GUIDELINES FOR REPORTING LOST AND UNACCOUNTED-FOR GAS
D.P.U. 19-44-A, Appendix C (eff. December 31, 2019)

I. GENERAL

A. Purpose and Scope

The purpose of these guidelines is to ensure that every gas company, municipal gas department, or other person engaged in the distribution of natural gas within the Commonwealth of Massachusetts calculates and reports its annual lost and unaccounted-for gas ("LAUF") in a uniform manner, pursuant to G.L. c. 164, § 147 and 220 CMR 115.00. These guidelines establish the specific methods by which the gas companies shall calculate LAUF and its components. In the event of a conflict between these guidelines and any Orders or regulations of the Department of Public Utilities ("Department"), said Orders and regulations shall govern.

These guidelines apply to every gas company, municipal gas department, or other person engaged in the distribution of natural gas within the Commonwealth of Massachusetts, collectively referred to herein as "gas company."

B. Definitions

In addition to the definitions set forth in 220 CMR 115.00, the following definitions apply to these Guidelines:

Billing Cycle Adjustments. Corrections to account for the fact that monthly billing cycles do not exactly coincide with the LAUF reporting cycles.

G3SEI Leaks. Grade 3 leaks of significant environmental impact as defined in 220 CMR 114.00.

Mcf. One thousand cubic feet.

Meter Error. Bias of a meter in a distribution system depending on operational and atmospheric factors. This can be a positive or a negative value, depending on whether the meter is running slow or fast.

Purchased Gas. For the purposes of determining and reporting the total amount of LAUF, Purchased Gas shall mean natural gas or propane that is purchased by a gas company and injected into the gas company's system for delivery to end-use customers.

Reporting Date. March 15th of each year.

Unknown. Any portion of LAUF that is not otherwise categorized.

Verified Theft. Gas that is stolen from the system, often by illegally accessing the distribution pipes or bypassing the meter

II. REPORTING REQUIREMENTS

By the Reporting Date, each gas company shall submit to the Department an annual report of LAUF for the previous calendar year, pursuant to 220 CMR 115.00 and these Guidelines. The report shall include the total amount of LAUF as well as the amounts of LAUF attributable to the categories below.

The reported LAUF volumes must be provided in Mcf and represent actual gas quantities. Estimates may be provided where necessary but must be clearly identified and accompanied by supporting justification, assumptions, and calculations.

The report must be submitted electronically, including spreadsheets in both PDF and Excel formats, and must contain the following information:

- The gas company's name and address;
- The year for which the information is submitted;
- Contact information for the official primarily responsible for the filing, including email address and telephone number;
- An authorized signature of a designated representative of the gas company and the following certification statement:

> I certify that I have personally examined and am familiar with the information contained in this report. I believe that the information is true, accurate, and complete.

III. CALCULATIONS

A. Fugitive Emissions

Each gas company shall report LAUF attributable to fugitive emissions using the metric tons of carbon dioxide equivalent per mile-year factors as set forth in the Massachusetts Department of Environmental Protection ("DEP") regulations, 310 CMR 7.73(5). This method applies the MADEP emissions factors, as set forth in 310 CMR 7.73(5)(b)8, Table 9 (and below), to a gas company's miles of mains and number of services, broken down by pipe material. The reported amounts must be converted into Mcf.

Table 9 – Methane Emissions Factors by Material Type	
Mains	Metric tons of carbon dioxide equivalent/mile-year
Cast or Wrought Iron	28.663225
Ductile Iron	
Copper	
Steel, cathodically unprotected and uncoated	20.281978
Steel, cathodically unprotected and coated	
Other	
Steel, cathodically protected and uncoated	1.804054
Steel, cathodically protected and coated	
Plastic	0.215583
Services	Metric tons of carbon dioxide equivalent/service-year
Steel, cathodically unprotected and uncoated	0.129589
Steel, Cathodically unprotected and coated	
Cast or wrought iron	
Ductile iron	
Other	
Steel, cathodically protected and uncoated	0.055982
Steel, cathodically protected and coated	
Plastic	0.005136
Copper	0.121920

In addition, for the first LAUF report due on March 15, 2020, each gas company is directed to calculate and report LAUF attributable to fugitive emissions using the following method:

Basic formula = [number of leaks] x [appropriate emissions factor]

This formula is applied to the following four categories, broken down by pipe material and type (i.e., main or service) within each category, as noted below. The Department has provided an Excel spreadsheet that can be used for these calculations (Att. 1, Fugitive Emissions Tab). The reported amounts must be converted into Mcf.

1. Unrepaired Leaks – Use proxy for number of unrepaired leaks for each pipe material/type, determined by multiplying:

   [actual number of unrepaired non-G3SEI leaks found in the current calendar year in its service territory]
   x
   [percentage of the current calendar year's repaired leaks that were found on each pipe material/type].

a. Unrepaired Non-G3SEI leaks -- Use DEP emission factors based on pipe material/type, (310 CMR 7.73(5)(b)8, Table 9).

b. Unrepaired G3SEI leaks -- Use the 95 percent upper confidence limit ("UCL") emissions factors from a 2015 study by Brian K. Lamb and associates ("Lamb Study")[1] based on pipe material/type, as shown in the table below.

Table 1. Comparison of National Methane Emission Factor Estimates from Underground Pipeline Leaks Based on the Current Study and the 1992 EPA/GRI Study

	this study			1992 GRI/EPA		
pipeline material	*n*	emission factor (g/min)	95% UCL (g/min)	*n*	emission factor (g/min)	90% UCL (g/min)
			main pipelines			
cast iron	14	0.90	3.35	21	3.57[a]	5.60[a]
unprotected steel	74	0.77	2.07	20	1.91	3.70
protected steel	31	1.21	4.59	17	0.76	1.40
Plastic	23	0.33	0.67	6	1.88	8.20
			services			
unprotected steel	19	0.33	0.93	13	0.74	1.53
protected steel	12	0.13	0.19	24	0.34	0.54
Plastic	38	0.13	0.19	4	0.11	0.27

[a]GRI/EPA EF converted from SCF/mile to g/min/leak using cast iron pipeline miles and equivalent leaks from this study.

2. Repaired leaks -- use actual number of repaired leaks for each pipe material/type, and multiply by average fraction of calendar year it took to repair.

a. Repaired Non-G3SEI leaks -- Use DEP emission factors based on pipe material/type, (310 CMR 7.73(5)(b)8, Table 9).

b. Repaired G3SEI leaks -- Use the 95 percent UCL emissions factors (Lamb Study, Table 1, above) based on pipe material/type.

B. External Damage

Each gas company shall report LAUF attributable to external damage using the following basic formula:

1 "Direct Measurements Show Decreasing Methane Emissions from National Gas Local Distribution Systems in the United States," Lamb et al., *Environ. Sci. & Technol.* 2015, 49, 8, 5161-5169, https://doi.org/10.1021/es505116p

[size of a puncture or defect in square inches] x [operating pressure of the pipe in question] x [the estimated duration of the damage]

There are two distinct formulas, one for pressure systems under twelve pounds per square inch gauge ("psig"), and the other for pressure systems equal to or greater than twelve psig, as outlined below.

The Department has provided an Excel spreadsheet that can be used for these calculations (Att. 1, External Damage Tab), which includes the following assumptions: final gas pressure; initial gas temperature; and discharge coefficient. The following is provided as an example:

Inputs:								
Operating Pressure [PSIG]	**Area of Puncture [SQ-IN]**	**Time [HR]**						
60	0.5	5						
Assumptions:								
Final Gas Pressure [PSIG]	**Initial Gas Temperature [F]**	**Discharge Coefficient**	**Compressibility Factor**	**Specific Heat Ratio**	**Molecular Weight [LB/LB*MOL]**	**Density [LB/CF]**	**Universal Gas Constant [FT*LB/LB*MOL*R]**	**Gravitational Constant [FT/S^2]**
0	40	0.62	1	1.27	19	0.045	1545.3	32.2
Assuming the final pressure is atmospheric	Assuming 40 degrees Fahrenheit based	Assuming coefficient for a sharp	Assuming a C.F. of 1. Accurate for pressures up to	Assumed S.H. ratio of natural gas at STP	Assumed to be constant varies with gas composition	Assumed to be constant varies with gas composition	Constant	Constant
Less than 12 PSIG:			**Greater than or equal to 12 PSIG**					
Gas Loss Rate [MCFH]	**Gas Loss [MCF]**		**Gas Loss Rate [MCFH]**	**Gas Loss [MCF]**				
NA	**NA**		**34.51**	**172.55**				

External Damage Formulas:

For Subsonic Conditions, Pressure Systems Less Than 12 PSIG:

$$Q = C_d A P_u \sqrt{\left(\frac{2 g_c M}{ZRT}\right)\left(\frac{k}{k-1}\right)\left[\left(\frac{P_a}{P_u}\right)^{\frac{2}{k}} - \left(\frac{P_a}{P_u}\right)^{\frac{k+1}{k}}\right]}$$

For Conditions 12 PSIG and Greater:

$$Q = C_d A P_u \sqrt{\left(\frac{g_c k M}{ZRT}\right)\left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$$

Inputs:

-Absolute Source Pressure: $P_u \left[\frac{lb}{ft^2}\right]$

-Discharge Hole: $A[ft^2]$

Output:

-Mass Flow Rate: $Q \left[\frac{lb}{s}\right]$

Knowns:

-Discharge Coefficient: $C_d = 0.62$

-Gravitation Conversion Factor: $g_c = 32.2 \left[\frac{ft}{s^2}\right]$

-Specific Heat Ratio of Natural Gas: $k = 1.27$

-Universal Gas Constant: $R = 1545.3 \left[\frac{ft*lb}{lb*mol*°R}\right]$

-Gas Temperature: $T = 40[°F\,] = 499.67\ [°R]$

-Gas Molecular Weight of Natural Gas: $M = 19.0 \left[\frac{lb}{lb*mol}\right]$

-Absolute Ambient Pressure: $P_a = 14.7\ PSIA = 2116.8 \left[\frac{lb}{ft^2}\right]$

-Gas Compressibility Factor: $Z = 1$

-Density of Natural Gas: $\rho = 0.045 \left[\frac{lb}{ft^3}\right]$

Testing for Subsonic Conditions:

Critical Pressure Ratio: $CPR = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = 0.5512$

If $CPR < \frac{P_a}{P_u}$, subsonic conditions exist

Solving for P_u:

$$p_u = \frac{P_a}{CPR} = 26.669\ PSIA = 11.969\ PSIG$$

Simplified Equation for Pressure Systems less than 12 PSIG:

$$Q = 4.280A\sqrt{68.911(P+14.7)^{0.425} - 122.029(P+14.7)^{0.213}}$$

$Q\ [MCFH]$

$A\ [IN^2]$

$P\ [PSIG]$

Simplified Equation for Pressure Systems 12 PSIG and Greater:

$$Q = 0.924A(P+14.7)$$

$Q\ [MCFH]$

$A\ [IN^2]$

$P\ [PSIG]$

C. Intentional Venting and Purging

NSTAR Gas Company d/b/a Eversource Energy ("Eversource"), Boston Gas Company and Colonial Gas Company each d/b/a National Grid ("National Grid") shall report LAUF attributable to intentional venting and purging using their actual operational data and the following formula. The reported amounts must be converted into Mcf:

Formula Derivation

Equation 1: General Gas Equation

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

P: Pressure
V: Volume
T: Temperature
Where state 1 is gas main pressure at the time of purging and state 2 is standard temperature and pressure

Equation 2: Volume of a Cylinder

$$V = \pi L \frac{D^2}{4}$$

V: Volume
D: Diameter
L: Length

Step 1: Solve Equation 1 for V_2

$$V_2 = \frac{P_1V_1T_2}{T_1P_2}$$

Step 2: Substitute Equation 2 into Equation 1 for V_1

$$V_2 = \frac{P_1T_2}{P_2T_1}\pi L\frac{D^2}{4}$$

The remaining gas companies shall report LAUF attributable to intentional venting and purging using the U.S. Environmental Protection Agency Greenhouse Gas Inventory ("GHGI") factor for venting and purging. The GHGI factor calculates LAUF attributable to intentional venting and purging by applying a factor of kilograms ("kg") of methane per miles of mains and services per year as in the following table.

Constants		
Kg Per Tonne	1,000	
Feet Per Mile	5,280	
Assumed Methane % of Natural Gas	100%	[Eq. W-32A in 40 CFR §98.233]
Density of Methane	0.0192	kg/cubic foot [40 CFR §98.233]
Cubic Feet Per Mcf	1,000	
EPA Greenhouse Gas Inventory Emission Factor	1.96452	kg of methane per mile of main and service, per year
GHGI 2019, Table 3.6-2, Row 172 https://www.epa.gov/sites/production/files/2019-04/2019final_ghgi_natural_gas_systems_annex_tables_2019-04-09.xlsx		

Each of the remaining gas companies shall input the following data to derive the total length of mains and services on its system:

1) Miles of mains on the distribution system;
2) Average length of the services; and
3) Number of services.

The miles of mains and services on a system are then multiplied by the GHGI factor of 1.96452 kg of methane per mile of mains and services per year to derive the LAUF attributable to intentional venting and purging in a calendar year. The amounts must be reported in Mcf.

D. Verified Theft

Each gas company shall report LAUF attributable to verified theft by calculating 0.005 percent of total LAUF.

E. Meter Error

Eversource, National Grid, The Berkshire Gas Company, and Fitchburg Gas and Electric Light Company d/b/a Unitil shall calculate and report LAUF attributable to meter error in Mcf, rounded to two decimal places (hundredths). Each of these gas companies shall use its individual average meter error (based on a ten-year rolling average) as the maximum allowable amount, with any remainder allocated to the Unknown category.

The remaining gas companies are not required to report LAUF attributable to meter error at this time but shall investigate and update the Department on their efforts to sample and test for meter error.

F. Unknown

Each gas company shall report as Unknown any portion of LAUF that is not otherwise categorized and shall explain the contents of this category.

G. Adjustments

1. Billing Cycle Adjustments

Each gas company shall explain its billing cycle adjustments under one of the following options:

a. If it made and reported billing cycle adjustments, what adjustments were made;

b. If it made but did not report billing cycle adjustments, explain why; or

c. If it did not make any billing cycle adjustments, explain why.

2. Other Adjustments

Each gas company shall report any other adjustments made to its calculation of LAUF. Adjustments must be supported by metered data, sound engineering practices, or other quantifiable results that clearly support the gas company's need for the adjustment.

Estimating Annual Leaked Gas from Distribution System Gas Leaks in Mass. Using Utility-Reported Gas Leak Numbers for use in Lost Gas Reporting

K) and base pressure of 14.73 pounds per square inch [psi] (101.560 kPa). Assuming a standard cubic foot in the US Customary System is approximately equivalent to 0.02833 standard cubic meters in the SI system.

Sample data for an imaginary gas company to demonstrate the calculations below

mains	% repaired leaks 2019	Unrepaired non-SEI leaks 2019	Repaired non-SEI leaks 2019		
cast iron			(not including SEIs)		(not including SEIs)
unprotected steel					
protected steel		Unrepaired SEIs 2019		Repaired SEIs 2019	
plastic					
services					
cast iron		Average Repair Time 2019			
unprotected steel			(average % of year that passed for repaired leaks from date of discovery to date of repair)		
plastic					

Average Annual Lost Gas : non-SEI Leaks

						Unrepaired non-SEIs	
						0	
mains	**Emissions factor (grams/min)**	**grams/day**	**grams/year**	**methane/year**	**% repaired leaks**	**Unrepaired leaks**	**Estimated Lost Gas (lbs CH4/yr)**
cast iron	0.9	1,296	473,040	1,043	0%	0	0
unprotected steel	0.77	1,109	404,712	892	0%	0	0
protected steel	1.21	1,742	635,976	1,402	0%	0	0
plastic	0.33	475	173,448	382	0%	0	0
	Table 1, Lamb et al, 2015	x 60 x 24	x 365	/ 453.592	From data above	% repaired leaks x	# unrepaired leaks x lbs
services	**(g/min) ***	**g/day**	**g/year**	**pounds methane**	**% repaired leaks**	**Unrepaired leaks**	**Estimated Lost Gas (lbs CH4/yr)**
cast iron	0.13	187	68,328	151	0%	0	0
unprotected steel	0.33	475	173,448	382	0%	0	0
plastic	0.13	187	68,328	151	0%	0	0
						Total	**0**

Average Annual Lost Gas : SEI (Significant Environmental Impact) Leaks

						Unrepaired SEIs	
						0	
mains	**95% UCL (g/min)***	**g/day**	**g/year**	**methane/year**	**% repaired leaks**	**Unrepaired leaks**	**Estimated Lost Gas (lbs CH4/yr)**
cast iron	3.35	4,824	1,760,760	3,882	0%	0	0
unprotected steel	2.07	2,981	1,087,992	2,399	0%	0	0
protected steel	4.59	6,610	2,412,504	5,319	0%	0	0
plastic	0.67	965	352,152	776	0%	0	0
services	**95% UCL (g/min) ***	**g/day**	**g/year**	**pounds methane**	**% repaired leaks**	**Unrepaired leaks**	**Estimated Lost Gas (lbs CH4/yr)**
cast iron	0.19	274	99,864	220	0%	0	0.0
unprotected steel	0.93	1,339	488,808	1,078	0%	0	0.0
plastic	0.19	274	99,864	220	0%	0	0.0
						Total	**0**

Repaired non-SEI leaks

	Repaired non-SEI leaks 2019		Average Repair Time 2019				
	0		0%				
mains	**calculated above)**	**% Repaired Leaks**	**Repaired non-SEIs**	**Estimated Lost Gas (lbs CH4/yr)**			
cast iron	1,043	0%	0	0			
unprotected steel	892	0%	0	0			
protected steel	1,402	0%	0	0			
plastic	382	0%	0	0	Unrepaired leaks x emissions x repair time		
services	**calculated above)**	**% Repaired Leaks**	**Repaired non-SEIs**	**Estimated Lost Gas (lbs CH4/yr)**			
cast iron	151	0%	0	0			
unprotected steel	382	0%	0	0			
plastic	151	0%	0	0			
			Total	**0**			

Repaired SEIs

	Repaired SEIs		Average Repair Time 2019				
	0		0%				
mains	**calculated above)**	**% Repaired Leaks**	**Repaired SEIs**	**Estimated Lost Gas (lbs CH4/yr)**			
cast iron	3,882	0%	0	0			
unprotected steel	2,399	0%	0	0			
protected steel	5,319	0%	0	0			
plastic	776	0%	0	0	Unrepaired leaks x emissions x repair time		
services	**calculated above)**	**% Repaired Leaks**	**Repaired SEIs**	**Estimated Lost Gas (lbs CH4/yr)**			
cast iron	220	0%	0	0			
unprotected steel	1,078	0%	0	0			
plastic	220	0%	0	0.0			
			Total	**0**			

Grand total estimated Lost Gas for Sample LDC 2019

0	Lbs CH4/yr
0	Mcf CH4/yr

Gas Loss Due To Damage

Inputs:

Operating Pressure [PSIG]	Area of Puncture [SQ-IN]	Time [HR]
60	0.5	5

Assumptions:

Final Gas Pressure [PSIG]	Initial Gas Temperature [F]	Discharge Coefficient	Compressibility Factor	Specific Heat Ratio	Molecular Weight [LB/LB*MOL]	Density [LB/CF]	Universal Gas Constant [FT*LB/LB*MOL*R]	Gravitational Constant [FT/S^2]
0	40	0.62	1	1.27	19	0.045	1545.3	32.2
Assuming the final pressure is atmospheric pressure	Assuming 40 degrees Fahrenheit based on typical gas system conditions	Assuming coefficient for a sharp orifice	Assuming a C.F. of 1. Accurate for pressures up to 125 PSIG	Assumed S.H. ratio of natural gas at STP	Assumed to be constant varies with gas composition	Assumed to be constant varies with gas composition	Constant	Constant

Less than 12 PSIG:

Gas Loss Rate [MCFH]	Gas Loss [MCF]
NA	NA

Greater than or equal to 12 PSIG:

Gas Loss Rate [MCFH]	Gas Loss [MCF]
34.51	172.55

For Subsonic Conditions, Pressure Systems Less Than 12 PSIG:

$$Q = C_d A P_u \sqrt{\left(\frac{2g_c M}{ZRT}\right)\left(\frac{k}{k-1}\right)\left[\left(\frac{P_a}{P_u}\right)^{\frac{2}{k}} - \left(\frac{P_a}{P_u}\right)^{\frac{k+1}{k}}\right]}$$

For Conditions 12 PSIG and Greater:

$$Q = C_d A P_u \sqrt{\left(\frac{g_c k M}{ZRT}\right)\left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$$

Inputs:

-Absolute Source Pressure: $P_u \left[\frac{lb}{ft^2}\right]$

-Discharge Hole: $A[ft^2]$

Output:

-Mass Flow Rate: $Q \left[\frac{lb}{s}\right]$

Knowns:

-Discharge Coefficient: $C_d = 0.62$

-Gravitation Conversion Factor: $g_c = 32.2 \left[\frac{ft}{s^2}\right]$

-Specific Heat Ratio of Natural Gas: $k = 1.27$

-Universal Gas Constant: $R = 1545.3 \left[\frac{ft*lb}{lb*mol*°R}\right]$

-Gas Temperature: $T = 40[°F\,] = 499.67\,[°R]$

-Gas Molecular Weight of Natural Gas: $M = 19.0 \left[\frac{lb}{lb*mol}\right]$

-Absolute Ambient Pressure: $P_a = 14.7\ PSIA = 2116.8 \left[\frac{lb}{ft^2}\right]$

-Gas Compressibility Factor: $Z = 1$

-Density of Natural Gas: $\rho = 0.045 \left[\frac{lb}{ft^3}\right]$

Testing for Subsonic Conditions:

Critical Pressure Ratio: $CPR = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = 0.5512$

If $CPR < \frac{P_a}{P_u}$, subsonic conditions exist

Solving for P_u:

$$p_u = \frac{P_a}{CPR} = 26.669\ PSIA = 11.969\ PSIG$$

Simplified Equation for Pressure Systems less than 12 PSIG:

$$Q = 4.280A\sqrt{68.911(P+14.7)^{0.425} - 122.029(P+14.7)^{0.213}}$$

$Q\ [MCFH]$
$A\ [IN^2]$
$P\ [PSIG]$

Simplified Equation for Pressure Systems 12 PSIG and Greater:

$$Q = 0.924A(P+14.7)$$

$Q\ [MCFH]$
$A\ [IN^2]$
$P\ [PSIG]$

Inputs (All values from annual DOT Report Part B)

Miles of Main	5,000.0	miles
Average Service Length	70	feet
Number of Services	300,000	

Venting/Purging/Blowdown Emissions	17.6	tons of methane
	919	Mcf (MMBtu) of natural gas

Constants		
Kg Per Tonne	1,000	
Feet Per Mile	5,280	
Assumed Methane % of Natural Gas	100%	[Eq. W-32A in 40 CFR §98.233]
Density of Methane	0.0192	kg/cubic foot [40 CFR §98.233]
Cubic Feet Per Mcf	1,000	
EPA Greenhouse Gas Inventory Emission Factor	1.96452	kg of methane per mile of main and service, per year
GHGI 2019, Table 3.6-2, Row 172		
https://www.epa.gov/sites/production/files/2019-04/2019final_ghgi_natural_gas_systems_annex_tables_2019-04-09.xlsx		