A National Estimate of Methane Leakage from Pipeline Mains in Local Natural Gas Distribution Systems

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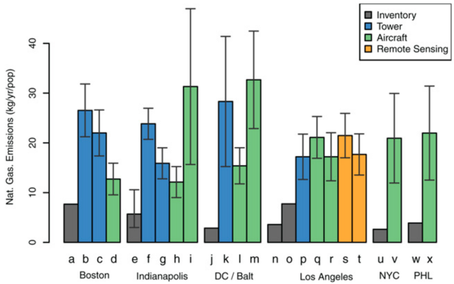
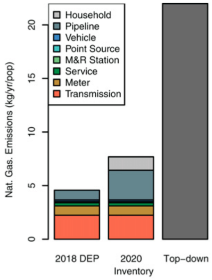
Evidence of Urban Emissions Undercounting

- Large gap between bottom-up and top-down that is attributed to distribution and end-use
- Plant et al. (2019):
    - Estimated NG emissions in 5 east coast cities
    - Emissions estimates 10x greater than Gridded EPA inventory
- Sargent et al. (2021):
    - Estimated NG emissions in Boston using top-down approach
    - Found a 2.5% loss rate from distribution and end use (6x greater than MassDEP)





Distribution Emissions: Bottom-Up Basis

- Current EPA activity and emissions factors: Lamb et al. (2015)
  - Emissions factors: measured n = 142 leaks that were known to utility companies
    - Some targeted leaks had been repaired
    - Did not measure any Class/Grade 1 leaks
  - Activity factors: based on utility leak inventories

- Ersoy et al. (2019): emissions from distribution mains and services in CA
  - Estimated EFs 34% larger than Lamb et al. (2015) (across material categories)
  - Plastic pipe and services 4x greater EF
- Moore et al. (2019): emissions from meters nationally
  - 450 meter leaks
  - EFs approximately 8x greater than current EPA values

Vehicle-Based Advanced Leak Detection

- Vehicle based ALD deployments permit rapid detection of leaks and emissions quantification (von Fischer et al., 2017)
- Advantages of vehicle based ALD over traditional surveys:
  - Highly sensitive instruments are finding more leaks than previously thought to exist: estimated 2.6x greater than current inventories (Weller et al., 2018)
  - Rapid spatial coverage
  - Rapid emissions quantification
- We analyzed data from deployments in four U.S. cities, covering 8900 miles of roadway (5800 miles of main pipeline)
  - Differing management histories
  - All have newer material and leak-prone materials of varying ages
  - Local utilities shared GIS database with pipeline location, age, and material

Estimate of Distribution Emissions Nationally

- Goal: estimate total emissions from distribution mains nationally and quantify uncertainty
- Utilize multiple data sources:
  - Pipeline GIS data & mapping results in four cities (activity factors)
  - PHMSA data on U.S. distribution main pipeline by material and age (activity)
  - Three studies validating our emissions quantification in the field (emissions factors)

$$\begin{aligned}\text{Total Emissions} &= \text{Activity Factors} \;\times\; \text{Activity} \;\times\; \text{Emissions Factors}\\ &= \;(\text{leaks/mile}) \;\times\; (\text{miles of pipe}) \;\times\; (\text{emissions/leak})\end{aligned}$$

Activity Factors

- Utility shared GIS database for distribution system mains where we conducted mobile methane surveys, which included:
  - Location
  - Length
  - Material
  - Install date (proxy for age)
- Material coded as bare steel (BS), cast iron (CI), coated steel (CS), and plastic (PL) to match PHMSA categories

Activity Factors

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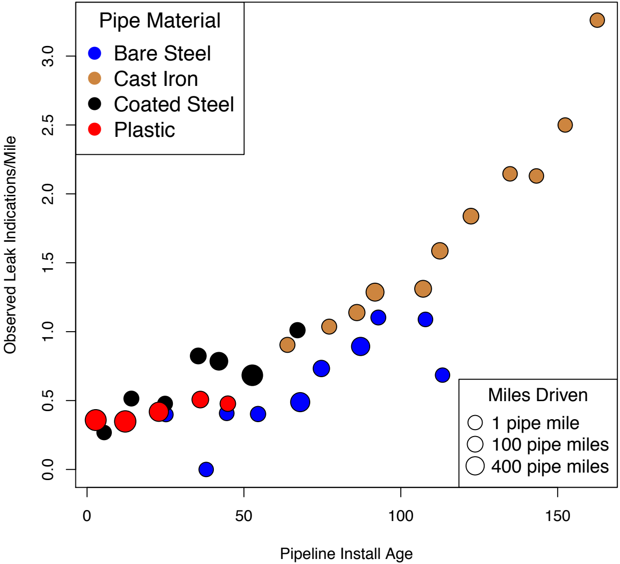
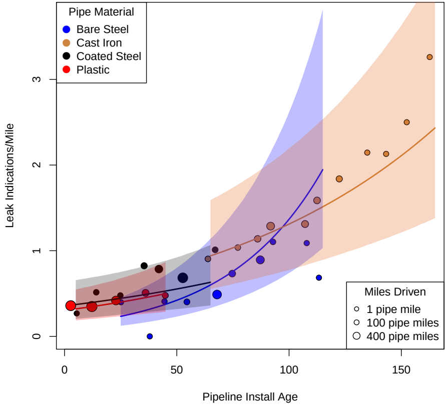
- Material coded as bare steel (BS), cast iron (CI), coated steel (CS), and plastic (PL) to match PHMSA categories
- We spatially joined ALD leak indications to nearest distribution main, requiring that pipeline infrastructure be within 40m
- Approximately **4000 leak indications** joined to 9300 km (5800 miles) of pipeline
- Leak indications and surveyed pipeline miles (km's) binned by decade

Estimated Activity Factors by Age & Material



Activity Factors



- Activity varies by pipeline age and material type
- Account for city-to-city variation

Activity

- Pipeline and Hazardous Materials Safety Administration reports **activity**: marginal totals of miles of distribution pipeline by decade and by material
- The joint distribution of age and material is not given

Install Decade →	unknown	Pre-1940	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019		
Age → **Material**	unknown	79+	70-79	60-69	50-59	40-49	30-39	20-29	10-19	0-9	**Total Miles**	**Pct Total**
Bare Steel											46583	4
Cast Iron											25056	2
Coated Steel											486305	38
Plastic											738067	57
Total Miles	84975* (84992)	53742	22030	99281	187096	130499	155996	234908	205694	121790	1296011	100
Pct Total	7	4	2	8	14	10	12	18	16	9	100	

*rounding error

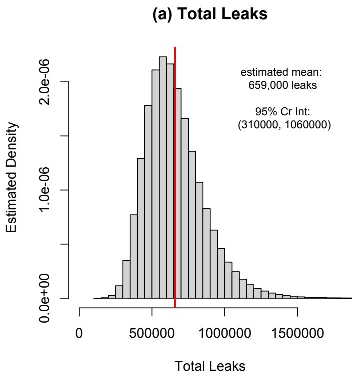
Activity

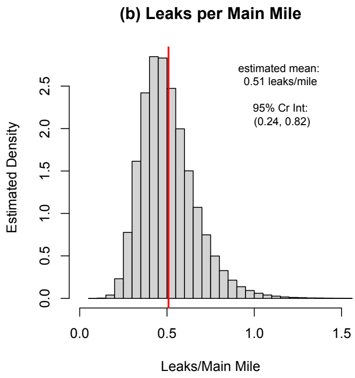
- Make assumptions regarding the joint distribution of age and material $\Longrightarrow$ constraints on the table
- Monte Carlo simulation provides hundreds of possible ways to fill the table, given the constraints. The average table is shown below:

install decade	unknown	Pre-1940	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	
Age	unknown	79+	70-79	60-69	50-59	40-49	30-39	20-29	10-19	0-9	Totals
BS	22168	3875	4268	4391	3927	3513	3462	0	0	0	46583
CI	23076	1316	285	378	0	0	0	0	0	0	25055*
CS	21062	48551	17477	94511	108491	138311	39569	45303	25708	6646	486304*
PL	18669	0	0	0	75040	44858	112965	189605	179986	115144	738068*
Totals	84975	53742	22030	99281*	187096	130499	155996	234908	205694	121790	1296011

AF × Activity

- Use the pipeline information (activity) + Bayesian model (AF) to estimate the total number of leaks for distribution mains nationally
- Uncertainty in model parameters + uncertainty in pipeline table ⟹ uncertainty quantification for the number of leaks





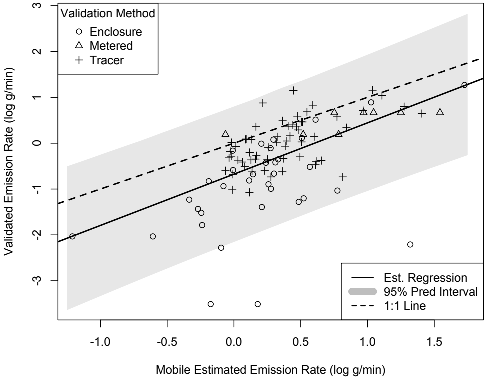
AF × Activity

- Our estimated leaks per mile are greater than previous estimates for coated steel and plastic
- Difficult to compare estimates due to different methods for estimating the lifetime of leaks

	study					
	Lamb 2015		GRI/EPA 1992		this study	
material	equiv leaks (thousands)	equiv leaks per mile	equiv leaks (thousands)	equiv leaks per mile	leaks (thousands) (95% cr int)	leaks per mile
bare (unprotected) steel	130.3	2.51	174.7	1.82	23.7 (7.9–43.0)	0.51 (0.17, 0.93)
cast iron	81.6	2.88	n/a	n/a	25.2 (9.9–43.5)	1.00 (0.40, 1.74)
coated (protected) steel	55.4	0.11	68.3	0.14	296.0 (111.0–513.5)	0.61 (0.23, 1.06)
plastic	32.2	0.05	49.2	0.18	314.1 (122.8–547.0)	0.43 (0.17, 0.74)
total	299.6	0.23	292.2	0.35[b]	659.1 (310.0–1061.1)	0.51 (0.24, 0.82)

Emissions Factors

- We previously found a positive (upward) bias in our mobile emissions estimates (Weller et al., 2018)
- We de-bias mobile emissions estimates using the results of three validation studies assessing mobile estimates ($n = 100$ leaks)



- Typically, the correction makes the estimated leak size *smaller*, but not exclusively

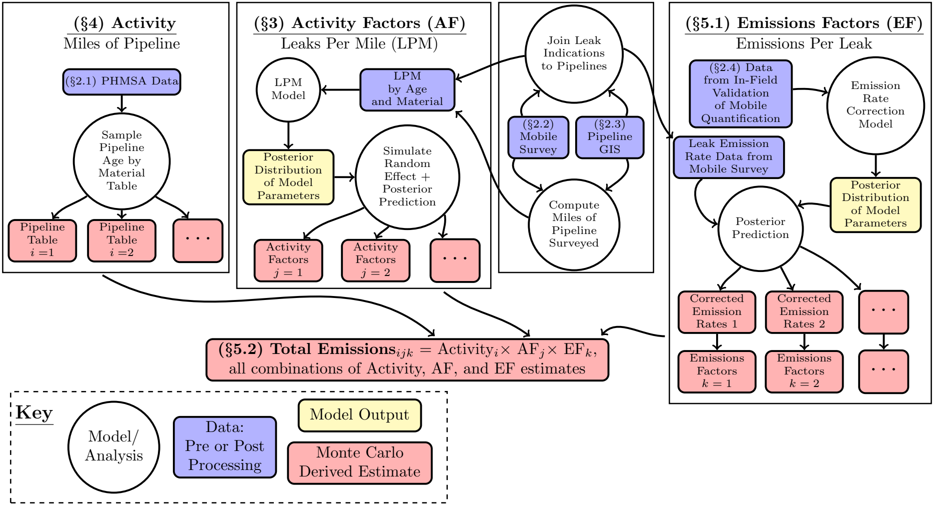
Emissions Factors

Material	EPA/GRI 1992* (g/min) Estimate (90% UCL)	Lamb 2015 (g/min) Estimate (95% UCL)	This Study (g/min) Estimate (95% cr int)
Bare (Unprotected) Steel	1.91 (3.70) n = 20	0.77 (2.07) n=74	2.25 (1.22, 3.40) n = 821
Cast Iron	3.57 (5.60) n = 21	0.90 (3.35) n = 14	1.72 (0.94, 2.64) n = 1567
Coated (Protected) Steel	0.76 (1.40) n = 17	1.21 (4.59) n = 31	2.04 (1.10, 3.12) n = 868
Plastic	1.88 (8.20) n = 6	0.33 (0.67) n = 23	2.03 (1.10, 3.12) n = 774
Total	n = 64	n = 142	n = 4030

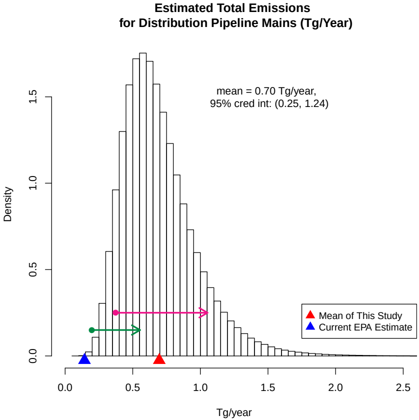
- No meaningful differences in emissions factors (EFs) with pipeline age
- Small differences in EFs among materials
- Our EFs were similar to EPA/GRI (1992) and generally bigger than Lamb et al. (2015)

Total Emissions

Combine previous results to estimate total emissions:



Total Emisssions



- 5x greater than current EPA estimate for main emissions
- 3x greater than current EPA estimate for main & service emissions
- Green arrow: Lamb et al. (2015) with 95% upper confidence level
- Pink arrow: Lamb et al. (2015) with 95% upper confidence level assuming leak find rate from Weller et al. (2018)

Recommendations/Suggestions

- Updated emissions estimates are needed
  - Our findings and others suggest EPA estimates are low
  - Undercounting of number of leaks and emissions from largest leaks are likely contributors
  - Use a combination of best available data (direct measurements, combining of results from various studies)
- Utility reporting (e.g., subpart W) should include pipeline age by material
- Spatially-resolved data reporting will improve EPA gridded emissions and infrastructure equity

Acknowledgements

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