



Significant Environmental Impact (SEI) Natural Gas Leaks

Shared Action Plan Year 2 (2020/2021)

Utilities Enacting the Leak Extent Method

Feb 9th 2022

Su·per e·mit·ters

/ˈsoʊpər əˈmɪdərs/

plural noun: **super emitters**

1. A small fraction of leaks that are responsible for half of the emissions.

"Super emitters need to be fixed with great urgency to combat climate change."

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Executive Summary

This report documents the progress of a first-in-the-nation shared action plan involving gas utilities identifying and repairing distribution system leaks with the largest environmental impact. HEET's role is to independently verify results and make recommendations to utilities for improvement.

Massachusetts has some of the oldest natural gas infrastructure in the country¹. Old pipes in this system are leaking methane, a greenhouse gas 86 times more potent than carbon dioxide over the first 20 years in the atmosphere.² The cost of this wasted gas is passed on to customers and is estimated to be millions of dollars per year.³ Methane from gas leaks also poses a safety hazard to both people and vegetation.

Research in 2016 showed that just 7% of the Metro Boston distribution system leaks emit half of all the gas by volume, creating a clear policy opportunity.⁴ Later the same year, the Massachusetts Legislature enacted a law requiring that these leaks of significant environmental impact ('SEIs') be repaired, since doing so would cut methane emissions in half for the least cost to the utilities and the least disruption to cities and towns. Gas companies had always been mandated to focus on the potential hazardousness of a leak and not emissions, and had no reliable and accurate method to identify SEIs. In 2017, HEET coordinated a large collaborative study to determine a new SEI identification method. Working with Eversource Gas of Massachusetts (formerly Columbia Gas, and now a part of Eversource Energy), and National Grid, Gas Safety Inc., Mothers Out Front and other stakeholders, the research team field-tested multiple methods and showed that a new leak identification protocol - the 'leak extent method'⁵ - is a quick, effective and low cost solution.⁶ The shared action plan emerged from this collaboration.

Since 2018, National Grid and Eversource Gas have been using the leak extent method to identify SEIs and prioritize them for repair. Based on the testing of hundreds of SEIs by HEET since the beginning of the program, utility SEI identification rate appears to be improving in accuracy over time.



Regulations require that SEI leaks are repaired within 1-3 years of identification, depending on the extent and repair method. Emissions reductions are therefore expected to trail identification by 1-3 years.

¹ Pipeline and Hazardous Materials Safety Administration, [Gas Distribution Annual Data, 2020](#)

² IPCC Climate Change Report, [Climate Change 2013: The Physical Science Basis](#), p714, Table 8.7

³ See [Appendix 4](#), Annual Total Cost from the Distribution System for more information

⁴ Hendrick et al, 2016, [Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments](#)

⁵ Originally suggested by Gas Safety Inc., [Appendix 2](#)

⁶ Zeyneb Magavi, Robert Ackley, Margaret Cherne-Hendrick, Dominic Nicholas, Eddie Salgado, Audrey Schulman, Jason Taylor, Nathan G. Phillips, Identification of Large Volume Leaks in Natural Gas Distribution System, publication pending

The annual estimated impact of all SEIs based on the 20 year global warming potential of methane is currently equivalent to approximately 3% of Massachusetts's greenhouse gas inventory, which is equivalent to the emissions of 1/3rd of all Massachusetts stores and businesses (i.e. the commercial sector) in 2017⁷.

Massachusetts is the first to enact legislation to identify SEIs, the first to determine an SEI identification protocol, and the first to test it widely in the field across multiple gas companies. We hope to report in coming years, when repairs of currently identified SEIs are confirmed completed, that we are also first in the nation to cut in half our methane emissions from the gas distribution system. This shared action plan work will continue to provide independent analysis, findings and assistance to utilities to help improve over time.

Shared Action Plan Year 2 Findings at a Glance

- National Grid, Eversource Energy and Eversource Gas of Massachusetts used the leak extent method to identify SEIs.
- In 2020, Massachusetts gas utilities reported 24,243 leaks, half of which were found that year, the other half were carried forward from previous years.
- *Reported Rates of SEIs*: Based on 2020 quarterly leak inventory reports to the DPU, National Grid, Eversource Energy and Eversource Gas of Massachusetts reported lower rates of SEIs compared to what we expected: 5.42%, 2.17% and 2.23% respectively. We recommend utilities adjust the SEI definition threshold to eliminate the largest 7% of leaks in any non-hazardous repair prioritization. This approach would allow those utilities that have eliminated a significant portion of their largest SEIs already to continue to capture half of the total emissions no matter the population of leaks.
- *Accuracy of Identification*
 - HEET sampled and studied 96 utility-identified SEIs this year to check that the leak extent method was being applied consistently. The utilities still appear to be over-identifying SEIs. National Grid improved, over identifying by only 60%, compared to 100% last year. Eversource Gas of Massachusetts over-identified by a factor of 4 compared to 3 last year. Eversource Energy only slightly over-identified by 10%. Given the over-identification tendency, the actual SEI rates may be lower than those reported.
 - National Grid's measured SEI extents were 40% less on average than HEET's confirmed extents. This appears to indicate a strong response from surveyors to the information we provided last year when they were measuring on average larger by a factor of 5. Eversource Gas of Massachusetts measured SEI extents twice as large on average as HEET's confirmed extents, which was about the same as last year. Eversource Energy SEI extents were very close to HEET's confirmed extents. HEET remains ready to meet with surveyors to assist through observation and training. HEET's assistance is free to gas utilities, including their subcontractors, and can potentially help utilities reduce emissions.

⁷ See [Appendix 6](#), Calculating The Greenhouse Gas Emissions of SEIs

- Of the confirmed SEIs, whilst there were differences between HEET's and utilities' leak extent measurements, these differences didn't result in any significant re-grading that would have required a change of repair scheduling or prioritization.
- *Missed SEIs:* HEET ran a mobile gas leak survey with a Cavity Ring Down Spectrometer (CRDS) and identified twice as many leaks as were currently reported by the utilities in their quarterly leak reports. Given this, it is possible that there are twice as many SEIs out there as the utilities have identified.
- *Repair Rates:* SEI repairs are not always successful. They appear to eliminate all gas from the entire leak footprint only 1/4 of the time. Most of the unsuccessful repairs occurred on cast iron pipe and thus could be from multiple leaks in one leak extent.
- *FluxBar:* The FluxBar is a tool that allows gas companies to compare the emissions of leaks. Whilst we had limited FluxBar data, National Grid showed an improved use of the tool and successfully measured leak flux, thus providing a path to confirmed methane reduction. No strong correlation between calculated steady state leak flux and reported leak extent was found in the six flux measures, nor were any of the six leak extent measurements confirmed by HEET. More study is required.
- *CRDS:* The cavity ringdown spectrometer continues to be an excellent tool for finding new potential gas leaks.

HEET is a nimble nonprofit that convenes and generates expertise, research, and ideas to drive a swift and just transition off fossil fuels. Our outsized impact is created through leading large networks of diverse stakeholders to enable information and ideas to emerge.

HEET verified⁸, analyzed and wrote up the information in this report. To maintain its independence, HEET has never taken money from a gas company. HEET is funded by foundations and individual donors.



HEET testing the FluxBar

[Gas Safety Inc](#) has over 40 years of professional experience with gas and gas leaks and six peer-reviewed scientific publications⁹. The 'leak extent' protocol tested in the Large Volume Leak Study was initially proposed by Gas Safety Inc.

[The Gas Leaks Allies](#) is a coalition of more than 25 organizations and researchers focused on reducing methane emissions from the natural gas distribution system in Massachusetts while transitioning to fossil-free energy sources. This unconventional, interdisciplinary collaboration of scientists, gas experts, activists, and concerned citizens is finding solutions for the problems caused by aging, leaking pipes buried in our neighborhoods.

⁸ Gas Safety Inc. was contracted by HEET to provide professional gas surveying third-party verification

⁹ <http://gassafetyusa.com/resources/>

Background

Gas Leaks Accelerate Climate Change

Pipe-quality natural gas is over 90% methane. If leaked to the atmosphere without being burned, it remains methane, a remarkably potent greenhouse gas, much more destructive to the climate than if the gas is burned and transformed to carbon dioxide. Because of the potency of methane, if a total of 3% or more of it is leaked unburned into the atmosphere anywhere from wellhead to point of use, its impact on the climate is worse than burning coal.¹⁰ A NASA study in 2019¹¹ found that natural gas-associated methane emissions are spiking globally in the atmosphere.

Research conducted by Harvard University and Boston University published in 2015, with an update published in 2021¹², measured the amount of both methane and ethane (a chemical marker found only in natural gas) in the atmosphere over the urban Boston region. From these ‘top-down’ measurement results, the researchers calculated that approximately 2.5% of the total natural gas entering this region was leaked unburned into the atmosphere, instead of being used as an energy source.

During the Large Volume Leak study¹³, HEET directly measured emissions from leaks on the distribution system. These ‘bottom-up’ measurements indicated that emissions from these leaks are responsible for approximately 31% (1.3 MMTCO₂e) of the top-down measurement¹⁴. Furthermore, Grade 3 leaks are estimated to be responsible for approximately 1.1 MMTCO₂e, or 26% of the top down measure. Our SEI program, which currently aims to cut emissions from Grade 3 leaks in half, is expected to result in approximately 0.55 MMTCO₂e reduction annually. Our efforts to significantly reduce these emissions are both a small portion of the problem identified by the top-down measure, and a significant reduction for our state’s greenhouse gas emissions.

The annual estimated impact of all super-emitting leaks based on the 20 year global warming potential of methane is currently equivalent to approximately 3% of the carbon dioxide emissions in the state, or the emissions of a 1/3rd of all Massachusetts stores and businesses (i.e. the commercial sector) in 2017¹⁵.

7% of Leaks Emit Half of All the Gas

Research conducted by Boston University¹⁶ in 2016 found that in Metro Boston just 7% of the leaks on the pipes under the streets in the distribution system emit fully half of all the leaked gas by volume. These leaks are called super-emitting leaks. Scientific research has duplicated this

¹⁰ Robert W. Howarth, [A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas](#)

¹¹ Worden, J.R. et al., [Reduced biomass burning emissions reconcile conflicting estimates of the post-2006 atmospheric methane budget](#)

¹² Sargent et al, 2021, [Majority of US urban natural gas emissions unaccounted for in inventories](#); McKain et al 2015, [Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts](#)

¹³ Zeyneb Magavi, Robert Ackley, Margaret Cherne-Hendrick, Dominic Nicholas, Eddie Salgado, Audrey Schulman, Jason Taylor, Nathan G. Phillips, Identification of Large Volume Leaks in Natural Gas Distribution System, publication pending

¹⁴ [See Appendix 6](#) for calculations

¹⁵ See [Appendix 6](#), Calculating The Greenhouse Gas Emissions of SEIs

¹⁶ Hendrick et al. 2016, [Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments](#)

relationship from wellhead to distribution system, showing that a small fraction of the leaks are responsible for half the emissions.¹⁷ Since the cost of the wasted gas is passed on to the customers, this also represents wasted money. *If super-emitting leaks could be identified and repaired, the state could cut emissions and wasted money for the least cost and the least disruption.*



Grading of Gas Leaks

Methane gas is explosive when it builds up to between 5% and 15% of the ambient air in any space. Leak grading has historically focused on this.

Grade 1 (hazardous): Any leak in or near a contained space, such as a building or manhole, that could explode. Grade 1 leaks are fixed immediately.

Grade 2 (potentially hazardous): Any leak that could become a Grade 1 – close to a building, etc. Grade 2 leaks are monitored and fixed within 12 months.

Grade 3 (non-hazardous): All other leaks, those that are not close to buildings or in contained spaces and that are determined to be non-hazardous at the time of detection and can be expected to remain non-hazardous. A Grade 3 leak in the middle of the street for instance could be leaking an enormous quantity of gas. Before the SEI law, there was no requirement that high emitting leaks like this be fixed by the gas company and some leaked for decades.

Significant Environmental Impact Law Passed in 2016

In 2016, the Gas Leak Allies worked to develop and pass new legislation¹⁸ requiring that these super-emitting gas leaks of “significant environmental impact” (SEIs) must be repaired. Grassroots mobilization by Mothers Out Front was a driving force in this effort.

Unfortunately, with the concept of super-emitting leaks so new, *the gas companies had no proven method to identify which of the over 17,500¹⁹ unrepaired leaks in the state were emitting the most.*

¹⁷ Brandt et al, 2016, [Methane Leaks from Natural Gas Systems Follow Extreme Distributions](#)

¹⁸ [Section 144, The 191st General Court of the Commonwealth of Massachusetts](#)

¹⁹ Report on the Prevalence of Natural Gas Leaks in the Natural Gas System, [DPU 17-GLR-01](#)

The 2017 Large Volume Leak Study

In response, in 2017 HEET coordinated the “Large Volume Leak Study”, working with the former Columbia Gas (now Eversource Gas of Massachusetts), Eversource Energy, and National Grid, as well as with Gas Safety Inc, Mothers Out Front and other stakeholders.^{20,21}

The study measured leak emissions using the chamber method, a peer reviewed method for measuring emissions over time, and then tested five proposed proxy methods for identifying the largest volume leaks quickly in the field. Gas workers worked together with grassroots volunteers and scientists to collect the data on leaks across the state.



Key Findings of the 2017 Large Volume Leak Study

The study concluded that the leak extent method was the fastest and most reliable proxy method for identifying high emitting leaks. This method classifies a leak with a gas-saturated surface area larger than 2,000 ft² as emitting enough gas to be considered an SEI leak.

The study found the emissions of a leak are strongly correlated (n=67, R²=0.86) with the leak extent, or size of the gas-saturated surface area over the leak. The bigger the leak, the greater the emissions.

One of the alternate methods tested was the “barhole method.” The barhole method involves making a hole in the ground using a handheld bangbar and inserting a combustible gas indicator in the hole. According to the method, any leak with any sub-surface reading over 50% gas would be considered an SEI leak. However, the study found no correlation (n=68, R²=0.008) between the emissions of a leak and a barhole subsurface reading of over 50%. In addition, National Grid trained gas personnel returned to their studied leaks using the same equipment at the same location and were unable to replicate the barhole readings, showing no correlation between past and present barhole method results.

Shared Action Plan

Based on the outcomes of the Large Volume Leak Study, in October 2017, HEET, the former Columbia Gas (now Eversource Gas of Massachusetts), Eversource Energy, and National Grid created a five-year “Shared Action Plan” ([Appendix 3](#)). The three gas companies and HEET submitted comments jointly to the Massachusetts Department of Public Utilities (DPU) with the request that the leak extent method and the Shared Action Plan be enacted as regulation.

The Shared Action Plan detailed that:

²⁰ Magavi, Z. 2018, [Identifying and Rank-Ordering Large Volume Leaks in the Underground Natural Gas Distribution System of Massachusetts](#)

²¹ Zeyneb Magavi, Robert Ackley, Margaret Cherne-Hendrick, Dominic Nicholas, Eddie Salgado, Audrey Schulman, Jason Taylor, Nathan G. Phillips, Identification of Large Volume Leaks in Natural Gas Distribution System, publication pending

- The leak extent method would be used by the gas companies to identify SEI leaks, until or unless replaced by a superior method.
- These SEIs would be fixed faster than the DPU had initially suggested.²²
- There would be data transparency, independent verification of the results coordinated by HEET, and annual reassessment of data to iterate and refine methods.



SEI Enactment

The Massachusetts Department of Public Utilities (DPU) issued the SEI regulation March 8, 2019. Before that date, the gas utilities have not been allowed to submit for reimbursement of SEI repair expenses. In spite of this uncertainty of reimbursement, for the 2018 field trial year, the gas companies identified 212 SEIs and performed repairs on 19 of those, honoring the Shared Action Plan.

In enacting this regulation, the Department of Public Utilities led the nation in prioritizing SEIs and in defining an effective procedure, leak extent, for their identification. Use of the leak extent method will save money for customers, reduce emissions, and potentially cut the equivalent of 4% of the state's greenhouse gas emissions inventory in as little as three years.

The department at the time also allowed gas companies to use the "barhole method", which the 2017 study found did not work at all. Thankfully utilities in the shared action plan have adhered to scientific findings and are using the leak extent method.

SEIs Are Worth Repairing, Both for the Climate and for the Wallet

In 2019, the Applied Economics Clinic (AEC)²³ created a top-down analysis on the likely return on investment of SEI repairs. As a top-down estimate, it represents the upper range of potentially wasted money and emissions. A bottom-up measurement of emissions would give a lower boundary to the potential range. An accurate bottom-up direct emissions measurement of SEI leaks would require a larger scale emissions study with many more leaks surveyed than has been done to date.

AEC used the findings of the 2016 Harvard University / Boston University study²⁴ to calculate the amount of gas lost into the atmosphere.²⁵ AEC assumed that just a third of that lost gas came from the distribution system (with the rest coming from inside buildings, LNG tanks, etc.) and multiplied that amount by the marginal cost of gas to get the total cost of the wasted gas.

Super emitting leaks (7% of the total leak population) are responsible for half of the leaked gas from our distribution system. The remaining 93% of the leaks emit the rest of the gas. With this

²² [Uniform Natural Gas Leaks Classification](#)

²³ [AEC Policy Brief 2019. Fixing Massachusetts' Gas Leaks Pays for Itself](#)

²⁴ McKain et al, 2015, [Methane emissions from natural gas infrastructure and use in the urban region of Boston](#)

²⁵ [EIA report](#) that year stated a smaller amount of lost gas in Massachusetts (1.9%)

information AEC calculated the amount of gas lost per super-emitter and gas lost per average leak. While the exact quantity of gas is estimated and varies over time, the relationship or ratio should hold true and indicate the relative savings of repairing large leaks first.

The average cost of a leak repair was calculated using the total cost of repairing all the leaks across the state divided by the total number of leaks remaining (both cost and number of leaks as reported by the gas companies).

SEI leaks are identified using a proxy method (the leak extent) that is easy and reliable, but not perfect; therefore the leaks identified are a slightly larger percentage of the leak population (~10%). The table below shows the results. Fixing an average SEI leak gives consumers a return on investment, with the given assumptions and approach, in approximately 14 months. This means the payback for an SEI repair is nine times faster than for a non-SEI repair.

	Total gas lost/year (therms)	Number of leaks	Gas lost per leak/year (therms)	Cost of lost gas/year	Return on Investment (years)
Average leaks	37,753,544	17,810	2,120	\$633	6.2
Super emitter leaks	18,876,772	1,186	15,915	\$4,752	0.8
Grade 3 leaks <u>excluding</u> super emitters	18,876,772	15,758	1,198	\$358	11
SEIs	20,009,378	1,781	11,235	\$3,355	1.2

The Shared Action Plan 2018-2019 SEI Field Trial

A field trial year of the shared action plan work began in 2018. Key findings are summarized below and the full report can be found [here](#).

- Gas companies were able to use the leak extent method to identify SEIs in the field. The measurements of individual leaks were relatively consistent over a work season, even when measured by different personnel from different organizations with varying weather conditions.
- A top-down analysis showed a fast 14-month return on investment for repairing SEIs.
- All three gas companies appeared to be under-identifying some SEIs, potentially because the protocol was new. A mobile CRDS (cavity ring-down spectrometer) survey also showed promise in identifying SEIs.
- The FluxBar, a tool for comparing and confirming the emissions of leaks through a proxy measure of flux, needed more data in 2019 to determine efficacy and refine the protocol.
- Leak repairs didn't appear to always be successful and the success rate needed to be further evaluated to maximize emissions savings per dollar.
- There was potential for refinement of the leak extent method, requiring more information sharing.

The Shared Action Plan 2019-2020 Year 1

The first non-trial year of the shared action plan spanned 2019 and 2020. Key findings are summarized below and the full report can be found [here](#).

- Gas companies' reported use of the leak extent method significantly increased.
- Whilst gas companies continued to use the leak extent method to identify SEIs in the field, they appeared to be over-reporting the actual number of SEIs, and reporting larger leak extents than the real extents, potentially because the protocol was still new.
- Former Columbia Gas (now Eversource Gas of Massachusetts) and Eversource Energy found lower rates of SEIs than in previous years, possibly due to these utilities having begun to identify and repair their SEIs in 2018, before the regulation was formally enacted. HEET recommended utilities continue using the leak extent method to measure leaks, whilst adjusting the SEI definition threshold to continue to capture the largest 7% of leaks.
- SEI repairs continued to appear to be successful only 1/3rd of the time.
- With the data available we didn't see the correlation we expected between FluxBar²⁶ steady state flux and leak extent and continued to study this relationship.
- The cavity ringdown spectrometer continued to be an excellent tool for finding new potential gas leaks.

Year 1 also included a study exploring how SEIs may evolve over time. Key findings are summarized below and the full report can be found in Appendix 6 of the [year 1 full report](#).

- SEI leak extent size was not a predictor of SEI leak extent growth rate.
- SEI grade 3 leaks evolved in terms of hazard potential at a similar rate to non-SEI Grade 3 leaks, with about 13% of both categories becoming grades 2 or 1.
- SEIs were found predominantly on low pressure 6" cast iron pipes installed before 1930 and intermediate pressure 2" coated steel pipes installed after 1930. Given that the same size hole on an intermediate pressure pipe will leak gas at a faster rate than one on a low pressure pipe, prioritizing leaks on intermediate pressure 2" coated steel pipes may be an effective method of cutting emissions rapidly.

Shared Action Plan Year 2 (2020-2021) Results

Eversource Gas of Massachusetts (formerly Columbia Gas), Eversource Energy and National Grid reported using the leak extent method²⁷ to successfully identify SEIs. HEET worked with Gas Safety Inc to perform independent verification and repair surveying of a random sampling of the utility-reported SEIs. This program is a first-in-the nation model, indicating that gas distribution companies can successfully identify and repair the gas leaks that emit the most methane in order to cut emissions most efficiently.

²⁶ See [FluxBar Adoption and Use](#)

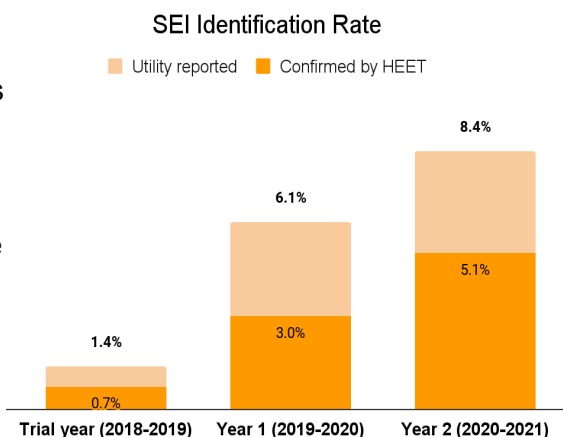
²⁷ See [Appendix 2](#)

Are the utilities identifying SEIs successfully?

Using the leak extent method, HEET independently surveyed 96 reported SEIs (73 from National Grid, 12 from Eversource Gas of Massachusetts, and 11 from Eversource Energy). Leak extents were measured between July 2020 and October 2020 and then compared with reported SEI leak extents from quarterly utility leak inventory reports obtained from the DPU. Reported SEI leaks were chosen by selecting reported SEI designation dates closest to HEET's survey dates, with an average of 83 days between the designation date and HEET's survey date.

Within our sample, we found that Eversource Gas of Massachusetts surveyors may be over-identifying SEIs; only a quarter of the reported SEIs were confirmed by HEET, compared to only a third of the reported SEIs in the previous shared action plan year. In addition to over-identification, similar to the previous shared action plan year, Eversource Gas of Massachusetts surveyors appeared to be over-measuring SEI leak extents by a factor of 2 on average. National Grid surveyors also appeared to be over-identifying SEIs, with 62% of the reported SEIs being confirmed by HEET. This is an improvement over the previous shared action plan year where only 54% of the reported SEIs were confirmed by HEET. In addition to over-identification, National Grid surveyors appeared to be under-measuring leak extents by 40% on average. This appears to indicate a strong response from surveyors to the information we provided last year when they were measuring on average larger by a factor of 5. Eversource Energy surveyors appear to be performing the leak extent method consistently and well in both identification and measurements with 91% of the reported SEIs being confirmed by HEET, and only a slight under-measurement of 7% on average.

In 2021, 8.4% of all grade 3 leaks were reported by the utilities as identified as SEIs to be prioritized for more rapid repair. Based on the testing of hundreds of SEIs by HEET since the beginning of the program in 2018, the utility SEI identification rate appears to be improving in accuracy over time. There are many factors involved which we continue to learn about and this shouldn't overshadow the progress to date. The shared action plan will continue to provide independent analysis, findings and assistance to utilities to help them continue to improve these outcomes over time.



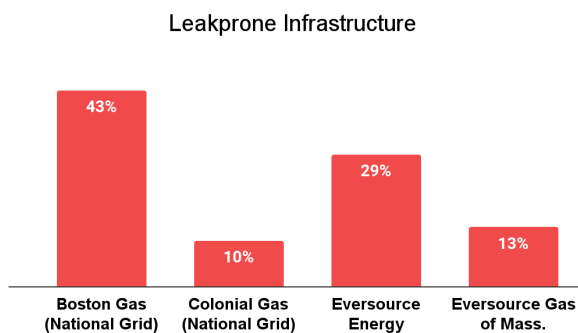
While feedback to the surveyors appears to be useful in improving their performance of the leak extent method, it is important to note the overall success of the gas utilities in prioritizing these SEIs for repair. Of the confirmed SEIs, whilst there were differences between HEET's and utilities' leak extents, these differences would not have required a significant change of repair prioritization based on current Massachusetts Department of Public Utilities regulations [220 CRM 114.07](#).

HEET remains ready to meet with surveyors to assist through observation and training. HEET's assistance is free to gas utilities, including their subcontractors, and can potentially help utilities reduce emissions.

Were Any SEIs Missed?

The aging infrastructure in Massachusetts is not evenly distributed across the state or within any one gas distribution company. This must be taken into account when evaluating results based on the subset of leaks studied here, which were mostly in the Boston Gas National Grid territory.

The chart on the right shows the percent of leakprone infrastructure for the largest Massachusetts gas utilities. Leakprone infrastructure has historically referred to non-cathodically protected steel, cast iron and wrought iron pipes. According to D.P.U. 20-GLR-01, 'Report to the legislature on the prevalence of natural gas leaks in the natural gas system', National Grid is now including pre-1985 plastic/Aldyl-A as leakprone, which was 3% of their system in 2020.



Source : Report to the Legislature (D.P.U 20-GLR-01), 2020

Based on prior research, we were expecting SEIs to account for 7-10% of all grade 3 leaks.

The distribution of 2,000 ft² leaks across the different historic gas utility territories is not necessarily even, but even in aggregate the SEIs reported are fewer than expected based on data reported in the quarterly leak inventory reports submitted to the DPU. National Grid, Eversource Energy and Eversource Gas of Massachusetts all reported lower than expected SEI rates of 5.58%, 2.17% and 2.23% respectively. Taking into account the over-identification error rates we found this year, these SEI rates are most likely lower. When compared to the previous shared action plan year of study, both National Grid and Eversource Gas of Massachusetts SEI rates have declined by about half, whilst Eversource Energy's has remained about the same.

Based on the population of leaks in the Large Volume Leaks study, leaks 2,000 ft² or larger accounted for approximately 50% of all of the emissions from that studied leak population. However, over time as SEIs are repaired and new ones appear, the population of leaks changes, and SEIs might now require a different threshold. This might explain these lower SEI rates.


We recommend utilities *adjust the SEI definition threshold to eliminate the largest 7% of leaks in any non-hazardous repair prioritization*. This approach would allow those utilities that have eliminated a significant portion of their largest SEIs already to continue to capture half of the total emissions no matter the population of leaks. A gas utility can define SEIs in their territory as the top 7% of their leak extents to ensure they are optimizing their methane emissions reduction. Alternatively, the leak extent threshold could be set annually based on the prior year's aggregated set of all grade 3 leak extents across gas territories, which would ensure that the state is cutting methane emissions from pipeline gas leaks in half.

Searching for Missed SEIs

In November 2020, Gas Safety Inc surveyed 300 miles of roads with the Picarro CRDS in areas that the utilities had already surveyed for SEIs. Over 150 miles were surveyed across 4 towns in National Grid territory, and 75 miles across 4 towns in Eversource Energy and Eversource Gas of Massachusetts territories.

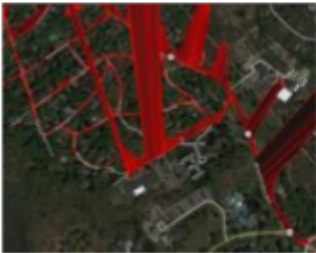
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A Picarro CRDS Natural Gas Analyzer



The Picarro CRDS installed in the car

As the car is driven, a sensor detects parts per million of methane and records the amounts found together with GPS coordinates. This CRDS is similar to the CRDS that the Environmental Defense Fund uses in its mobile surveys.



Gas leaks in Lexington, MA

The Picarro data can be visualized in Google Earth. The red lines shows where the car drove; the peaks show where methane was found.

CRDS Survey Found New Potential Leaks

In total, we found 346 new potential leaks which did not correspond to any of the 357 reported unrepaired leaks on our route. In the previous shared action plan year we found 325 new potential leaks which didn't correspond to any of the 479 unrepaired leaks on the route.

Utility	Reported unrepaired leaks on route	New potential leaks
Eversource Gas of Mass.	72	97
Eversource Energy	46	139
National Grid	239	110
Total	357	346

The possible reasons for these new potential leaks include:

- Not all unrepaired leaks were included in the 2020 annual service quality report
- Partially repaired leaks were being categorized as completely repaired

- New gas leaks had developed since the area was last surveyed
- Differences in sensitivity and specificity between CRDS and traditional mobile surveying methods
- Rarely, elevated CRDS methane readings may come from landfills, sewers, septic, ruminants and swamps

We did not have the resources to survey many potential leaks on the route to check if they were SEIs. Of the few we did survey, no new SEIs were found.

See [Appendix 5](#) - CRDS Analysis Methods for more details on how this analysis was performed.

The CRDS Detected Already Identified Leaks

On average, 40% of the time, the CRDS located elevated methane at locations of reported unrepaired leaks.

Utility	Reported unrepaired leaks on route	CRDS matches	CRDS rate of correspondence
Eversource Gas of Mass.	72	23	32%
Eversource Energy	46	25	54%
National Grid	239	83	35%
Total	357	131	Average: 40%

The possible reasons for this lower correspondence rate include :

- Some reported unrepaired leaks were repaired between date of data reporting and date of our survey
- Some reported unrepaired leaks were not detected due to being too small and too far away from the road. Whilst the CRDS is extremely sensitive (measuring parts per billion of methane), given the right wind conditions, small distant leaks - particularly service line leaks - may not be detected.

CRDS Summary

In order to develop a complete picture and make conclusions about CRDS effectiveness, we would need to survey all reported unrepaired and repaired leaks, and all additionally newly found elevated methane locations (new potential leaks). We were not able to do this during this project due to time and resource constraints. However, the implications of finding so many new potential leaks with the CRDS - almost the same number as were reported - cannot be overstated. We propose that a larger study be conducted to survey unrepaired, repaired and new potential leaks to develop a more conclusive understanding of the effectiveness of the CRDS system. Especially during winter patrol, the CRDS could allow more frequent surveys, increasing safety for all.

Where Do SEIs Occur ?

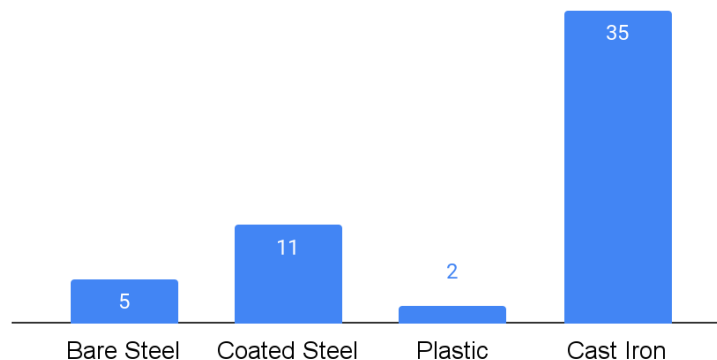
Our hope is that as we learn about SEIs in terms of their tendency to appear on different types of pipe materials or different amounts of pipe pressure, we might be able to refine the leak extent method to help the gas companies prioritize the areas most likely to have SEIs.

In summary, in this shared action plan year of study the confirmed SEIs occurred most frequently on low pressure 4-6” cast iron pipe installed over 90 years ago. This finding corresponds with a previous finding from the 2019 SEI evolution study.

Multiple cast iron joint leaks may be responsible for these leaks being sufficiently large in footprint to make them SEIs. Based on previous studies, we also strongly suspect that SEIs are also occurring on higher pressure infrastructure on other materials.

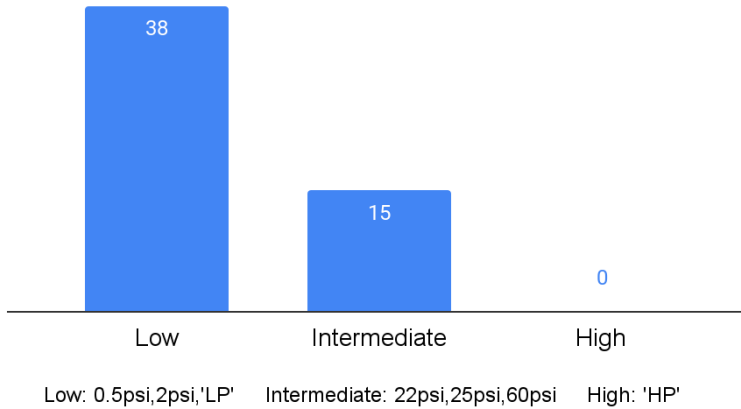
Distribution of Confirmed SEIs by Pipe Material

Cast iron pipes appeared to be more likely to develop SEIs, especially when compared to the material distribution of the utilities. This is consistent with our understanding of where most leaks in general are occurring. More data is needed to confirm this tendency since this was a small dataset.



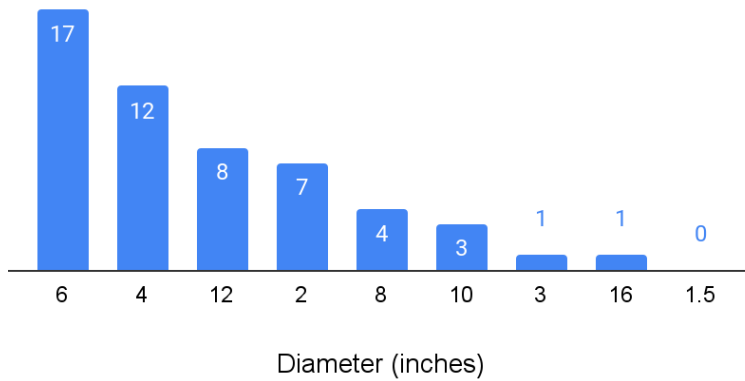
Distribution of Confirmed SEIs By Pipe Pressure

Overall, the majority of confirmed SEIs were found on low pressure pipes. That pattern held when looking at National Grid or Eversource Gas of Massachusetts specifically. Eversource Energy had slightly more on intermediate pressure.



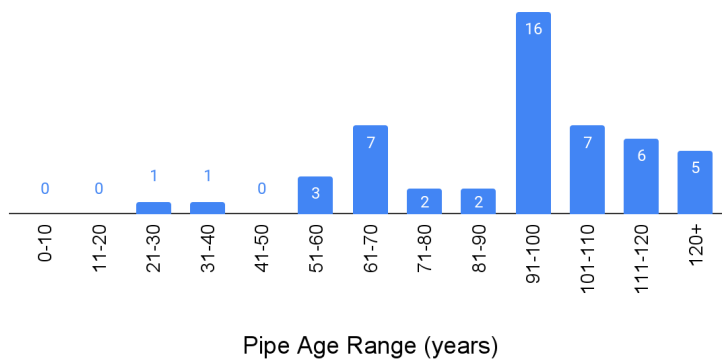
Distribution of Confirmed SEIs By Pipe Diameter

Overall, confirmed SEIs occurred most frequently on 4" and 6" pipe.



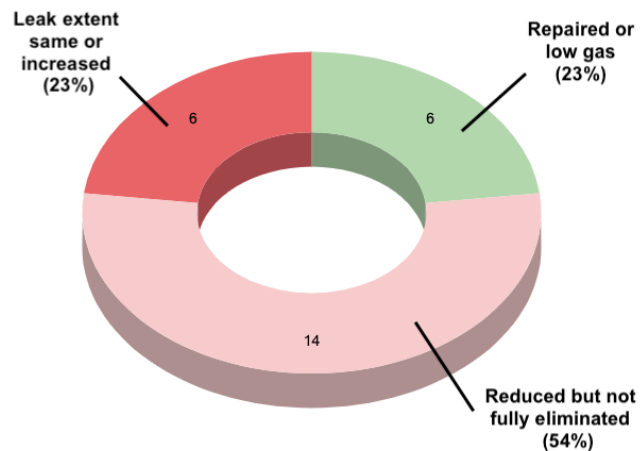
Distribution of Confirmed SEIs By Pipe Age

Overall, confirmed SEIs occurred most frequently on pipes installed over 90 years ago. The median age was 92 years old.



Success Rate of Verified SEI Repairs

Of the 96 leaks we surveyed, 26 leaks were reported repaired by the utilities, all of which HEET verified as SEIs. To allow all residual gas to leave the soil in the area, HEET returned to these leaks at least a month - and on average 120 days - after repair to check for the presence of gas. If there was any, we measured and recorded the leak extent. Whilst this data set is too small to be conclusive, the results follow a concerning trend from the previous shared action plan years, the large volume leak study, and the SEI evolution study, where only a subset of the leaks are eliminated by repair work.



Repair crews are careful and effective and we have observed that they are repairing leaks at leak sites. However, leaks tend to cluster since the gas pipes for neighborhoods tend to be laid at the same time and from the same material, thus becoming leakprone at the same time. It is likely that some SEIs are made up of more than one hole in one pipe under the ground. Some of the potential reasons for gas existing at the site a month after repair are:

- The repair crew repaired one hole in one pipe, and did not repair all holes in all pipes within the leak extent.
- The loosened dirt from the repair created a pathway for gas from a different but nearby leak to exit the ground.
- The repair jarred the aging pipe and caused further damage.

Leaks whose gas footprint was not fully eliminated occurred most frequently on low pressure cast iron 4" pipe installed over 90 years ago. Given that leaks that were not fully eliminated were mostly on cast iron pipe, we recommend evaluating whether SEI repairs might be improved by encapsulating or otherwise sealing every cast iron joint in the SEI leak extent. Acknowledging that this would require markout (Dig Safe marking before repair) of the full leak footprint and also that there may be other better solutions, HEET would be open to exploring small pilots with the utilities of this and other ideas for optimizing the repair of SEIs.

According to the gas companies' *Report to the Legislature 2020*²⁸, the estimated cost of repairing all 16,044 leaks left in the state at the end of 2020 was \$35 million. In the previous *Report to the Legislature 2019*²⁹, the estimated cost of repairing the 17,533 leaks left in the state at the end of 2019 was \$59 million. This means that learning how to increase the success rate of leak repair will be money well spent for both gas companies and customers. The least expensive time to repair a leak is the first time.

²⁸ [Report to the Legislature on the Prevalence of Natural Gas Leaks in the Natural Gas System, 2020, D.P.U.](#)

²⁹ [Report to the Legislature on the Prevalence of Natural Gas Leaks in the Natural Gas System, 2019, D.P.U.](#)

FluxBar Adoption and Use

Background



The FluxBar was invented during the pilot study through a collaboration of HEET, Eversource Energy, Eversource Gas of Massachusetts (formerly Columbia Gas), Gas Safety Inc, Boston University Nathan Phillips and Millibar. The FluxBar is a utility-familiar tool that was redesigned to allow gas companies to compare the emissions of leaks in order to identify which were the largest just prior to repair. The FluxBar is not intended as a tool to identify SEIs as it requires a truck compressor and therefore can only be used by the leak repair crew just prior to repair. This repair crew use of the FluxBar on a significant number of SEIs could help result in data about SEIs, such as the pipe material, age or pressure that are correlated with SEIs, making identifying SEIs more efficient. It could also provide much needed directly measured flux data, potentially quantifying emissions reduced for carbon credits.

The FluxBar is inserted through a hole drilled through the road over the leak. It is connected to a truck compressor that blows air through the horizontal top of the tool. The flow of air, thanks to the Venturi effect³⁰, vacuums air up the standpipe at a steady three cubic feet per minute. A combustible gas indicator connected to the FluxBar head can then measure the percent of gas in that steady air flow from under the road surface, right over the leak. The gas readings over time are noted to calculate the steady state plateau. The result allows a consistent comparison of directly measured flow rate from one leak to the next.

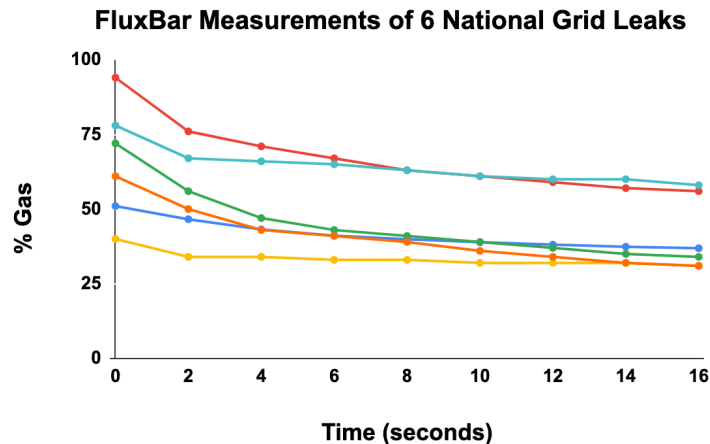
In 2017, the large volume leak study found a correlation between FluxBar results and emissions, as measured using the chamber method which is a peer-reviewed method. Since emissions are also correlated with leak extent, there should be a relationship between leak extent and FluxBar results. Later in 2017, Eversource Gas of Massachusetts (formerly Columbia Gas) captured a different leak extent through holes that were drilled through the road surface, instead of through “bar holes” made using a handheld tool on the side of the road. We analyzed this second data set and found that while the distribution of the FluxBar steady state readings was similar to our initial data set, there was no correlation between the drill hole leak extent and the Fluxbar steady state. In 2018, we got no new FluxBar data and could not report any advances in understanding. In 2019 both Eversource Gas of Massachusetts and Eversource Energy used the FluxBar during SEI repairs using the correct protocol. Based on a very small dataset, we didn’t see the correlation expected between steady state flux calculations.

2020 Results

National Grid acquired FluxBars and training on their use in 2020 and chose SEIs for FluxBar use during repair in 2021. HEET offered to attend these repairs to observe and offer assistance. FluxBar readings from six reported SEI repairs were shared with HEET, the leak extents of

³⁰ https://en.wikipedia.org/wiki/Venturi_effect

which were not confirmed by HEET. During repairs National Grid successfully measured leak flux from which steady state flux readings could be calculated, thus providing a path to confirmed methane reduction. No strong correlation between calculated steady state leak flux and reported leak extent was found. Eversource Energy and Eversource Gas of Massachusetts completed their commitments to using the FluxBar in 2019.



While the FluxBar measures physical flux at that location, we haven't yet seen the correlation expected between steady state flux calculations and leak extent measures. This may be related to the presence of multiple physical pipe leaks in a given leak extent and more data is needed for analysis. HEET continues to work with gas companies using the FluxBar to develop our understanding and potential future studies may include:

- Exploring the relationship further between FluxBar measurements, chamber method measurements and subsurface leak extent measurements
- Testing the zone of influence of FluxBar in different soils under different conditions
- Exploring drill hole leak extent protocol consistency and explore questions about dynamic changes in initial hour measurements

Shared Action Plan Year 3

HEET continues to work to meet our Shared Action Plan commitments, providing independent verification, analysis and reassessment. Surveying of utility-reported SEI leaks was completed in September and October 2021. By the end of 2021 we completed the CRDS road survey and SEI repair surveying will start in spring 2022.

With the SEI regulations enacted, the Commonwealth has a plan to reduce its emissions by the equivalent of 3% of its greenhouse gas emission inventory within 3 more years. Through this work, HEET continues its persistence and commitment to cutting carbon.

Appendices

Appendix 1 - Definitions and Acronyms

- **Barhole** : a hole made into the ground using a bangbar, into which a CGI is typically inserted to measure gas.
- **Barhole method** : The barhole method involves making a hole in the ground using a handheld bangbar and inserting a combustible gas indicator in the resulting barhole. Barhole reads are performed in different locations around a gas leak. Any leak with a barhole (sub-surface reading over 50% gas was considered an SEI leak.
- **Chamber method** : the scientific gold standard for leak emission measurement, using chambers of varying sizes to capture flux, or flow of methane over time, across the surface area of a leak.
- **Combustible Gas Indicator (“CGI”)** : a device used to detect flammable gas concentrations. The CGI is equipped with a 2-3 foot probe rod and hose assembly normally attached to an electronic unit that draws in an air sample using a built-in pump or by squeezing a rubber bulb.
- **Department of Public Utilities (DPU)** : In Massachusetts, the government agency charged with regulating the utility companies, with leadership appointed by the secretary of energy and environmental affairs.
- **EDF** - Environmental Defense Fund
- **Flame Ionization Unit (“FIU”)** : a device used to detect flammable gas concentrations. The FIU is comprised of a 2-3 foot probe rod and hose assembly normally attached to an electronic unit that draws in an air sample using a built-in pump which will provide a direct readout of gas in air concentrations.
- **Flux** : the rate of flow of a gas, such as methane, per unit area over time.
- **FluxBar** : a device used just prior to repair to capture and compare leak emissions
- **Grade 3 Gas Leak** : A leak classified as non-hazardous by utility workers at the time of detection and expected to remain non-hazardous..
- **Grade 3 SEI, or SEI** : a leak of Significant Environmental Impact. A grade 3 (non-hazardous) leak that emits enough gas to be in the top 10% of gas leaks in terms of emissions
- **GSEP** - Gas System Enhancement Plan is the 20 to 25 year plan of the gas companies to replace all the leakprone pipes under the ground in Massachusetts.
- **Large Volume Leaks (LVLs)** : large leaks in the distribution system, defined by a threshold leak extent measure of 2000 sq ft or more. Research so far indicates this is approximately 10% of all leaks, though further data may adjust the threshold. Also known as a leak of significant environmental impact (SEI).
- **Leak Extent** : surface area in which a gas company has detected positive CGI or FIU readings surrounded by an area of negative CGI or FIU readings.
- **Leakage Perimeter** : the process of creating a boundary of the leak extent. The leakage perimeter consists of subsurface inspection locations that can be monitored for changes in CGI readings. The leakage perimeter is established when 0% gas is obtained in two consecutive subsurface inspections (e.g., barholes, available openings).
- **Natural Gas** : a fossil fuel that, when processed and distributed as ‘pipe quality’, is roughly 97% methane.
- **SEI** - Significant Environmental Impact leak prioritized for repair in 2016 law passed in MA.
- **Subsurface Gas Detection** is the sampling of the subsurface atmosphere through barholes and/or available openings (e.g. cracks in the pavement, subsurface structures such as manhole covers, valve boxes, catch basins, etc.) with a combustible gas indicator (i.e. placing the indicator at least 6 inches into the barhole and/or available openings)
- **Super-emitting leak** : the top 7% of any population of leaks, emitting half of all the total gas by volume.
- **Surface Gas Detection** is a continuous sampling of the atmosphere at or near ground level for buried gas facilities and adjacent to above-ground gas facilities using an instrument approved for this type of survey on the appropriate sensitivity scale

Appendix 2 - Leak Extent Method

A Proposed Standardized Survey Method to Measure Leak Footprint

This protocol was created by all MA gas companies in Spring of 2018 in order to enact the leak extent method, adhering to the Shared Action Plan. (Note: definitions not included)

Suggested Method to Establish Leak Extent using CGI and Barhole

1. Establish the initial leakage perimeter of the suspected leakage area using a surface gas detection survey in accordance with appropriate Company standards or procedures.
2. If a gas indication is found, continue to establish the leakage perimeter by using the subsurface gas detection survey in accordance with appropriate Company standards or procedures.
3. Leak Extent is measured by multiplying the greatest width (perpendicular to the pipe) by the longest length (parallel to the pipe) to get total surface area. The width and length is established based on zero to zero readings.

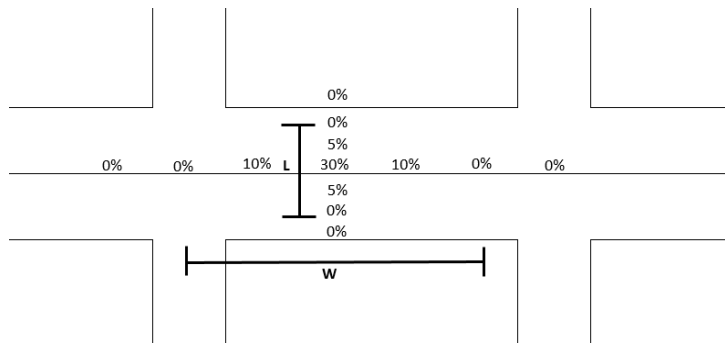


Figure 1 Capturing Leak Extent

Appendix 3 - Shared Action Plan

This is the Shared Action Plan agreed to by Columbia Gas, Eversource Gas, National Grid MA, and HEET, and supported by Mothers Out Front and the Gas Leaks Allies. The announcement of this agreement was at an MIT Summit in October of 2017. It was submitted to the Massachusetts Department of Public Utilities with a request that it be enacted statewide later the same month.

Identification

- Grade 3 LVL determined using leak extent as sole proxy method, at least for the first year.
- Leak footprint evaluated with a consistent and defined method across utilities (i.e. either with CGIs/FIs, barhole or drill holes). Method to be decided by utilities.
- Leaks over 10 years old not prioritized for repair unless it is LVL.

Repair

- Leaks > 10,000 sq. ft. fixed within 12 months of determination by leak repair or main replacement.
- When 2,000 to 10,000 square foot leaks are discovered and verified, we will endeavor to repair them within two years with the exception of inaccessible or challenging leaks which shall be repaired when access can be gained. If any 2,000 to 10,000 square foot leaks are on pipe that will be replaced through GSEP within five years, we will endeavor to eliminate the leak within three years.
- An LDC (a gas utility) may choose to cap its environmentally significant leak repairs in any one calendar year at 7% of its total Grade 3 leak inventory as indicated in the previous year's final quarterly leak report on file with the Department of Public Utilities.

Verification

- For first year, at minimum, a statistically significant randomized sample of Grade 3 LVL leak repairs are FluxBarred prior to repair. Method of verification to be reassessed annually. See below.

Reporting (Department of Public Utilities)

- On GSEP reports, the number of known LVL leaks on each pipe segment.
- On Annual Service Quality reports the leak address, leak footprint, date leak was reported, LVL classification date and repair date.

Reassessment

- Methods and results reassessed and adjusted annually for at least five years by a panel made up of utilities, HEET research team, and a mutually agreed-upon independent third party to provide recommendations to DPU.

Collaboration

- Initial Year Collaboration to support the transition. Leak addresses, reports and repair dates of all high emitters shared with HEET so we can randomly survey 100 leaks to ensure consistency across utilities. FluxBar data forms shared with HEET for the first year so we can provide any needed assistance. Fluxbar results will allow for apples-to-apples comparison between leaks, progress to be benchmarked and further learning to allow for more efficient allocation of resources.

Appendix 4 - Applied Economics Clinic Calculation Additional Information

Calculating the estimated costs of gas lost from the distribution system and repairs per leak.

Calculations made in 2019

Measure		Source
Annual MA total gas consumption (therms)	4,660,931,310	EIA, MA total annual natural gas consumption, 2017
Annual share lost in transmission	2.7%	McKain K, et al 2015
Annual total gas lost in transmission (therms)	125,845,145	(Share X consumption)
Annual share lost in distribution system	30.0%	Estimating between 30% and 50%
Est. Annual gas lost in distribution (therms)	37,753,544	(Transmission loss X share lost)
Gas cost (per therm)	\$0.30	Marginal cost of gas/MMBtu: EIA Henry Hub Gas Spot Price , 2017 average; EIA conversion factors :
Est. Annual total cost of gas lost in distribution	\$11,272,579	(Gas cost X gas lost)
MA total number of reported leaks	17,810	DPU report to legislature December 2017
MA utility reported estimates of leak repair	\$70,085,286	DPU report to legislature December 2017
Cost of repair/leak (calculated)	\$3,935	(Total cost / leaks)

Revised calculations made in 2021

Measure		Source
Annual MA total gas consumption (therms)	4,012,740,434	EIA Total gas consumption MA statewide 2020 Source
Annual share lost in transmission	2.5%	Sargent et al, 2021
Annual total gas lost in transmission (therms)	100,318,511	(Share X consumption)
Annual share lost in distribution system	30.0%	Estimating between 30% and 50%
Est. Annual gas lost in distribution (therms)	30,095,553	(Transmission loss X share lost)
Gas cost (per therm)	\$0.20	Marginal cost of gas/MMBtu: EIA Henry Hub Gas Spot Price , 2020 average; EIA conversion factors :
Est. Annual total cost of gas lost in distribution	\$6,019,111	(Gas cost X gas lost)
MA total number of reported leaks	16,044	DPU report to legislature December 2020, 20-GLR-01
MA utility reported estimates of leak repair	\$35,880,786	DPU report to legislature December 2020, 20-GLR-01
Cost of repair/leak (calculated)	\$2,236	(Total cost / leaks)

Appendix 5 - CRDS Analysis Methods

- The Picarro generated KML data for the survey route was compiled and plotted in Google Earth
- Towns were identified through which the CRDS route went
- Unrepaired leaks from the Annual Service Quality Reports (ASQR) for 2020 were cleaned and geocoded, correcting reporting errors and providing accurate mapping, and then overlaid onto the CRDS route data in Google Earth
- ASQR unrepaired leaks on the CRDS route were summed up for each utility and town on the route
- Correspondences between CRDS elevated methane readings and ASQR unrepaired leaks were summed up for each utility and town on the route
- Correspondence rate for each utility was calculated as : $\text{sum of on-route correspondences across all towns} \div \text{sum of on-route ASQR unrepaired leaks across all towns}$
- Elevated CRDS readings that didn't correspond with ASQR 2020 unrepaired leaks were counted as elevated methane locations (potential leaks) and summed up.
- **Notes**
 - There was 1-2 months of time between the CRDS data and the ASQR report (i.e. fairly fresh data)
 - Correspondences were visually tested for in Google Earth and programmatically
 - Utilities report leak locations using addresses, so a certain amount of experience-based latitude/buffer around the leaks was allowed when matching elevated CH₄ readings with leak location

Appendix 6 - Calculating The Greenhouse Gas Emissions of SEIs

Calculating the Greenhouse Gas Emissions ³¹	
Total gas consumption MA statewide 2019 Source: EIA, https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMA_a.htm)	433.8 billion cubic feet
Rate of gas leaked annually into atmosphere in Greater Boston ³²	2.5%
Total MA statewide annual leaked gas (assuming leak rate applies statewide)	10.8 billion cubic feet
20 year timeframe of methane's impact on the climate - its global warming potential (GWP ₂₀) (Source: IPCC)	86
Total annual leaked gas CO2 equivalent (million metric tonnes CO2 equivalent)	18.9 MMCO2e
Most recently available 2011 MA Greenhouse Gas Inventory ³³	78.6 MMCO2e
Total MA statewide annual leaked gas, as a proportion of the MA GHG inventory	24%
Total MA statewide annual leaked gas from distribution infrastructure (conservatively estimated as 30% of all leaked gas) as a proportion of the MA GHG inventory	7.2%
Distribution infrastructure leaked gas attributed to Grade 3 SEIs leaks	3%, or, 2.4 MMCO2e of MA GHG
MA GHG 2017 emissions for commercial sector ³⁴	7.3 MMCO2e
Grade 3 SEI leak emissions as a percentage of commercial sector	33%
Natural Gas losses from Sargent et al 2021 paper	49 Gg / year
Large Volume Leak (LVL) study average flux per leak	32,704 cu ft / year
Total reported leaks from annual service quality reports in 2019	29,205 leaks
Total estimated flux from all 2019 leaks, based on LVL study average flux	55,120,320 cu ft / year
Total estimated flux from all 2019 leaks, based on LVL study average flux	15.0 Gg / year (1.3 MMCO2e)
Total estimated flux from Grade 3 leaks based on proportion of their leak days in 2019	12.7 Gg / year (1.1 MMCO2e)
Total estimated flux from Grade 3 SEIs leaks based on proportion of their leak days in 2019	6.3 Gg / year (0.55 MMCO2e)
Total leaks emissions as a proportion of Sargent et al top down NG losses	31%
Grade 3 leaks emissions as a proportion of top down emissions	26%
Grade 3 SEI leaks emissions as a proportion of top down emissions	13%

³¹ This uses the same calculation approach as described in [Dr Phillips blog article](#)

³² Sargent et al <https://www.pnas.org/content/118/44/e2105804118>

³³ Source: MassDEP <https://www.mass.gov/files/documents/2016/11/xv/gwsa-update-16.pdf>

³⁴ [Appendix C: Massachusetts Annual Greenhouse Gas Emissions Inventory: 1990-2017, with Partial 2018 Data](#)

Appendix 7 - Acknowledgements

The stakeholder ecosystem that supported this work was vast and ever changing. It is our intent to acknowledge all. Any names or organizations overlooked are unintentional. Our sincere thanks to all.

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PARTICIPATING ORGANIZATIONS: Eversource Energy, Eversource Gas of Massachusetts, National Grid, Gas Safety Inc, Brian Ferri of Millibar Inc, MAPC, and grassroots support and action from Gas Leaks Allies and Mothers Out Front volunteers and teams.

GAS LEAKS ALLIES: Arise for Social Justice, Boston Climate Action Network, Boston Park Advocates, Brookline Green Space Alliance, Clean Water Action, Climate Action Now—Western Massachusetts, Climate Reality Project—Boston Chapter, Climate Action Business Association (CABA), Community Labor United, Conservation Law Foundation, Emerald Necklace Conservancy, Friends of the Public Garden, Garden Club of the Back Bay, Gas Safety USA, Greater Boston Physicians for Social Responsibility, Green Committee, Neighborhood Association of Back Bay, HEET, Longmeadow Pipeline Awareness Group, Mothers Out Front, SAFE—Salem Alliance for the Environment, Sierra Club—Massachusetts Chapter, Springfield Climate Justice Coalition, Toxics Action Center, 2degrees@greenneighbors.earth, 350MA, Dr. Margaret Cherne-Hendrick, Fresh Energy, Dr. Nathan Phillips, Boston University