Elevated Methane in Massachusetts and Rhode Island Homes Using Fracked Gas

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Abstract

We surveyed 197 Massachusetts and Rhode Island houses ranging in building style and age to test whether homes served by fracked gas have higher indoor methane concentrations ([CH_4]) than in homes without gas. The answer is clearly “Yes”. From basements and single-floor slab homes to third floors of triple deckers, indoor [CH_4] in households with gas service was significantly elevated over outdoor [CH_4], averaging 1.48 parts per million (ppm) elevation over outdoor ambient [CH_4] ($p < 0.0001 - 0.0068$), and up to 38.2 ppm above outdoor ambient [CH_4]. Ninety-three percent of houses with gas showed higher indoor [CH_4] than the average [CH_4] in non-gas houses. As in other parts of the fracked gas supply chain where a few “super-emitter” leaks account for a disproportionately large percent of total emissions, the distribution of indoor [CH_4] was skewed, with a smaller proportion of houses showing much larger [CH_4] than the average household [CH_4] elevation. For example, the 20% of the houses with highest indoor [CH_4] averaged a [CH_4] of 8.4 ppm, more than quadruple outdoor ambient [CH_4]. By contrast, indoor [CH_4] in gas-free homes was not significantly different from outdoor conditions ($p > 0.05$), except marginally on the first floor (0.10 ppm elevation; $p = 0.029$), less than 1/10th the average first floor [CH_4] elevation in homes served with gas. In 88% of homes investigated, the source of leaks from fracked gas pipes or appliances could be confirmed. There was no relationship between indoor [CH_4] and house age or square footage; residents should not assume that newer homes are less prone to indoor gas leaks. This result provides statistical and direct evidence that fracked gas leaks and exposure is not only commonplace, but likely in New England homes served by gas within the housing types studied. While we did not assess health impacts, leaks of any size are of concern because leaks do not tend to decrease over time and also constitute a condition of chronic exposure. A national program testing for indoor methane concentrations would broaden understanding of how widespread and persistent the pattern observed in this study is, including in low income and rental households.

Introduction

Methane leaks across the fracked gas process chain create tree damage (Schollaert et al., 2020), explosion risks (Ackley et al. 2019), air pollution and climate damage (Staniaszek et al., 2022), and ratepayer expense (Phillips et al. 2012, McKain et al., 2015). The global monthly mean methane concentration ([CH_4]) is currently 1.93 parts per million, approaching a tripling of its pre-industrial level and having risen over the last decade at a rate comparable to the highest rates observed since global monitoring began in 1984 (NOAA 2024)[1]. While indoor fracked gas leaks have been a known problem for decades (John, 2023), renewed emphasis on gas leaks across the fracked gas process chain have returned to the household as a focal point of health, safety, cost, and climate concern. In addition to increasing evidence of negative health impacts from combusted gas in homes (e.g., Krasner et al., 2021, Kashtan et al. 2023), recent studies have progressed from documenting health-concerning compounds in uncombusted gas piped into households (e.g., Mechaniwicz et al., 2022), to documenting leaks from gas appliances (Merrin & Francisco 2019, Lebel et al., 2020; Lebel et al. 2022a), to the presence or emissions rate of fracked gas compounds in household air (e.g. Fischer et al., 2018, Lebel et al., 2022b, Nicholas et al., 2023, Rowland et al., 2024), consistent with indoor gas leaks. Indoor, "behind-the-meter" methane leaks have been speculated to account for a significant portion of total gas distribution system leaks (Sargent et al. 2021).

In this study we examine how commonplace elevated methane concentrations are in bulk room air across a range of housing types in two New England states. We compare homes with gas service to those without gas. To conduct this survey, we took in-house measurements of bulk room air as an indicator of indoor gas leaks, prioritizing the number of homes over comprehensive investigations to pinpoint leaks. We measured indoor methane with high precision in 197 different households in two New England states. We obtained data from houses in a total of 52 municipalities (or officially designated neighborhoods of Boston), with 45 municipalities visited in Massachusetts and seven in Rhode Island (Figure 1; interactive map).

To our knowledge, this is the largest survey to examine detectable household methane elevations to date. One notable study which complements and motivates this study is the recent study of Rowland et al. (2024). In that study, methane in bulk indoor air was tested across 323 homes. However, in the leak survey performed by the authors, the goal was "to emulate a general leak detection survey for near-Lower Explosion Level concentrations that would be performed by licensed appliance technicians (e.g. gas utility employees) or firefighters responding to a reported leak." The Lower Explosion Level concentration of methane in air at standard temperature and pressure is between 44,000 and 50,000 parts per million. The minimum elevation in [CH_4] used in Rowland et al. (2024) to designate a leak was 10 ppm above background, which would potentially miss a large number of houses with [CH4] elevations below a 10 ppm threshold.

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[1]Methane is a powerful but short-lived greenhouse gas (Szopa et al. 2021), which makes solving the problem of methane leaks from fracked gas infrastructure timely and strategic to address climate change.

There are at least two key reasons why documenting the presence of gas leaks that produce $[CH_4]$ in bulk room air less than 10 ppm is important. First, relatively large gas leaks that unnecessarily add to ratepayer bills and pollute the climate may produce smaller elevations of $[CH_4]$ due to poor house insulation (Nicholas et al. 2023). Second, degree of exposure and potential health impacts of exposure to low level but continuous gas leaks are under-studied, including the impacts from added sulfuric odorants (Michanowicz et al. 2023). Our study fills an important gap in determining the prevalence of elevated $[CH_4]$ in houses across a range of size and age that have not previously been examined.

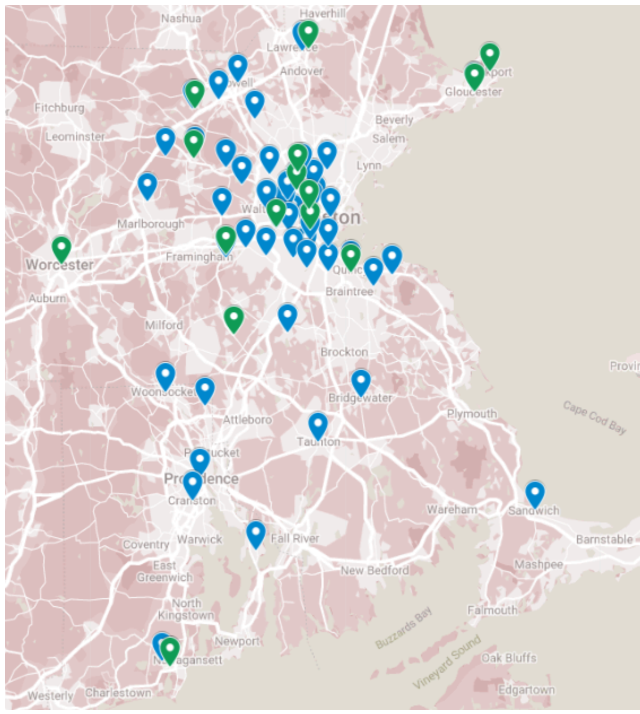

Figure 1. Interactive map of houses tested for methane across 52 communities in eastern Massachusetts and Rhode Island. Blue pins indicate houses with gas service; green pins indicate gas-free houses.

Materials and Methods

House selection:

Houses were selected across eastern Massachusetts and Rhode Island (Figure 1) using a combination of quota sampling (Moser 1952) and snowball sampling (Goodman 1961). Quota sampling was used to achieve a relatively balanced set of households of different types and ages (single family, multi family, and multi-unit apartments). Snowball sampling was used to recruit households via word of mouth and social networks. We recruited a total of 197 houses for this study, 177 of which had gas service and 20 of which had no gas service. Household addresses were not shared beyond the investigators. A limitation of this study is that of the 197 households, only two were rentals. Indoor [CH4] data from houses was collected on 40 dates during the period of February 24, 2024 to June 20, 2024.

A breakdown of the housing types studied here is shown in Figure 2. For context, the US Census Bureau estimates that in 2023, 57.2% of Massachusetts and 61.1% of Rhode Island households are single family.

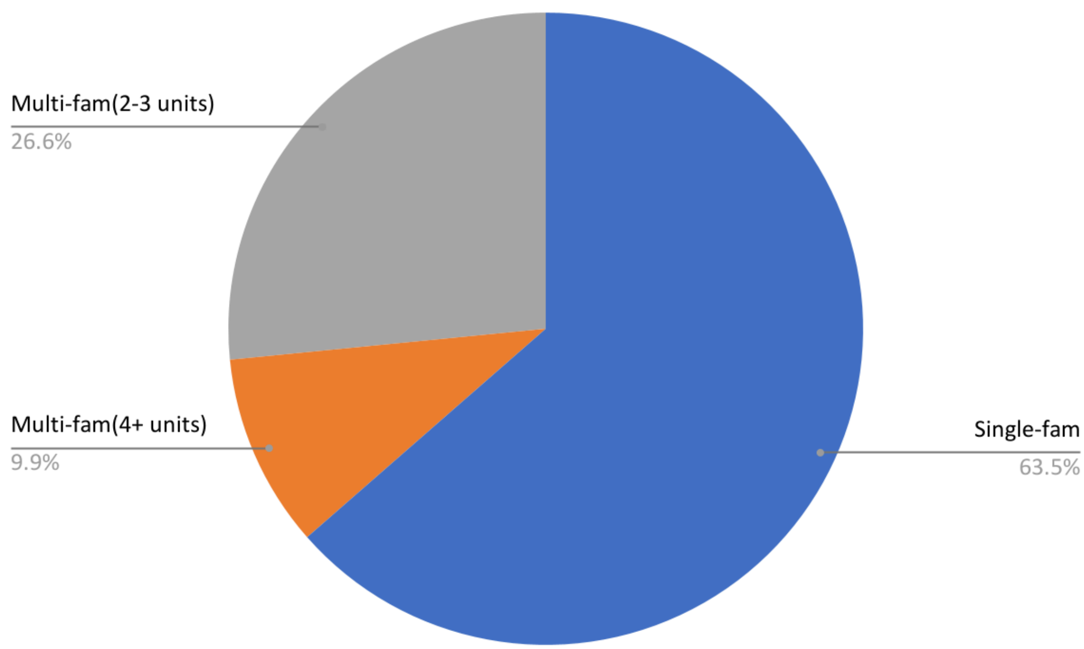

Figure 2. Breakdown of housing types investigated in this study, by number of units.

Methane concentration data collection:
We utilized Cavity Ringdown Spectrometry (Gas Scouter G4301 Mobile Gas Concentration Analyzer, Picarro, Inc., Santa Clara, CA USA) to visit houses to measure indoor air samples, in basements and first, second, and third floors as applicable/available. This instrument, with a raw precision of 0.003 ppm [CH_4], is suitable for detecting elevated [CH_4] in bulk air at greater precision than the 1 ppm resolution instruments used in Rowland et al. (2024) for the bulk air leak survey part of that study. Residents were not asked to change any aspect of their daily routine, including cooking. Methane measurements were made in the center of rooms, without regard to proximity to gas appliances. Checks on the analyzer calibration were performed three times during the course of this study; near when sampling began (February, 29, 2024), approximately midway during sampling (April 23, 2024), and near the conclusion of house sampling (June 19, 2024). Calibration check results are presented in Appendix 1.

Because outdoor ambient [CH_4] values can vary by up to hundreds of parts per billion on a diurnal basis, we sampled outside air immediately prior to entering, and immediately after exiting test homes. With a rising (10% -90%) or falling (90% - 10%) instrument response time of 5 seconds, we waited at least 30 seconds for readings to stabilize in an indoor or outdoor environment before recording values. We recorded the difference between indoor and outdoor methane so that each house studied had its own outdoor [CH_4] comparison value. This work was completed during late winter to late spring 2024, when New England houses typically keep windows and exterior-facing doors closed. To ensure comparable indoor conditions, householders were asked to minimize ventilation through windows or doors for at least a day prior to measurements. We did not request any further special weather sealing or insulation.

When possible and convenient for the householder, we conducted brief searches for sources of elevated [CH_4] inside homes, typically on pipes, pipe connections and gas appliances including stoves, water heaters and gas boilers. A combination of close-up [CH_4] readings and bubble observations from a soap solution applied to suspected leak points were used to pinpoint leaks that could contribute to elevated [CH_4] in the bulk room air.

Results and Discussion

Homes supplied by fracked gas showed significantly higher [CH_4] concentrations than homes not served by gas (Figure 3, Table 1). The largest [CH_4] elevations were in basements, averaging 1.93 ppm above outdoor [CH_4], while [CH_4] in 1st, 2nd, and 3rd floors averaged about 1.3 ppm higher than outdoor ambient. If assuming Gaussian, or bell-shaped statistical distributions, these elevations were highly statistically significant (p values in Table 1). By contrast, homes without gas service were either not significantly different from outdoor ambient ($p > 0.05$, Table 1), or only marginally on first floors with a [CH_4] elevation of 0.10 ppm ($p = 0.029$).

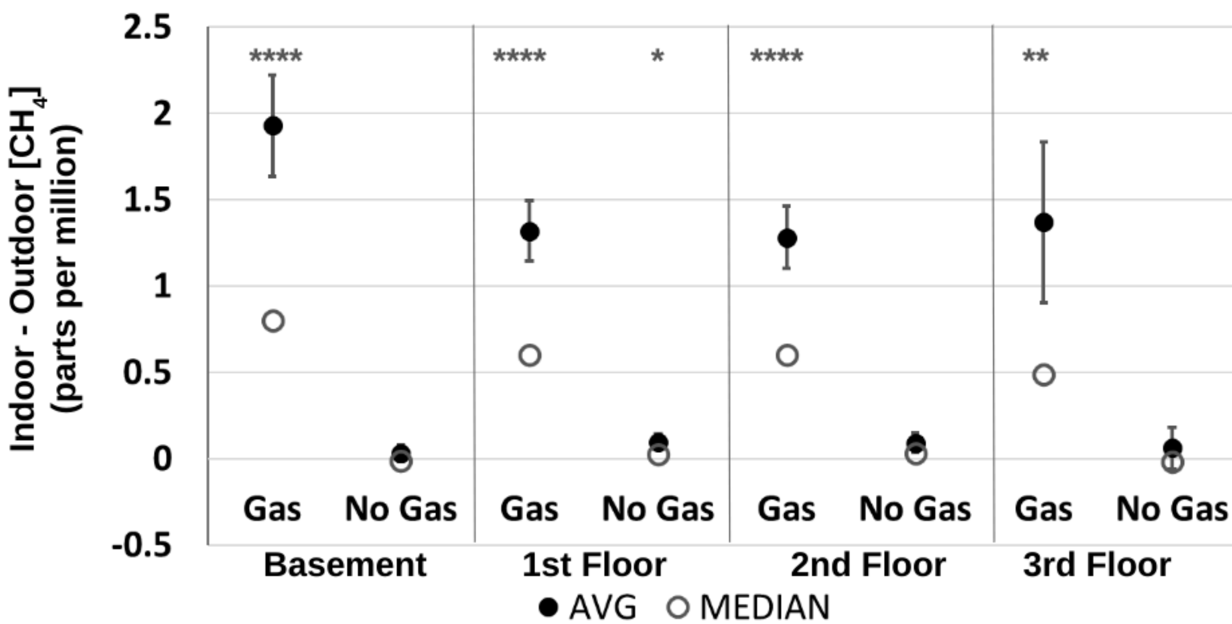

Figure 3. In 197 households studied, homes with fracked gas service showed elevated indoor methane concentrations ([CH_4], parts per million) relative to outside, while homes without gas service did not show consistent elevated [CH_4] relative to outside. Symbols denote averages (black circles) and medians (white circles) among households. Differences in [CH_4] between the indoors and outside of households are shown by floor (basements, 1st, 2nd, and 3rd floors, from left to right). Not all homes had basements or 2nd and 3rd floors. Error bars are standard errors of the mean. "Gas" refers to households with fracked gas service; "No Gas" refers to households without fracked gas service, all-electric and without propane. Statistical significance is denoted as $p < 0.0001$ (****); $p < 0.001$ (***); $p < 0.01$ (**) and $p < 0.1$ (*).

Yet, the distribution of leak sizes in homes with gas service did not appear to be bell-shaped, as indicated by the downward shift of the median values of [CH_4] difference shown in Figure 3 (open circles) from the mean [CH_4] values (closed circles). As across other sectors of the fracked gas process chain (Brandt et al., 2016, Hendrick et al., 2016), the distribution of leak sizes in homes with gas service were skewed with a "long tail" containing a small proportion of large [CH_4] values and a large proportion of houses with lower [CH_4] elevations (Figure 4).

Table 1. Summary statistics of indoor - outdoor methane concentrations ($[CH_4]$, parts per million) from 197 households surveyed in this study.

Category	Floor	Average	Standard Deviation	Number of homes (n)	Standard Error	Median	P value
Gas	Basement	1.93	3.81	163	0.30	0.8	< 0.0001
No Gas		0.027	0.18	18	0.043	-0.01	0.50
Gas	1st Floor	1.32	2.30	166	0.18	0.6	< 0.0001
No Gas		0.10	0.19	20	0.041	0.025	0.029
Gas	2nd Floor	1.28	2.17	142	0.18	0.6	< 0.0001
No Gas		0.093	0.17	12	0.048	0.03	0.080
Gas	3rd Floor	1.37	2.90	37	0.48	0.49	0.0068
No Gas		0.063	0.19	4	0.095	-0.015	0.56

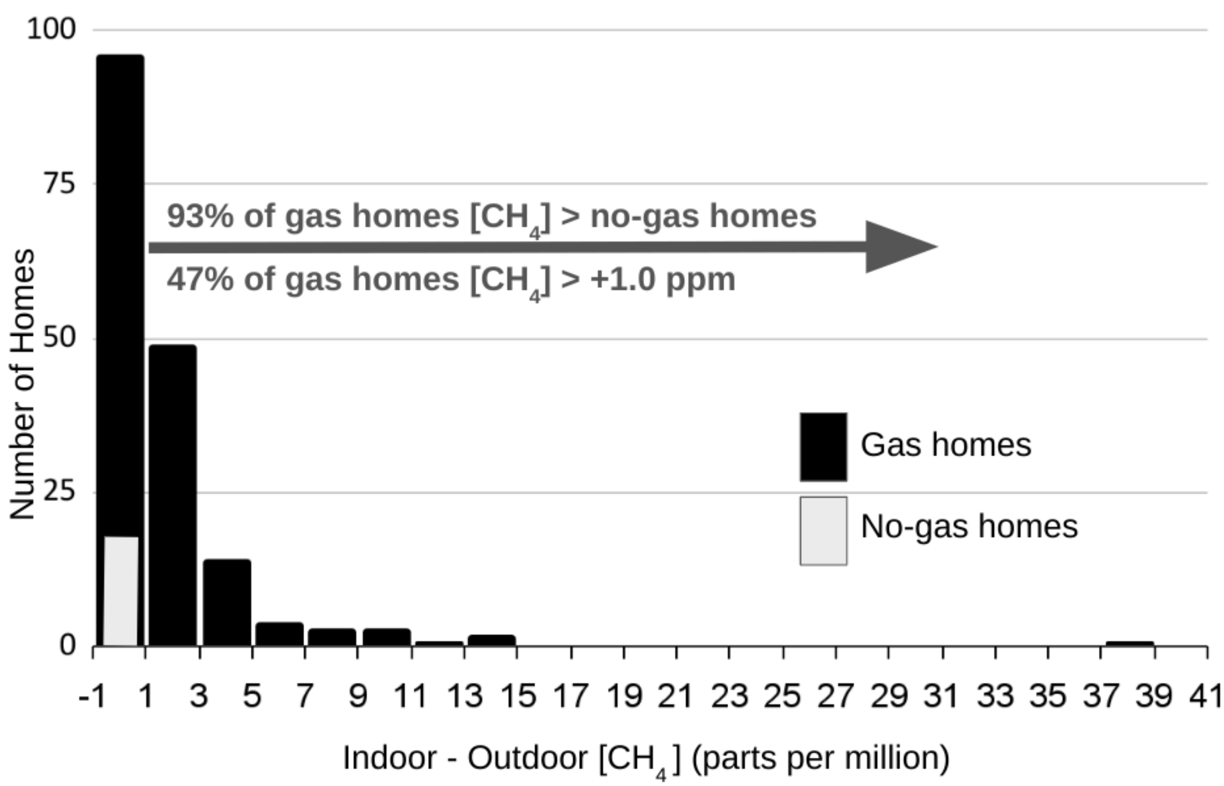

Figure 4. Histogram showing numbers of houses with different levels of indoor minus outdoor methane ($[CH_4]$) concentrations. $[CH_4]$ shown is the highest $[CH_4]$ obtained at any floor. Black bars represent houses with gas service; the gray bar represents houses without gas service. The +1.0 ppm enhancement noted in the figure is equivalent to a 3.0 ppm total $[CH_4]$ reading.

While the presence of small gas leaks in a household raises unique health considerations owing to extended exposure, relative to small outdoor gas leaks, a practical implication of our finding of a skewed distribution of [CH_4] in houses is that they can be prioritized for repair, and to assess leak flux rates according to a recently developed method (Nicholas et al., 2023). It is important to note that just because a house exhibits relatively large [CH_4] does not mean it has a large flux rate, as it depends sensitively on the level of insulation in the home. A small leak in a house with a tight envelope could show a large elevation in methane, while conversely a large leak in a house with a high level of air exchange could show a small elevation in methane.

We had the opportunity to conduct brief searches for suspected leak sources for elevated [CH_4] in 136 of the homes with gas service. Of these homes, we positively identified leak sources in 120 houses, or in 88% of houses checked. Beyond the statistical association of higher [CH_4] in houses with gas, this provides further evidence linking elevated [CH_4] in houses to leaks from gas pipes, connections, and appliances.

There did not appear to be a relationship between house attributes or geography and elevated [CH_4] in homes served by gas. For example, the 10 houses showing the highest elevation of [CH_4] relative to outdoors were located in nine different municipalities and in both states. Of these top 10 houses, all contained basements and first floors, eight had second floors, and three had third floors, and all ten were found in single family homes. There was no relationship between indoor [CH_4] and either house age ($P > 0.1$) or square footage ($P > 0.1$). Thus, living in a relatively newer home should not be a reason to assume it is less likely to contain elevated methane.

Degraded service lines

Although it was not an objective of this study to investigate leak origins or the condition of pipes, fittings and appliances, when possible, attribution of elevated [CH_4] to gas leaks was evaluated by identifying leak locations. In doing this work, one unanticipated finding was that three of 18 (17%) bare steel service lines (observed in the opportunistic process of leak origin determination) in homes served by gas were found to be in poor condition, and called in for repair. Bare steel services comprise 40.1% of all service line miles in Massachusetts and 74.3% of all service line miles in Rhode Island (US DOT 2024). The majority of leak-prone service lines are bare steel (Ackley et al., 2019). Our preliminary finding that one sixth of service lines were in poor condition is a safety concern and warrants focused attention on bare steel pipe condition.

Air quality and health

Little is known about potential health impacts of chronic exposure to low-level leaks of fracked gas. Fracked gas contains compounds including benzene, of concern for human health due to both acute and chronic exposure[2]. Moreover, odorants in gas were documented to have acute health impacts, such as from a large gas leak in Aliso Canyon, California, in 2015 (California Office of Environmental Health Hazard Assessment 2018). While little is known about long-term exposure to low level gas odorants (mercaptans), chronic mercaptan exposure caused lung

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[2]Health impacts of benzene may be found here.

Inflammation and apoptosis in rats (Jiang et al., 2021).

Of particular concern regarding the health impacts of sulfur odorants is that people may have a poor or compromised sense of smell or can become adapted or habituated to persistent odors to the point that they no longer detect them (Wise et al., 2021). On streets and sidewalks, our previous experience (e.g., in informal observations during research published Phillips et al. 2013) is that many people, if focused on the task, can smell gas leaks at methane levels only 1 part per million (ppm) above the ambient background of 2 ppm, or at 3 ppm. In our study, 47% of households with gas that we studied had methane concentrations at or above 3 ppm. While they are "smellable", at least to the occasional visitor with a keen nose, they may not be detected by habituated or adapted residents. Odorants from low level persistent gas leaks that create unhealthy air may also go undetected in many homes with gas.

Almost all relevant studies on health impacts of gas in homes to date have focused on health impacts of *combusted* (not leaked) gas, and almost all of those studies focused on the upstream fracked gas sector, near locations of fracking. This study complements studies that document constituents of gas (e.g., Michanowicz et al. 2022) to better assess exposure and potential health impacts of residents living with a chronic low level gas leak condition, manifesting as elevated indoor [CH_4]. This study represents, to our knowledge, the largest household survey documenting the presence and prevalence of elevated methane in bulk room air, and demonstrating its association with gas equipment in homes. Other studies involving aspects of gas combustion or leakage have studied more houses than this study, but not for the purpose of documenting elevated methane in bulk indoor air and associating it with the presence of gas equipment in homes.

Prevalence of indoor gas leaks

This research demonstrates that in houses served with fracked gas, elevated indoor methane is not only common, but to be expected. Conversely, in gas-free houses, elevated indoor methane levels were found only marginally on first floors, with less than 1/10th the elevation of [CH_4] on average than in houses served with gas. Prior to this research, the only categorical finding on prevalence of detectable elevated [CH_4] in bulk air in gas-served homes reported 13 of 323 homes with a gas leak, or about 4% of households (Rowland et al., 2024). With the finer resolution analyzer used in this study, we estimate from the data presented in Figure 4 that 92% of homes served with gas had greater [CH_4] than homes without gas. Reconciling these vastly different estimates is obtained by comparing the number of houses found with [CH_4] of 10 ppm elevation relative to outdoors. In this study we find 6 houses of 180 gas-served houses, or 3.3% to compare with the 4% found in Rowland et al. (2024). Analogous to the "super-emitter" character of gas leaks across the gas process chain, these findings indicate a "super-polluted' indoor air phenomenon due to gas leaks, which provides a basis for cost effective repair prioritization and quantification of leak rates using methods described in Nicholas et al., (2023).

Implications for safety and methane emissions

This study was not designed to determine methane emission rates but rather stable concentrations, where steady indoor air composition is promoted by springtime conditions when windows and doors are likely to be closed. To obtain rate estimates, at least two measurements must be made over a recorded time interval, with an additional informational constraint such as a known [CH_4] starting point, or a known room or house air exchange rate. This approach to estimate emissions was made in Nicholas et al. (2023). That study nevertheless is in broad consistency with this study. For example, Nicholas et al. (2023) identified leaks in 18 of 20 (90%) of houses, similar to the 93% of houses with gas documented here that had [CH_4] higher than the average of non-gas houses, and the 88% of houses in which we opportunistically pinpointed the leak origin. Secondly, the suggestion of a long-tailed distribution with potential "super-emitters" in Nicholas et al. (2023) is further supported by the long tailed distribution found here (Figure 4) with almost ten times as many houses studied. Together, these studies suggest that, probabilistically, if we had measured more than the order of 200 houses, but ~2000 houses, we may have found a house far beyond the maximum found here of 40 ppm [CH_4], but rather 400 ppm [CH_4]. Further along the long tail, a sample size of 20,000 houses may yield a super polluter/ super emitter with 4,000 ppm [CH_4], a value that is still at least ten times below the lower explosive limit for methane, but possibly a large greenhouse gas emitter depending on house insulation/air exchange rate. While the 197 houses studied here exceed sample sizes in prior studies on bulk indoor air [CH_4], implications of the long-tailed distribution found here call for wider sampling, both within Massachusetts and Rhode Island and beyond. Indoor air sampling of [CH_4] in 20 million houses would sharpen our knowledge of the long-tail distribution across geography and out to levels that approach and protect against [CH_4] levels associated with large greenhouse emitters and even explosion hazards.

Acknowledgments

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Appendix 1. Instrument calibration check

We tested the analyzer prior to the beginning of the survey, on February 29, 2024; during a midpoint of the survey, on April 23, 2024, and near the conclusion of the survey on June 19, 2024, against nominal 0.0 ppm; 2.0 ppm and 10 ppm test gasses in ultrapure air. The test gas tanks (Scott-Marrin, Riverside, CA USA) were certified to contain < 0.01 ppm; 2.072 ppm; and 10.32 ppm [CH_4] respectively (+/- 1% NIST). Test gasses were supplied to the analyzer using Tedlar bags filled with test gasses, and connected to the analyzer inlet during normal operation. Tedlar bags of test gas supply were maintained until the graphical data display indicated the analyzer [CH_4] reading stabilized near the nominal value. Table 1 shows the match between analyzer values of [CH_4] and test gas values. These results demonstrate that our analyzer was working properly and with adequate precision for the study.

Table 1. Analyzer calibration checks.

Date	[CH_4] = < 0.01 ppm	[CH_4] = 2.072 ppm	[CH_4] = 10.32 ppm
2/29/2024	0.011	2.042	10.21
4/23/2024	0.008	2.046	10.06
6/19/2024	0.027	2.019	10.07