodging	NorCal	Threaded joint	1	1	9.31E-06
Lodging	NorCal	Threaded joint	1	1	1.66E-05
Lodging	NorCal	Union	1	1	2.59E-05
Lodging	NorCal	Union	1	1	5.03E-05
Lodging	NorCal	Threaded joint	1	1	1.35E-05
Lodging	NorCal	Threaded joint	1	1	3.85E-05
Lodging	NorCal	Threaded joint	1	1	9.47E-04

Building type	Region	Joint type	# of points identified	# of points measured	Average SCFM measured
Lodging	NorCal	Threaded joint	1	1	4.09E-05
Lodging	NorCal	Threaded joint	1	0	N/A
Lodging	NorCal	Threaded joint	1	1	8.36E-06
Lodging	NorCal	Threaded joint	1	1	2.86E-03
Lodging	NorCal	Threaded joint	1	1	3.54E-05
Lodging	NorCal	Threaded joint	1	1	6.56E-06
Lodging	NorCal	Threaded joint	1	1	1.14E-05
Lodging	NorCal	Threaded joint	1	0	N/A
Education	NorCal	Threaded joint	1	1	2.13E-06
Education	NorCal	Threaded joint	1	1	2.98E-06
Lodging	NorCal	Threaded joint	1	1	2.28E-05
Lodging	NorCal	Threaded joint	1	1	2.07E-05
Lodging	NorCal	Valve	1	1	5.51E-05
Lodging	NorCal	Valve	1	1	4.20E-05
Lodging	NorCal	Threaded joint	1	1	1.62E-06
Office	SoCal	Union	1	0	N/A
Office	SoCal	Other	1	0	N/A
Office	SoCal	Union	1	1	1.64E-04
Office	SoCal	Threaded joint	1	1	3.75E-05
Office	SoCal	Threaded joint	1	1	6.00E-06
Office	SoCal	Threaded joint	1	1	1.59E-05
Office	SoCal	Other	1	1	3.18E-05
Office	NorCal	Threaded joint	1	1	5.47E-04
Warehouse	NorCal	Valve	1	1	1.48E-05
Warehouse	NorCal	Valve	1	1	3.42E-05
Warehouse	NorCal	Threaded joint	1	1	1.07E-04
Warehouse	NorCal	Threaded joint	1	1	1.28E-05
Food	NorCal	Threaded joint	1	1	1.23E-05
Food	NorCal	Threaded joint	1	1	1.32E-05
Office	NorCal	Union	1	1	8.05E-05
Office	NorCal	Threaded joint	1	1	1.10E-05
Office	NorCal	Threaded joint	1	1	2.55E-04
Office	NorCal	Threaded joint	1	1	2.03E-04
Office	NorCal	Union	1	1	5.93E-05
Office	NorCal	Threaded joint	1	1	4.24E-05
Office	NorCal	Threaded joint	1	1	1.18E-05
Office	NorCal	Threaded joint	1	1	2.67E-05
Office	NorCal	Threaded joint	1	0	N/A
Office	NorCal	Threaded joint	1	0	N/A
Office	NorCal	Threaded joint	1	0	N/A
Food	SoCal	Threaded joint	1	1	1.01E-03
Office	SoCal	Threaded joint	1	1	2.74E-06
Lodging	SoCal	Threaded joint	1	1	4.59E-05

Building type	Region	Joint type	# of points identified	# of points measured	Average SCFM measured
Education	SoCal	Threaded joint	1	1	2.46E-05
Education	SoCal	Threaded joint	1	0	N/A
Office	NorCal	Flange	1	1	5.11E-05
Office	NorCal	Threaded joint	1	1	1.87E-04
Office	NorCal	Threaded joint	1	1	1.20E-04
Office	NorCal	Threaded joint	1	1	2.26E-04
Office	NorCal	Threaded joint	1	1	4.39E-06
Office	NorCal	Threaded joint	1	1	1.32E-05
Office	NorCal	Threaded joint	1	1	2.22E-06
Lodging	NorCal	Threaded joint	1	1	9.60E-07
Lodging	NorCal	Threaded joint	1	1	1.01E-06
Lodging	NorCal	Threaded joint	1	1	2.07E-05
Lodging	NorCal	Threaded joint	1	1	4.95E-04
Education	NorCal	Other	1	1	3.91E-06
Education	NorCal	Threaded joint	1	1	1.88E-06
Food	SoCal	Threaded joint	1	1	5.34E-06
Food	SoCal	Threaded joint	1	1	5.21E-06
Food	SoCal	Threaded joint	1	1	1.87E-05
Food	SoCal	Threaded joint	1	1	1.93E-04
Food	SoCal	Threaded joint	1	1	2.03E-05
Food	SoCal	Threaded joint	1	1	2.11E-04
Food	SoCal	Union	1	1	1.24E-05
Food	SoCal	Union and threaded joint	2	2	1.32E-04
Food	SoCal	Threaded joint	1	1	1.22E-04
Food	SoCal	Threaded joint	1	1	1.26E-04
Food	SoCal	Threaded joint	1	1	1.24E-04
Food	SoCal	Threaded joint	1	0	N/A
Food	SoCal	Threaded joint	1	0	N/A
Food	SoCal	Threaded joint	1	0	N/A
Food	SoCal	Threaded joint	1	0	N/A
Food	SoCal	Valve	1	0	N/A
Food	SoCal	Quick connect	1	0	N/A
Office	SoCal	Valve	1	1	1.45E-04
Warehouse	SoCal	Threaded joint	1	1	4.23E-06
Lodging	SoCal	Union	1	1	1.80E-05
Lodging	SoCal	Valve	1	1	2.13E-04
Lodging	SoCal	Valve	1	1	7.96E-05
Lodging	SoCal	Threaded joint	1	1	7.09E-06
Lodging	SoCal	Threaded joint	1	1	1.35E-06
Lodging	SoCal	Valve	1	1	4.51E-05
Lodging	SoCal	Other	1	1	7.95E-05
Lodging	SoCal	Valve	1	1	2.67E-06

Building type	Region	Joint type	# of points identified	# of points measured	Average SCFM measured
Lodging	SoCal	Threaded joint	1	1	4.63E-04
Lodging	SoCal	Threaded joint	1	1	1.74E-05
Lodging	SoCal	Valve	1	1	1.92E-05
Lodging	SoCal	Valve	1	1	3.10E-05
Lodging	SoCal	Threaded joint	1	1	6.09E-05
Lodging	SoCal	Other	1	1	3.42E-05
Lodging	SoCal	Other	1	1	2.37E-06
Lodging	SoCal	Union	1	1	4.59E-04
Lodging	SoCal	Flange	1	1	3.07E-05
Lodging	SoCal	Threaded joint and valve	2	2	4.66E-03
Lodging	SoCal	Union	1	1	6.56E-05
Office	SoCal	Threaded joint, valve	2	2	1.01E-05
Education	SoCal	Threaded joint	1	1	4.66E-05
Education	SoCal	Threaded joint	1	1	4.96E-06
Education	SoCal	Union	1	1	1.97E-05
Education	SoCal	Threaded joint	1	1	7.52E-06
Education	SoCal	Threaded joint	1	1	1.78E-05
Warehouse	SoCal	Threaded joint	1	1	7.09E-05
Warehouse	SoCal	Threaded joint	1	1	4.66E-06
Education	NorCal	Threaded joint	1	1	9.20E-04
Education	NorCal	Valve	1	1	6.25E-04
Office	NorCal	Threaded joint	1	1	3.15E-06
Office	NorCal	Threaded joint	1	1	1.43E-05
Office	NorCal	Threaded joint	1	1	2.09E-05
Office	NorCal	Threaded joint	1	1	6.51E-06
Education	NorCal	Threaded joint	1	1	6.68E-05
Education	NorCal	Threaded joint	1	0	N/A
Education	NorCal	Threaded joint	1	1	6.29E-05
Food	NorCal	Threaded joint	1	1	3.65E-04
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Threaded joint	1	1	8.63E-06
Education	NorCal	Threaded joint	1	0	N/A
Education	NorCal	Threaded joint	1	1	1.19E-05
Education	NorCal	Threaded joint	1	1	1.49E-05
Education	NorCal	Union	1	1	1.54E-04
Education	NorCal	Flange	1	1	7.83E-04
Office	NorCal	Valve	1	1	1.24E-04
Education	NorCal	Threaded joint	1	1	2.38E-06
Education	NorCal	Threaded joint	1	1	1.20E-05
Education	NorCal	Threaded joint	1	1	3.11E-05
Education	NorCal	Threaded joint	1	1	1.74E-05
Education	NorCal	Threaded joint	1	1	4.69E-05

Building type	Region	Joint type	# of points identified	# of points measured	Average SCFM measured
Education	NorCal	Threaded joint	1	1	1.79E-05
Education	NorCal	Threaded joint	1	1	1.66E-03
Education	NorCal	Threaded joint	1	1	1.43E-03
Education	NorCal	Threaded joint	1	1	2.38E-04
Education	NorCal	Threaded joint	1	1	1.96E-06
Education	NorCal	Valve	1	1	9.96E-07
Education	#N/A	Threaded joint	1	1	2.05E-05
Education	#N/A	Threaded joint	1	1	3.03E-04
Education	#N/A	Union	1	1	1.13E-05
Education	NorCal	Valve	1	1	5.42E-05
Education	NorCal	Threaded joint	1	1	1.49E-06
Education	NorCal	Threaded joint	1	1	9.90E-06
Office	NorCal	Threaded joint	1	1	5.00E-03
Office	NorCal	Threaded joint	2	2	3.14E-04
Office	NorCal	Threaded joint	1	0	N/A
Office	NorCal	Threaded joint	1	1	8.08E-05
Office	NorCal	Threaded joint	1	1	8.86E-06
Office	NorCal	Threaded joint	1	1	1.37E-04
Office	NorCal	Threaded joint	1	1	8.22E-06
Office	NorCal	Threaded joint	1	0	N/A
Office	NorCal	Threaded joint	1	1	7.86E-05
Office	NorCal	Threaded joint	1	1	3.91E-05
Office	NorCal	Threaded joint	1	1	6.93E-06
Office	NorCal	Other	1	1	3.06E-04
Lodging	NorCal	Threaded joint	1	1	7.93E-04
Lodging	NorCal	Threaded joint	1	1	5.22E-06
Lodging	NorCal	Threaded joint	1	1	1.72E-05
Lodging	NorCal	Threaded joint	1	1	1.97E-06
Lodging	NorCal	Valve	1	0	N/A
Lodging	NorCal	Valve	1	0	N/A
Lodging	NorCal	Threaded joint	1	1	7.57E-05
Lodging	NorCal	Union	1	1	3.49E-05
Lodging	NorCal	Threaded joint	4	4	8.68E-05
Lodging	NorCal	Flange	1	1	2.63E-04
Lodging	NorCal	Threaded joint	1	1	1.62E-05
Lodging	NorCal	Valve	1	1	4.64E-05
Lodging	NorCal	Threaded joint	1	1	1.30E-05
Lodging	NorCal	Threaded joint	1	1	6.24E-06
Lodging	NorCal	Threaded joint	1	1	2.78E-06
Lodging	NorCal	Threaded joint	1	1	5.74E-06
Lodging	NorCal	Threaded joint	1	1	1.31E-06
Lodging	NorCal	Flange	1	1	4.57E-05
Food	NorCal	Threaded joint	1	0	N/A

Building type	Region	Joint type	# of points identified	# of points measured	Average SCFM measured
Food	NorCal	Threaded joint	1	1	1.12E-05
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Regulator	1	1	9.60E-06
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Threaded joint	1	0	N/A
Food	NorCal	Threaded joint	1	1	1.73E-04
Food	NorCal	Threaded joint	1	1	1.44E-05
Food	NorCal	Threaded joint	1	1	3.99E-05
Food	NorCal	Threaded joint	2	2	3.39E-05
Food	NorCal	Threaded joint	1	1	5.11E-06
Food	NorCal	Regulator	1	1	2.41E-05
Food	NorCal	Threaded joint	1	1	2.08E-04
Food	NorCal	Threaded joint	1	1	5.72E-06
Food	NorCal	Quick connect	1	0	N/A
Food	NorCal	Other	1	1	7.69E-04
Food	NorCal	Threaded joint	1	1	3.06E-05
Lodging	NorCal	Threaded joint	2	2	9.61E-06
Lodging	NorCal	Threaded joint	1	1	3.89E-05
Lodging	NorCal	Threaded joint	1	1	4.59E-05
Lodging	NorCal	Threaded joint	2	2	2.14E-05
Lodging	NorCal	Threaded joint	1	1	1.57E-04
Lodging	NorCal	Threaded joint	1	1	1.63E-04
Lodging	NorCal	Threaded joint	2	2	7.20E-05
Lodging	NorCal	Threaded joint	1	1	9.66E-06
Lodging	NorCal	Threaded joint	2	2	2.95E-05
Lodging	NorCal	Threaded joint	1	1	1.05E-05
Lodging	NorCal	Other	1	1	1.15E-05
Lodging	NorCal	Threaded joint	1	1	1.39E-05
Lodging	NorCal	Threaded joint	1	1	2.27E-05
Lodging	NorCal	Threaded joint	1	1	2.50E-05
Lodging	NorCal	Threaded joint	1	1	1.30E-06
Lodging	NorCal	Threaded joint	1	1	6.62E-05
Lodging	NorCal	Threaded joint	1	1	6.59E-04
Lodging	NorCal	Threaded joint	1	0	N/A
Lodging	NorCal	Threaded joint	1	1	5.86E-05
Lodging	NorCal	Threaded joint	1	1	5.62E-06
Lodging	NorCal	Threaded joint	1	1	1.12E-05
Lodging	NorCal	Threaded joint	1	1	9.19E-06

Building type	Region	Joint type	# of points identified	# of points measured	Average SCFM measured
Lodging	NorCal	Valve	1	1	1.15E-04
Food	NorCal	Threaded joint	2	2	1.81E-05
Food	NorCal	Threaded joint	1	1	4.72E-05
Food	NorCal	Threaded joint	2	2	5.80E-05
Food	NorCal	Threaded joint	1	1	8.47E-06
Food	NorCal	Threaded joint	1	1	1.80E-06
Food	NorCal	Threaded joint	1	1	1.93E-04
Food	NorCal	Threaded joint	1	1	9.50E-05
Food	NorCal	Threaded joint	1	1	4.74E-04
Food	NorCal	Threaded joint	1	1	4.05E-06
Lodging	NorCal	Valve	1	1	8.60E-05
Lodging	NorCal	Threaded joint	1	1	1.50E-05
Lodging	NorCal	Threaded joint	1	1	2.02E-04
Lodging	NorCal	Threaded joint	1	1	6.83E-05
Lodging	NorCal	Threaded joint	1	1	5.71E-06
Lodging	NorCal	Threaded joint	1	1	N/A
Food	SoCal	Valve	1	1	1.66E-03
Food	SoCal	Valve	1	1	1.11E-05
Food	SoCal	Threaded joint	1	1	1.96E-05
Food	SoCal	Threaded joint	1	1	1.64E-06
Office	SoCal	Valve	1	1	1.40E-04
Office	SoCal	Threaded joint	1	1	2.19E-05
Office	SoCal	Other	1	1	8.20E-06
Office	SoCal	Threaded joint	1	1	6.59E-06
Office	SoCal	Threaded joint	1	1	1.60E-04
Office	SoCal	Other	1	0	N/A
Office	SoCal	Threaded joint	1	1	9.76E-04
Office	SoCal	Threaded joint	1	1	5.85E-05
Office	SoCal	Other	1	0	N/A
Office	SoCal	Threaded joint	1	1	2.59E-05
Office	SoCal	Threaded joint	1	1	9.20E-06
Education	SoCal	Threaded joint	2	2	1.18E-04
Education	SoCal	Threaded joint	1	1	2.81E-05
Education	SoCal	Threaded joint	1	1	4.68E-05
Education	SoCal	Threaded joint	1	1	1.81E-03
Education	SoCal	Threaded joint	2	2	3.27E-05
Education	SoCal	Threaded joint	1	0	N/A
Education	SoCal	Valve	1	1	3.49E-04
Education	SoCal	Threaded joint	1	1	7.37E-06
Education	SoCal	Threaded joint	1	1	3.25E-04
Office	SoCal	Threaded joint	2	2	4.17E-04
Office	SoCal		1	1	1.62E-04
Office	SoCal	Threaded joint	1	1	1.47E-05

Building type	Region	Joint type	# of points identified	# of points measured	Average SCFM measured
Office	SoCal		0	0	N/A
Office	SoCal	Threaded joint	2	2	4.74E-05
Office	SoCal	Threaded joint	1	1	3.10E-06
Office	SoCal	Other	1	1	1.87E-04
Office	SoCal		1	1	1.09E-05
Office	SoCal		1	0	N/A
Office	SoCal	Threaded joint	1	1	1.66E-06
Office	SoCal	Threaded joint	1	0	N/A
Office	SoCal	5 threaded joint, 1 regulator	6	6	4.07E-04
Office	SoCal	Threaded joint	1	1	3.85E-04
Office	SoCal	Threaded joint	1	0	N/A
Education	SoCal	Threaded joint	1	1	1.12E-04
Education	SoCal	Threaded joint	1	1	2.77E-05
Education	SoCal	Threaded joint	1	1	2.36E-03
Education	SoCal	Threaded joint	1	0	N/A
Education	SoCal	Threaded joint	1	0	N/A
Education	SoCal	Threaded joint	1	0	N/A
Education	SoCal	Threaded joint	1	1	9.19E-06
Food	SoCal	Other	1	1	3.36E-03
Food	SoCal		1	0	N/A
Food	SoCal	Regulator	1	1	1.51E-03
Food	SoCal	Threaded joint	1	0	N/A
Food	SoCal	Threaded joint	1	1	2.47E-04
Food	SoCal	Union	1	1	2.64E-05
Food	SoCal	Valve	1	1	1.91E-04
Food	SoCal		1	0	N/A
Food	SoCal	Threaded joint	1	1	1.38E-05

Source: ICF

Table B-4: Pipe-Related Fugitive Methane Data Zero Values

Row Labels	Flange	Other	Quick connect	Regulator	Threaded joint	Union	Valve	Grand Total
NorCal	**152**	**402**	**92**	**111**	**7220**	**271**	**705**	**8953**
Education	54	134	2	28	1750	75	204	2247
Food	24	103	83	23	1427	31	151	1842
Lodging	65	107	1	38	2816	117	255	3399
Office	9	18	5	22	855	47	72	1028
Warehouse	0	40	1	0	372	1	23	437
SoCal	**45**	**368**	**73**	**85**	**5037**	**165**	**501**	**6274**
Education	6	29	0	10	560	31	45	681
Food	2	73	48	26	881	15	103	1148
Lodging	2	106	0	24	1304	52	132	1620
Office	28	87	25	24	1250	42	127	1583
Retail	7	62	0	0	822	17	80	988
Warehouse	0	11	0	1	220	8	14	254
Grand Total	**197**	**770**	**165**	**196**	**12257**	**436**	**1206**	**15227**

Source: ICF

APPENDIX C:
Detailed Data Analysis Tables

Table C-1: Full Results of Logit-Normal / Log-Normal Model for Appliance Fraction of Unburnt Methane

Region	Building Type	EndUse	Empirical Weighted mean	n	Sim weighted mean	SE sim weighted mean	Sim weighted mean_025	Sim weighted mean_975
NorCal	Education	Other	4.40E-07	1				
NorCal	Education	Space_Conditioning	4.40E-07	10				
NorCal	Education	Water_Heating	5.55E-05	29	9.76E-06	8.83E-05	3.75E-07	1.67E-04
NorCal	Food	Cooking	9.62E-04	53	6.63E-04	1.95E-03	7.82E-05	5.66E-03
NorCal	Food	Other	1.43E-03	1				
NorCal	Food	Space_Conditioning	1.08E-03	4				
NorCal	Food	Water_Heating	1.67E-04	6	3.60E-03	5.36E-02	7.87E-06	1.72E-01
NorCal	Lodging	Cooking	1.92E-03	20	1.55E-03	5.15E-03	8.31E-05	1.62E-02
NorCal	Lodging	Other	1.58E-02	2				
NorCal	Lodging	Space_Conditioning	2.45E-04	3				
NorCal	Lodging	Water_Heating	1.35E-02	29	8.26E-03	1.13E-02	4.63E-04	4.26E-02
NorCal	Office	Cooking	2.03E-04	8	2.72E-04	4.98E-03	2.97E-06	1.22E-02
NorCal	Office	Space_Conditioning	4.40E-07	2				
NorCal	Office	Water_Heating	1.87E-04	19	3.50E-04	1.02E-03	1.36E-05	3.53E-03
NorCal	Warehouse	Space_Conditioning	4.40E-07	13				
NorCal	Warehouse	Water_Heating	1.55E-05	1				
SoCal	Education	Cooking	1.91E-04	4	7.70E-04	5.75E-02	1.74E-07	1.64E-01
SoCal	Education	Space_Conditioning	1.23E-04	2				
SoCal	Education	Water_Heating	1.30E-04	15	1.11E-05	1.73E-04	9.88E-08	3.67E-04
SoCal	Food	Cooking	1.12E-02	50	2.89E-03	8.45E-03	3.88E-04	1.94E-02
SoCal	Food	Other	1.22E-03	1				
SoCal	Food	Space_Conditioning	5.78E-03	12	3.95E-02	3.91E-02	2.57E-03	1.44E-01
SoCal	Food	Water_Heating	1.08E-02	8	1.01E-02	7.60E-02	2.32E-05	2.72E-01
SoCal	Lodging	Cooking	2.53E-02	5	3.22E-02	5.03E-02	2.45E-04	1.64E-01
SoCal	Lodging	Other	7.26E-05	6	2.05E-04	2.92E-03	2.27E-06	8.48E-03
SoCal	Lodging	Water_Heating	8.67E-05	18	3.18E-05	1.66E-04	3.67E-06	5.37E-04
SoCal	Office	Cooking	5.51E-03	22	3.08E-03	1.01E-02	1.29E-04	3.24E-02
SoCal	Office	Space_Conditioning	6.50E-07	8	6.34E-07	1.91E-07	3.63E-07	1.09E-06
SoCal	Office	Water_Heating	4.43E-03	28	5.36E-03	9.22E-03	3.18E-04	3.27E-02

Region	Building Type	EndUse	Empirical Weighted mean	n	Sim weighted mean	SE sim weighted mean	Sim weighted mean_025	Sim weighted mean_975
SoCal	Retail	Space_Conditioning	2.41E-05	8	1.04E-05	1.03E-04	4.57E-07	3.01E-04
SoCal	Retail	Water_Heating	2.30E-05	3	2.30E-06	2.88E-03	1.74E-10	2.90E-03
SoCal	Warehouse	Space_Conditioning	3.42E-04	7	2.74E-03	5.53E-03	2.12E-05	1.99E-02
SoCal	Warehouse	Water_Heating	7.75E-04	1				

Source: ICF

Table C-2: Full Results of Logit-Normal / Log-Normal Model for Total Pipe-Related Unburnt Methane

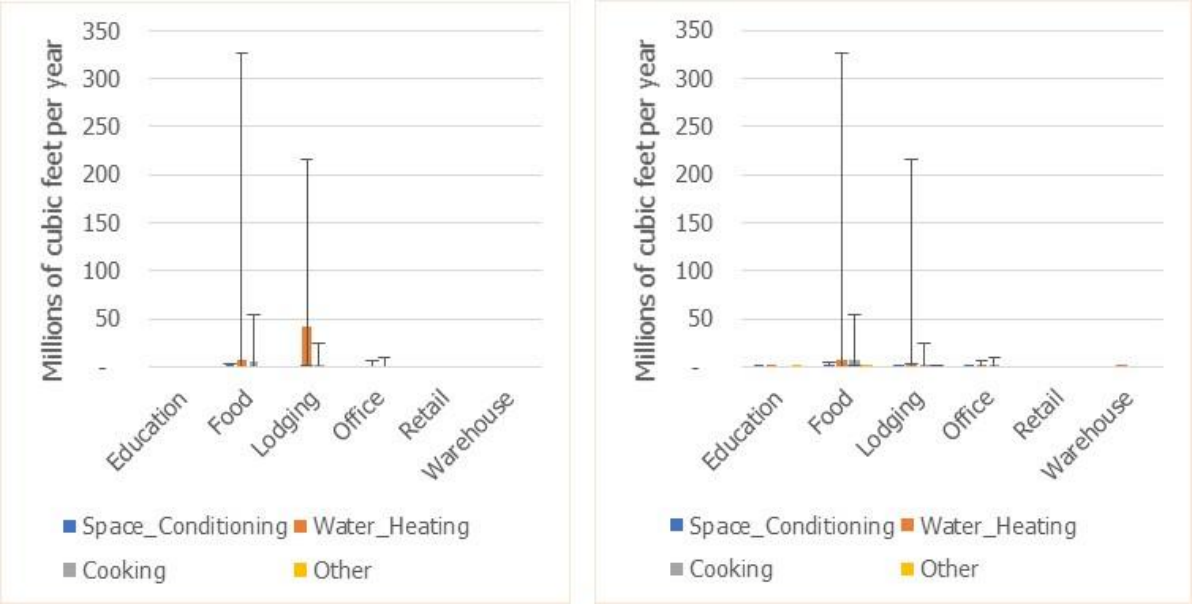
Region	BuildingType	n	semeantotalscf	meantotalscf	meantotalscf_025	meantotalscf_975
NorCal	Education	19	100.41	243.91	80.33	474.66
NorCal	Food	7	115.81	235.56	32.64	473.85
NorCal	Lodging	22	91.82	222.81	92.98	429.68
NorCal	Office	11	239.24	395.17	81.05	932.71
NorCal	Warehouse	2	42.96	76.47	14.52	138.41
SoCal	Education	5	312.33	582.00	29.66	1146.62
SoCal	Food	7	356.47	701.36	146.90	1503.03
SoCal	Lodging	8	276.72	446.01	100.79	1063.16
SoCal	Office	11	89.55	186.19	31.62	395.39
SoCal	Retail	5	11.03	32.49	13.06	54.58
SoCal	Warehouse	3	13.37	26.40	5.30	58.94

Source: ICF

APPENDIX D:
Uncertainty Graphs

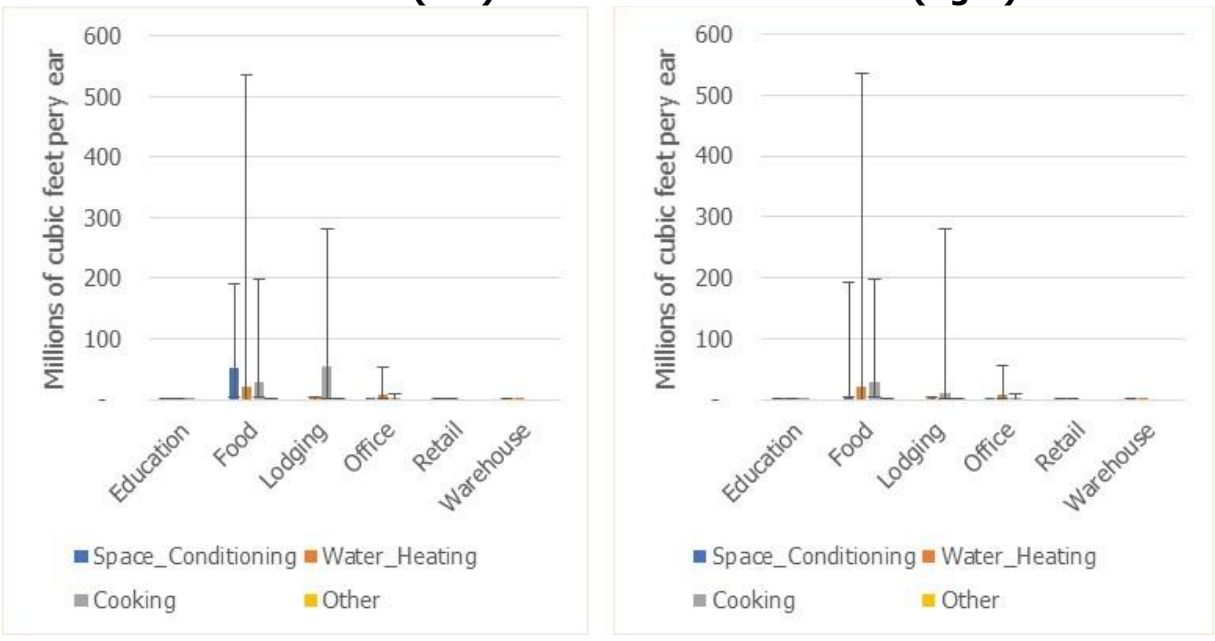
As a simple approximation, for the alternative estimates shown in Figures D-1, D-2, D-3, and D-7, the researchers used the same uncertainty intervals as the original estimates.

Figure D-1: Northern California Estimated Appliance Methane Emissions As Measured (left) and Alternative Estimate (right)



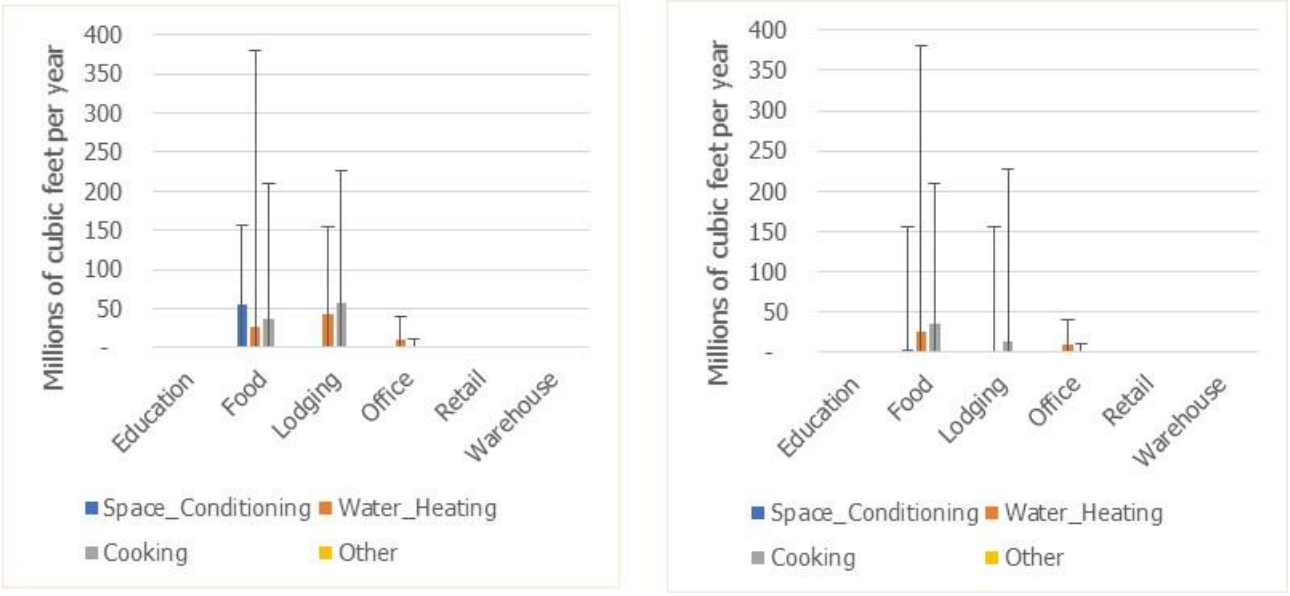
Source: ICF

Figure D-2: Southern California Estimated Appliance Methane Emissions As Measured (left) and Alternative Estimate (right)



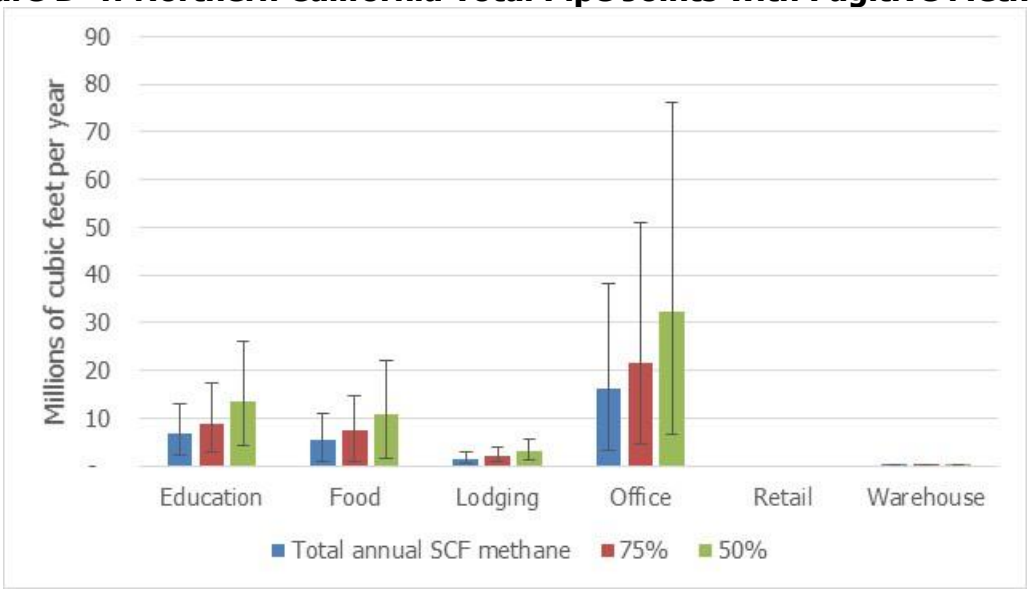
Source: ICF

Figure D-3: Statewide Estimated Appliance Methane Emissions
As Measured (left) and Alternative Estimate (right)



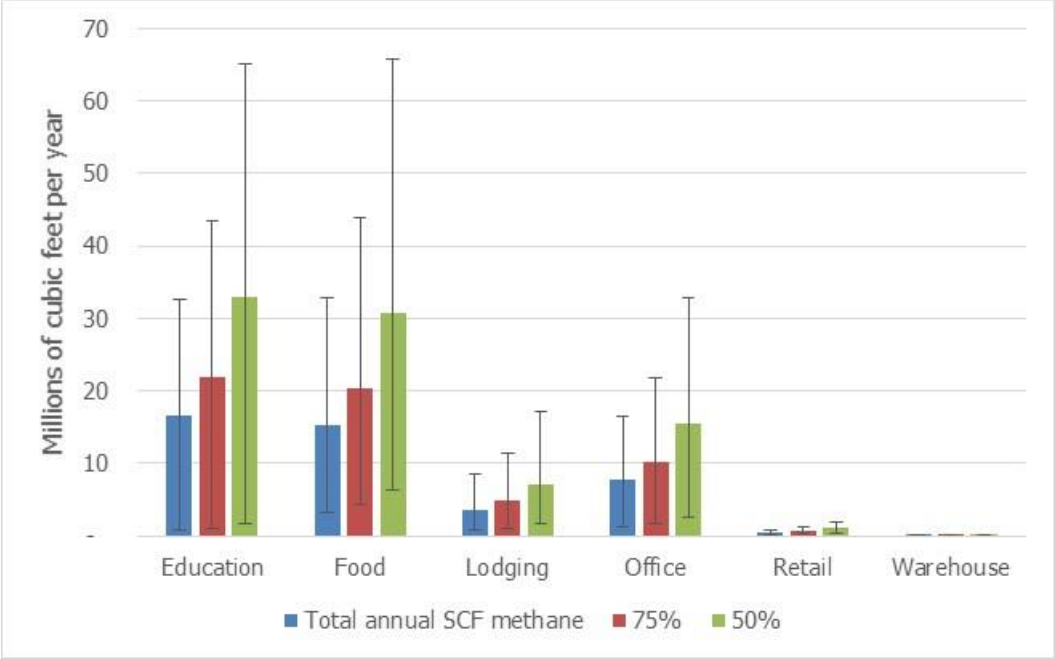
Source: ICF

Figure D-4: Northern California Total Pipe Joints with Fugitive Methane



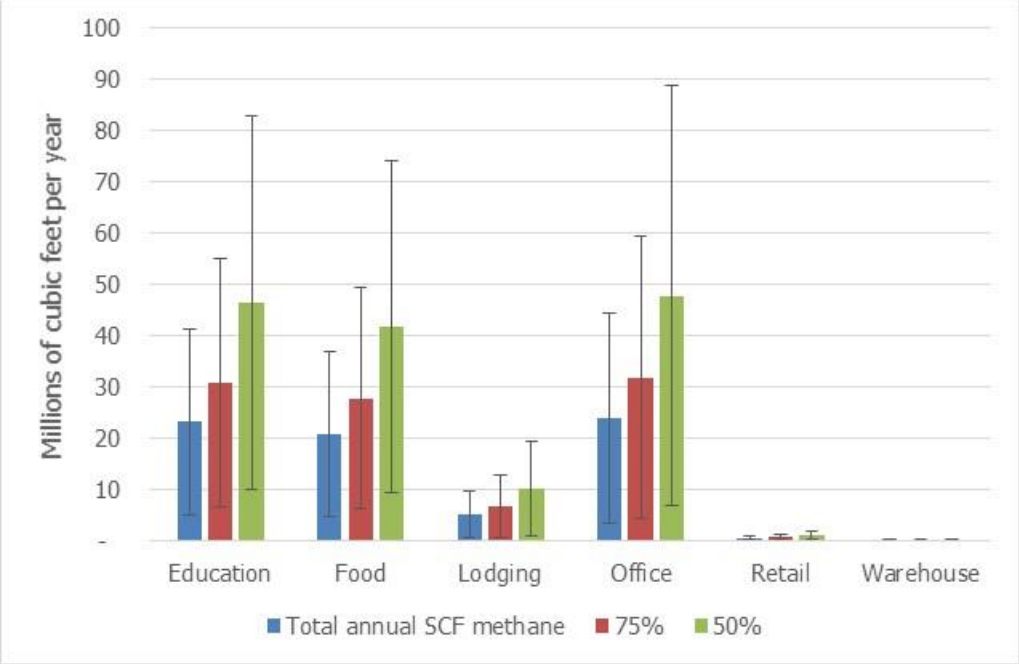
Source: ICF

Figure D-5: Southern California Total Pipe Joints with Fugitive Methane



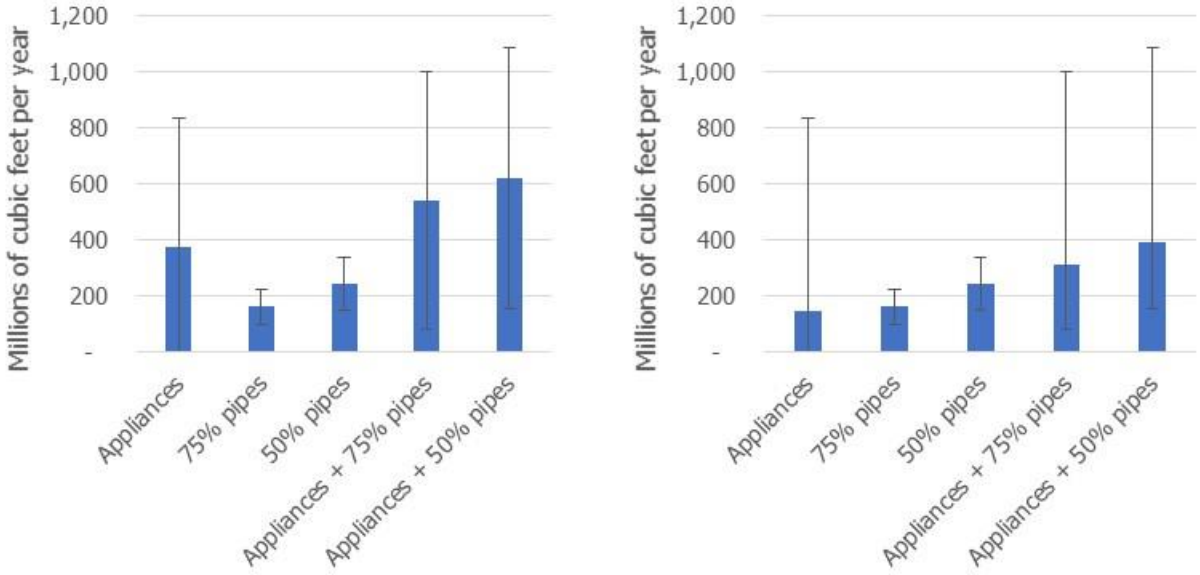
Source: ICF

Figure D-6: Statewide Total Pipe Joints with Fugitive Methane



Source: ICF

Figure D-7: Statewide Estimated Total Emissions
As Measured (left) and Alternative Estimate (right)



Source: ICF