Measuring Residential Natural Gas Leakage and its Impact on CH_4 Emission Inventories in California

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ABSTRACT

CH_4 is a very potent greenhouse gas but its emissions are not well understood. Previous studies have shown that the current estimates of CH_4 emissions vastly underestimate emissions throughout California, including in urban areas. Natural gas, comprised of >90% CH_4, is used in more than 10 million homes in the state. However emission inventories assume combustion of all this natural gas, resulting only in CO_2 emissions. Thus residential natrural gas had not been measured for CH_4 emissions. This study examines CH_4 leakage in residences. To determine its impact, I measured leakage rates at 5 houses in the San Francisco Bay Area with a methane analyzer and a blower door. I found a rate of 4.24 ± 2.62 cc/min house-level leakage. This accounts for 1.1% of current California emissions inventories when scaled up to statewide emission levels. I also found during my tests that some natural gas appliances, especially on-demand water heaters, emit CH_4 while in use at a far greater rate than the steady state leakage found in my tests. It is clear from this study that residences are emitting CH_4 that has been previously ignored by emission inventories. Future research is needed on the residential natural gas system appliances to determine the total magnitude of residential CH_4 emissions.

KEYWORDS

methane, house, greenhouse gas, on-demand water heater, tankless water heater

INTRODUCTION

Due to increasing climate change, greenhouse gasses have been a major focus in recent environmental studies. Carbon dioxide (CO_2), the greenhouse gas with the largest total impact on climate change, has become the main focus of studies and its sources are increasingly well understood. Due to its chemical structureMethane (CH_4) is a greenhouse gas 21 times more potent than carbon dioxide; each molecule will affect the climate much more over the time that it is in the atmosphere (US EPA 2012). However, despite the larger impact of CH_4 per unit volume, CH_4 sources are not as well understood as those of CO_2. For this reason, CH_4 emission reduction has not received the same degree of attention as CO_2 reduction. Before effort can go to reducing emissions, we need to know what sources exist and which can be reduced. Therefore, complete CH_4 emission inventories, a record of emissions by source, are a critical step in reducing greenhouse gas emissions.

Measured CH_4 emissions and existing emission inventories differ significantly, showing that CH_4 emissions from many sources are not well understood. The US Environmental Protection Agency makes emission inventories for various harmful compounds that we emit. This includes greenhouse gases such as CH_4, however these inventories are not always complete or accurate. For instance, CH_4 emissions in California may exceed the CA emission estimates significantly (Jeong et al. 2012). This discrepancy may be partially due to agricultural CH_4 emissions, which have been difficult to measure (Zhao et al. 2009). However, CH_4 measurements from urban areas are also much haigher than reported inventories (Wunch et al. 2009). This urban discrepancy would include residential impacts due to natural gas, which is 70-90% CH_4 and leaks into the atmosphere throughout its lifecycle (Venkatesh et al. 2011).

Natural gas leaks are a source of CH_4 emissions that have not been thoroughly studied (Alvarez et al. 2012). Leakage during natural gas production is better understood and regulated than other parts of its lifecycle: processing, transmission or use (Venkatesh et al. 2011). Residential CH_4 usage in the United States totals almost 5 trillion cubic feet of natural gas per year. Even if a small percentage of this gas is leaking, residential natural gas leakage would be contributing billions of cubic feet to CH_4 to the atmosphere. However, due to the large number of other CH_4 sources that also need to be measured, there have not been any studies to look at levels of CH_4 leakage in residential applications, the gas lines, fittings and appliances such as those for

heating homes, hot water, cooking and clothes drying. On-demand water heaters, also referred to as tankless or instantaneous water heaters, are a relatively new and growing part of residential natural gas consumption (California Utilities Statewide Codes and Standards Team 2011). However, their CH_4 emissions are also poorly understood. This gap in understanding means that residential CH_4 leaks represent a source of error in CH_4 emissions inventories used to estimate CH_4 being added to the atmosphere.

METHODS

Residences

I selected residences in Berkeley, Oakland and San Francisco as my sample for data collection. I sampled 5 houses to measure for CH_4 leakage rate. I selected residences with a range of ages and sizes and recorded this building demographic data before starting measurements. I also recorded the natural gas usage by requesting the past year's gas bills from the residents for natural gas usage from PG&E, the gas and electric utility in the area.

CH_4 Measurement

I determined the magnitude of CH_4 leakage in each residence by blowing air out of the residence through a CH_4 analyzer. I used a TEC Minneapolis blower door and a TEC DG-700 digital manometer. These instruments allowed me to blow air out of the house at a rate which varied by residence but which allowed for a turnover of all the air in the residence in around 10 minutes. This also causes the pressure in the residence to be lower than the outside, ensuring that the flow through the blower door is the only outflow of CH_4 from the residence. The DG-700 manometer compared the pressure outside as well as the pressure in the fan to in-house pressure, which let me calculate the airflow through the blower door. In order to measure the background rate, I ran a line outside to draw air from a location that is not in the airstream leaving the house. I drew air from the house outflow next to the blower door fan into a Picarro CH_4 isotope analyzer to measure CH_4 to an accuracy of about 5 ppb. I used a valve to manually switch the source of air being measured: the house outflow or outside.

I turned on the blower door and periodically took measurements of the background CH_4 levels and those in the house outflow. I used the blower door to blow air out of the house until CH_4 level stabilized. To shorten testing time I used the highest flow rate possible for each house while keeping the pressure difference between the house and outside to no more than 60 Pa so that the manometer would be able to accurately measure the flow. I measured the background concentration three to four times per residence throughout the test to control for changes in the background CH_4 level over time throughout the test. Each of these background measurements lasted at least 5 minutes. I also used a peristaltic pump to put CH_4 into the house at a consistent rate of 17cc/min to calibrate the test. I note the time in the data file and while this pump is on, I measure the CH_4 in the airflow with all other testing procedure staying the same.

I also measured an on-demand water heater that smelled of natural gas while it was running. To measure its CH_4 emissions, I used the fan from the blower door on a high speed right next to the heater's exhaust. I used the manometer to measure the flow through the fan and measured the CH_4 concentration in the airflow and intermittently measured the background levels for 5-minute intervals. In the same way as for the leakage test, I calculated the emission rate of the water heater while it was running by multiplying the concentration enhancement by the flow rate through the fan.

Analyzing Emission Impact

I analyzed the data to determine for CH_4 leakage values. Using the pressure readings to calculate flow, I calculated a leakage rate for the residence. I used the difference in CH_4 concentration between the house outflow and background and multiplied this with the airflow rate through the blower door to calculate the CH_4 leakage rate for the residence. I scaled up the house-level leakage to a larger scale emission estimate for California using the number of residential natural gas customers in the state. I then compared these scaled up residential leakage estimates to emissions inventories for the state. I also compared the estimate to the total natural gas usage for the state. I also estimated a possible impact of water heaters such as the ones I measured assuming that the heaters are running for one hour per day and looked at how they would impact CH_4 emissions based on the percentage of households that rely on this kind of water heater.

RESULTS

CH_4 Leakage Rates

Leakage rates in residences were measurable in every residence tested. Results from each test cycle clearly showed this difference in concentration (Fig. 1). The CH4 levels measured in the outflow from the house ranged from 0.01-0.3ppm over background levels of CH4 outside the house (Table 1). This translated to an average of 4.24 ± 2.62 cc/min rate of natural gas leakage with blower door flow rate. The geometric mean is used to give less weight to the outlying house result with 3 times the leakage of any other tested residence. The measured leakage values corresponded to to a statewide leakage rate of 837 million cubic feet. This is 0.16% of residential natural gas use in California.

Table 1. House-level CH_4. The data taken for each test and the corresponding leakage rate.

Residence	Enhancement CH_4 (ppb)	Flow rate (m^3/hr)	Leakage (cc/min)
1	177	5470	16.14
2	99	3420	5.64
3	67	4430	4.95
4	8	7230	0.96
5	68	2796	3.17

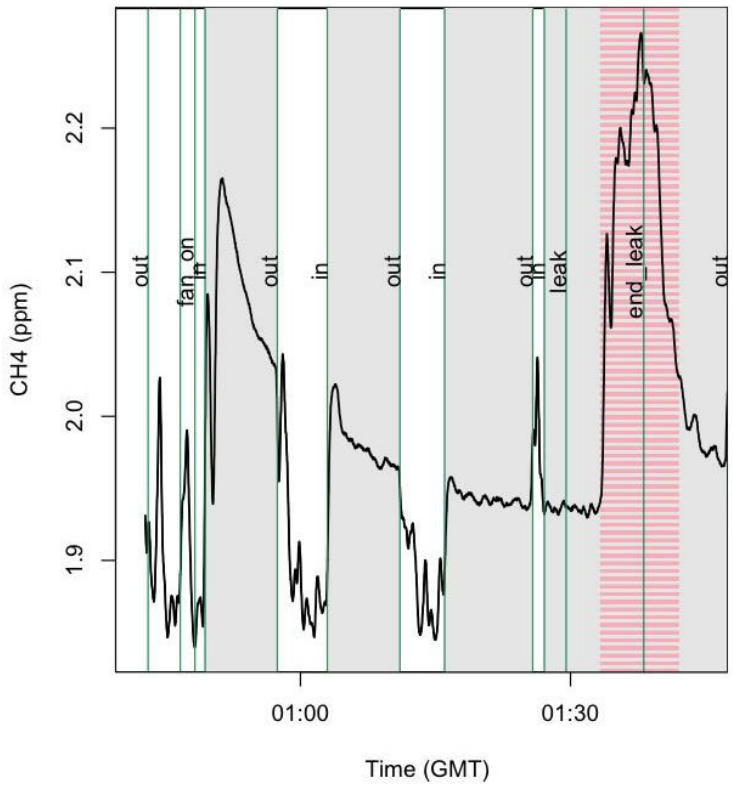

Figure 1. Time series of a typical test of house level leakage. The grey portions are measurements taken from inside while the white portions are bacground measurements and the red portion is the calibrated 17cc/min leak.

DISCUSSION

CH_4 emissions from residential natural gas leakage represent an ignored source of greenhouse gas emissions that have not been previously considered. House level CH_4 leakage is relatively low on a house level. It also represents 1.1% of current CH_4 emission inventories (CARB 2013). While this represents a small portion of total emissions, the findings fill an unknown part of our knowledge of CH_4 emissions because residential sources have not been measured before. This illustrates how many sources of CH_4 emission are not well understood and is a step toward understanding these sources.

House Level Leakage

House level leakage was measurable in every sample. All measurements were taken while natural gas appliances were not being used, so the leak is likely to be a consistent source of CH_4.

As such, over my study sites, this comes out to an average leakage per year of 79ft^3/house. At current prices, this amount of natural gas would cost an average homeowner $0.71/year. This means that it is not going to be economically troubling to an individual homeowner enough to justify the cost of repairs, which would be difficult because the leaks are currently hard to pinpoint.

Broader Emissions

The statewide emissions calculated represent a nonnegligable portion of the emissions inventories of the state. The total leakage was 1690±1040 tonnes CH_4. Although this is only about 0.16% of California's residential natural gas usage, at 0.36±0.22 million tonnes of CO_2 equivalent, it is approximately 1.1% of current CH_4 emissions inventories for California (CARB 2013). This source could explain part of the difference observed in measured emissions compared to assumed emissions. Adding in the water heaters' emissions assumed to be running for one hour per day would account for another 0.24% of current emissions inventories if 25% of houses have this kind of system. This is a reasonable estimate in the near future as more than 24% of new water heaters are on-demand water heaters, a number which continues to grow at an estimated 10% per year (California Utilities Statewide Codes and Standards Team 2011). In all, the CH_4 emissions I measured are a previously ignored source that accounts for part of the discrepancy between measured and reported emissions (Wunch et al. 2009).

Limitations

The study revealed that there is leakage that needs to be more well understood, however the small size and limited variety of samples in the study mean that the estimates have large uncertainties. Having measured only five houses, the sample size is too small to draw very statistically signficant conclusions. There is also a significant selection bias, as the procedure was somewhat invasive I had to rely on a convenience sample, which may not be a representative sample of California homes. I also did not have a large sample of on-demand water heaters to test. However, the results still show a definite source of CH_4 that had previously not been accounted for.

Future

More research into this and other sources of CH_4 emissions in the natural gas lifecycle would lead to a better understanding of greenhouse gas emissions. Emissions inventories for CH_4 in California have already been shown to be inacturate and this study confirms at least one ignored source. Natural gas emissions are uncertain or completely unknown in many other parts of its lifecycle as well, including production, transmission and end-use other than residential. There are also other residential factors including the water heaters that I tested, as well as other appliances which may have similar emissions. In all, there are many other sources that need to be studied to fully understand its impact on CH_4 emissions (Grunwald et al.).

Conclusion

This study shows that natural gas leakage after delivery by utilities could actually represent a large source of greenhouse gas in the atmosphere. At a house level, the leakage seems in some cases to be too small to be concerned about. However, as a whole state, this represents a large source of emissions. More importantly however, it highlights the lack of understanding both of the natural gas lifecycle and how it fits into overall CH_4 emission inventories. In order to reduce our greenhouse gas emissions and our impact on the environment, we first must understand where the emissions are coming from. This study is an important step on the way to improving that.

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