Fugitive Greenhouse Gas Emissions from Natural Gas Systems

Accounting Methods for the Rhode Island Greenhouse Gas Inventory

State of Rhode Island
Department of Environmental Management
235 Promenade Street
Providence, RI 02908

May 1, 2025, v. 2.7

Table of Contents

Acronyms and Abbreviations 3
Executive Summary 4
Background 5
History of Natural Gas Systems in Rhode Island 5
Past Efforts to Quantify Emissions 6
Proposal to Improve Emissions Quantification 8
Infrastructure Data 9
Interstate Transmission Pipeline 9
Compressor Stations 9
LNG Storage Facilities 10
Meter and Regulator Stations 10
Distribution Mains and Services 11
Customer Meters 12
Post-Meter Equipment 12
Emissions Factors 13
1996 EPA/Gas Research Institute Study 14
EPA Greenhouse Gas Reporting Program 14
2015 Lamb et al. Local Distribution Company Study 15
Other Sources 16
Natural Gas Systems Emissions Results 17
Transmission and Storage 18
Distribution 18
Post-Meter 19
Reconciliation with Distribution System Unaccounted for Gas 20
Conclusion 22
References 23

Acronyms and Abbreviations

AGP	Algonquin Gas Pipeline
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
DEM	Department of Environmental Management
EC4	Executive Climate Change Coordinating Council
EIA	Energy Information Administration
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
GHGRP	Greenhouse Gas Reporting Program
GRI	Gas Research Institute
GTI	Gas Technology Institute
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
ISR	Infrastructure, Safety, and Reliability Plan
LDC	Local Distribution Company
LNG	Liquified Natural Gas
LPP	Leak Prone Pipe
M&R	Meter and Regulator
MassDEP	Massachusetts Department of Environmental Protection
$MMTCO_2e$	Million Metric Tons Carbon Dioxide Equivalent
NASA	National Aeronautics and Space Administration
NESCAUM	Northeast States for Coordinated Air Use Management
PHMSA	Pipeline and Hazardous Materials Safety Administration
PUC	Public Utilities Commission
RIE	Rhode Island Energy
SEI	Stockholm Environment Institute
SIT	State Inventory Tool
TGP	Tennessee Gas Pipeline
UFG	Unaccounted for Gas

Executive Summary

The Department of Environmental Management's (DEM) annual *Rhode Island Greenhouse Gas Inventory* (GHGI) is the primary scientific tool used by the Executive Climate Change Coordinating Council (EC4) to assess the state's progress with the economy-wide greenhouse gas (GHG) emissions reduction mandates required by the 2021 Act on Climate (R.I. Gen. Laws § 42-6.2-9).[1] The Intergovernmental Panel on Climate Change's (IPCC) *2006 Guidelines for National Greenhouse Gas Inventories* and its refinements (the "2006 Guidelines") are the accounting framework used by DEM to assess emissions unless endorsements are made by the EC4.[2] The 2006 Guidelines identify many sources of fugitive emissions from natural gas systems, which are emissions that result from the direct release of a gas to the atmosphere (i.e., not through combustion). The GHGI has historically only included fugitive methane (CH_4) emissions from the distribution segment. Rhode Island also produces emissions from other components of the natural gas industry, such as interstate transmission pipelines, compressor stations, meter and regulator (M&R) stations, and customer meters. Behind-the-meter consumer appliances, combined heat and power (CHP) generators, and electric power plants also produce fugitive emissions.

The U.S. Environmental Protection Agency's (EPA) *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (the "U.S. GHGI") is the official record of the country's GHG emissions. EPA uses peer-reviewed science to inform hundreds of emissions calculations. DEM proposes to leverage the emissions factors used in the U.S. GHGI to estimate fugitive CO_2 and CH_4 emissions from all sources of Rhode Island's natural gas industry. These emission factors were developed with significantly newer methods to quantity emissions than those currently used by DEM. Specifically, these emissions factors reconcile differences in studies undertaken during the 1990s and 2010s to measure gas leaks. DEM proposes to organize natural gas system emissions into three segments following the 2006 IPCC Guidelines: transmission and storage, distribution, and post-meter.

Robust information about the physical characteristics of Rhode Island's natural gas industry was collected data back to 1990 to estimate the entire timeseries. Natural gas systems infrastructure data was obtained from publicly accessible Federal databases and from State-regulated facilities under 250-RICR-120-05-14 (Part 14: Record Keeping and Reporting). All infrastructure data was applied to EPA's emissions factors to estimate fugitive natural gas system emissions. DEM estimated natural gas systems produced 0.14 $MMTCO_2e$ in 2022, a 62.2% decrease from 1990 (0.37 $MMTCO_2e$). The proposed estimates for all segments of natural gas systems are 44% lower than the 2022 GHGI's estimate (see page 14). The results of this study are believed to be more representative of fugitive natural gas system emissions than those in the 2022 GHGI. Other literature, such as the atmospheric based "top-down" studies around Boston, MA, present different results. Research on fugitive GHG emissions should be conducted in the Providence area to reduce uncertainty with natural gas system emissions in the GHGI. Those that rely on the GHGI to inform policy decisions should be aware of the uncertainty associated with the data and methodologies used to estimate emissions in this report. To aid readers, confidence levels are expressed with three qualifiers: "low", "medium", and "high".

Background

History of Natural Gas Systems in Rhode Island

Rhode Island's complex natural gas system is one of the oldest in the United States. In 1810, Pelham Street in Newport was the first street in the U.S. to be lighted by gas lamps. Manufactured gas from coal-gasification plants began to illuminate many more streets in Newport and Providence by the mid-1800s. Early gas mains were crafted with eight-foot-long segments of cast iron. Bell and spigot joints, stuffed with packing material that absorbed moisture, connected the segments together. By the 1920s, new mains and services were constructed with steel instead of cast iron. Hundreds of miles of steel mains and services were installed during the period of suburbanization after World War II. By the mid-1950s, the Big Inch and Little Inch pipelines in the central U.S., originally built to carry petroleum, were converted to supply natural gas to regions that relied on manufactured gas. The Algonquin Gas Pipeline (AGP) Company and the Tennessee Gas Pipeline (TGP) Company both constructed transmission pipelines to provide natural gas to local distribution companies throughout New England. As demand increased for heating and electricity generation, compressor stations, liquified natural gas (LNG) storage tanks, and city gate stations were built to ensure a safe and reliable system.

Figure 1: Newport's Pelham Street during the early 1880s. Credit: Lost New England.[28]

Natural gas has a relatively low moisture content compared with manufactured gas. The packing material originally used to seal the joints of cast iron pipelines dried out and decayed when the transition from manufactured gas to natural gas occurred in the 1950s. New England's frequent frost/freeze cycles also disrupted the original bell and spigot joints that held the cast iron segments together. The combination of disintegrating packing material and shifting joints caused most cast iron pipelines to

Figure 2: National Grid replaces LPP near Ives and Fremont streets in Providence. Credit: The Providence Journal.[29]

leak. Further, many of the steel mains installed from the 1920s to the 1970s corroded in the ground and now leak through small perforations. The Federal government required new steel mains and services to be cathodically protected to prevent corrosion in 1971. Today, plastic is the leading choice for new mains and services because of its low cost and resistance to corrosion. Replacement of "leak prone pipe" (LPP) with modern materials is a major focus of Rhode Island Energy's (RIE) annual Gas Infrastructure, Safety, and Reliability (ISR) plan required by R.I. Gen. Laws § 39-1-27.7.1. Since natural gas is almost entirely composed of CH_4, leaking gas traps heat in the atmosphere and is a significant contributor to climate change. LPP replacement is also very expensive; the FY 2026 Gas ISR budget for main replacement and rehabilitation is $107.8 million.[3]

Past Efforts to Quantify Emissions

DEM has estimated fugitive CH_4 emissions from natural gas distribution since the *2010 Rhode Island Greenhouse Gas Inventory* was developed by the Northeast States for Coordinated Air Use Management (NESCAUM) in 2013.[4] The 2010-2019 iterations of the GHGI relied on EPA's Greenhouse Gas Reporting Program (GHGRP) for CH_4 emissions from gas distribution. This decision was made by NESCAUM and DEM in lieu of obtaining infrastructure data to estimate emissions with EPA's State Inventory Tool (SIT). EPA's GHGRP requires facilities that have the potential to emit over 25,000 metric tons of carbon dioxide equivalent (as calculated with the IPCC's GWP_{100} from the *Fifth Assessment Report*) to report their emissions annually.[5,6] RIE fulfills this obligation as the only gas utility in the state. The GHGRP requires facilities to estimate emissions with specific guidelines and emission factors under Subpart W: Petroleum and Natural Gas Systems.[7] CH_4 emissions for "The Narragansett Electric Company" (d/b/a Rhode Island Energy) ranged from 0.18 $MMTCO_2e$ in 2011 to 0.12 $MMTCO_2e$ in 2019.[6]

Several stakeholders of the EC4 believe DEM significantly underestimates CH_4 emissions from gas distribution. One notable example was the report *Deeper Decarbonization in the Ocean State: The 2019 Rhode Island Greenhouse Gas Reduction Study*, authored by Stockholm Environment Institute (SEI) and the Brown University Climate and Development Lab.[8] This report pointed out that "Several Studies have shown that the EPA's leakage rates far underestimate the amount of natural gas actually lost in areas with old gas pipes." SEI and Brown referenced several studies. One, conducted by Boston University and Gas Safety, Inc., measured 100 gas leaks around Boston, MA and found just 7% of the leaks contributed 50% of the total CH_4 emissions measured.[9] Another study conducted in the Boston metro region found the transmission, distribution, and post-meter segments lost 2.7% (± 0.6%) of total gas to the atmosphere.[10] SEI and Brown noted that until a similar study is undertaken in the Providence metro area, it is impossible to know the exact leakage rate of the gas distribution system in Rhode Island. In 2019, DEM recognized this study as plausible given the similarities between the Boston and Providence gas distribution system but did not have the staff bandwidth to engage the issue.

In 2023, DEM compiled its own estimate of fugitive CH_4 emissions from natural gas distribution for the first time.[11] Detailed information on the physical characteristics of RIE's gas distribution system was obtained from the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA). A complete count of gas mains by material type (cast iron, unprotected steel, protected steel, and plastic) and gas services by material type (copper, unprotected steel, protected steel, and plastic) was used to estimate emissions from each type of main and service individually. This aligns with the methodology employed by NESCAUM to create the GHGI's 1990 baseline. Infrastructure data was obtained for the entire timeseries, which allowed DEM to estimate historical emissions between 1991 and 2011 for the first time. EPA's SIT provides material-specific emissions factors to estimate emissions from natural gas distribution. DEM's SIT-generated CH_4 emissions estimates were twice as large as those reported in the EPA's GHGRP between 2011 and 2020. In correspondence between DEM and EPA, staff in the Office of Atmospheric Protection noted "*As a general rule of thumb, using more disaggregated data and emissions factors will generate more accurate emissions estimates. We recommend using the more detailed SIT methodology to estimate emissions for Rhode Island, given that you have access to data disaggregated by pipeline/service type*." Though both methodologies used the same emissions factors, DEM's internal estimate used more disaggregated activity data. This is primarily the cause of DEM's higher CH_4 emissions estimate than EPA's. Since 2023, DEM has followed EPA's recommendation to estimate natural gas distribution emissions internally.

Numerous stakeholders acknowledge significant progress has been made to improve the scope and accuracy of the GHGI. DEM recognizes its natural gas systems emissions estimate remains inadequate. Emissions that occur from other segments of Rhode Island's natural gas industry, such as interstate pipelines, compressor stations, LNG storage tanks, city gate stations, customer meters, routine maintenance, pipeline upsets, residential and commercial appliances, and industrial and electric power generation equipment, also produce fugitive CH_4 and CO_2 emissions. Lifecycle or "upstream" emissions from the exploration, production, and processing segments are also associated with in-state consumption of natural gas. These are not within the scope of the GHGI because their emissions occur outside of Rhode Island. Additionally, the current emissions factors for distribution are nearly 30 years old and should be replaced with emission factors that reflect the current state-of-the-science.

Proposal to Improve Emissions Quantification

EPA's U.S. GHGI is submitted each year to the United Nations in accordance with the Framework Convention on Climate Change. This publication informs many aspects of the GHGI, particularly the natural and working lands sector.[13] DEM was informed by the Massachusetts Department of Environmental Protection (MassDEP) that the *Massachusetts Annual Greenhouse Gas Emissions Inventory* utilizes emission factors from the U.S. GHGI to estimate all segments of natural gas system emissions. MassDEP generously provided DEM an overview of their methodology that leverages the U.S. GHGI's emission factors. Subsequent research found these emissions factors to meet all the requirements of DEM:

1. Publicly available and updated when new and improved science arises.
2. Applicable to all years of the GHGI (i.e., back to 1990).
3. Covers all segments of natural gas system emissions that occur in Rhode Island.

DEM staff researched a few of the studies cited in the report *Deeper Decarbonization in the Ocean State: The 2019 Rhode Island Greenhouse Gas Reduction Study* to see if other emission factors were readily available for the GHGI. Hendrick et al. only measured leaks from cast iron pipelines and did not provide emission factors for other material types.[9] The more comprehensive McKain et al. study also did not provide emissions factors since it was a top-down study.[10] McKain et al. deployed a network of air monitoring stations to measure atmospheric ethane (C_2H_6), a tracer of CH_4, for input into an atmospheric transport model that compared measurements with spatially explicit natural gas consumption data.[10] Little guidance to reconcile top-down and bottom-up emissions estimates exist at the state level. State agencies across the U.S. are limited to incorporating bottom-up emissions estimates into official inventories until guidance emerges from an authoritative source, such as EPA or the U.S. Climate Alliance.

The results of the Hendrick et al.[9] and McKain et al.[10] studies highlight the need for research to be conducted on fugitive emissions from natural gas systems in Rhode Island. The exact leakage rate of the distribution system in the Providence metro area, and smaller microcosms such as Newport, will remain unknown until a robust "ground truthing" study is undertaken. Use of the 2.7% (± 0.6%) leak rate as reported by McKain et al.[10] to calculate emissions is too simplistic because the Boston, MA metro area is significantly larger and contains more gas infrastructure than Providence, such as an LNG import terminal, that could misrepresent Rhode Island's emissions. Satellite observations of individual methane plumes – such as those measured by the National Aeronautical and Space Administration (NASA) Carbon Monitoring System project and Carbon Mapper, Inc. – are useful to detect large "super emitters" but cannot capture neighborhood-scale emissions. Considering these limitations, DEM proposes to use the emissions factors from the U.S. GHGI to significantly improve the science and scope of the GHGI's natural gas systems sector.

Infrastructure Data

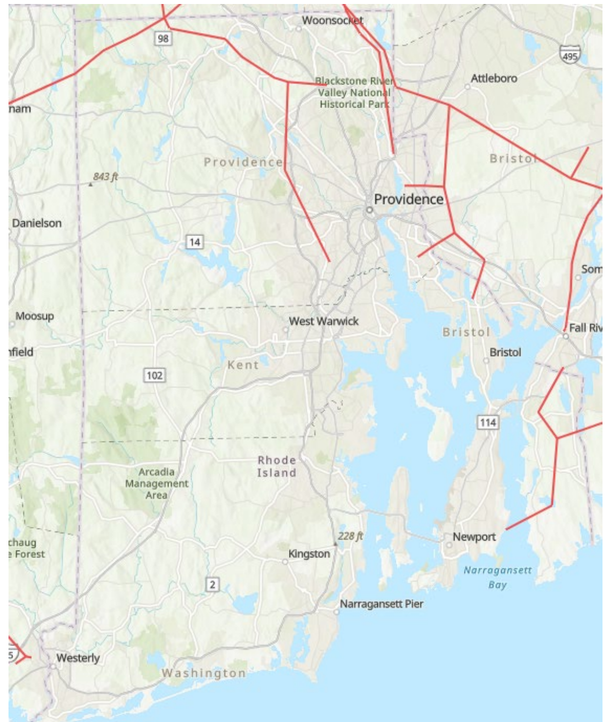

Figure 3: Interstate natural gas pipelines in Rhode Island. Credit: U.S. Energy Information Administration.

Interstate Transmission Pipeline

Before DEM could estimate fugitive emissions from natural gas systems, it was necessary to obtain a complete account of Rhode Island's natural gas systems infrastructure. Natural gas first crosses into the state when the Algonquian Gas Pipeline (AGP) enters Burrillville from Thompson, CT, and the Tennessee Gas Pipeline (TGP) enters Burrillville from Uxbridge, MA. Both pipelines make other crossings into Rhode Island from Norfolk and Bristol counties in Massachusetts. In total, 95 miles of transmission pipeline existed in the state at the end of 2023, up from 87 miles in 1990. (*high confidence*). Figure 3 identifies the interstate natural gas pipelines in Rhode Island that traverse Providence, Bristol, and Newport counties. The transmission system in Rhode Island carries natural gas at pressures ranging from 800 to 1,200 pounds per square inch gauge (psig) in steel pipes 24 and 36 inches wide.[15,16] DEM obtained all transmission pipeline mileage data from PHMSA.

Compressor Stations

Interstate pipelines often carry natural gas hundreds of miles from production basins to end users. Along the way, pressure is lost in the pipeline due to friction and changes in topography. Compressor stations maintain pressure to keep natural gas flowing at a safe and reliable rate. Rhode Island has two compressor stations, both in Burrillville. Enbridge (owner of the AGP) operates a large compressor station that contains three (3) dry seal compressors and one (1) reciprocating compressor (*high confidence*). Kinder Morgan (owner of the TGP) operates a small compressor station with 1 reciprocating compressor (*high confidence*). Each compressor station has pneumatic controllers, which are automated devices that control compressor scrubber liquid levels, gas flow, and pipeline pressure.

Figure 4: AGP compressor station, Burrillville. Credit: RIGIS, RIDEM Environmental Resource Map.

Pneumatic controllers emit or "bleed" intermittently or continuously. Enbridge's AGP compressor station, shown in Figure 4, has 43 intermittent-bleed pneumatic controllers as of 2023 (*high confidence*). Kinder Morgan's compressor station for the TGP has 2 intermittent-bleed pneumatic controllers as of 2023 (*high confidence*). When more-than-routine maintenance is performed at a compressor station, all the gas within the compressors and associated piping are directly vented to the atmosphere in a "blowdown" event.[17] The number of blowdown events varies each year based on maintenance schedules. In 2023, Enbridge's compressor station for the AGP experienced 33 blowdown events (*high confidence*). DEM obtained all compressor station information from EPA's GHGRP and communication with Enbridge and Kinder Morgan.

LNG Storage Facilities

New England's natural gas system relies on several sources of gas to ensure reliable service. Interstate transmission pipelines provide most of the region's day-to-day gas demand, but two LNG import terminals in Massachusetts also supply a significant portion of the region's natural gas. One LNG import terminal, the Northeast Gateway, is located 13 miles offshore and is connected to the AGP.[18] Another LNG import terminal is in Everett, MA and is also directly tied to the transmission system. Both terminals support New England's high natural gas demand during in the winter when interstate transmission pipelines near capacity.

Figure 5: National Grid Fields Point LNG Facility, Providence. Credit: Offshore Energy, NGLNG.

Rhode Island has four (4) LNG storage facilities that serve a similar purpose (*high confidence*). National Grid's Fields Point LNG storage facility in Providence, shown in Figure 5, is the largest in the state and can supply up to 40% of the distribution system's demand during the coldest days of the year.[19] The Fields Point facility is a "peak shaving" facility that operates only when demand is very high. LNG is delivered via truck from the Everett, MA facility or liquified into LNG from gas delivered by the AGP. RIE also operates LNG storage facilities for the distribution system. One permanent LNG tank is in Exeter and two mobile storage tanks are seasonally deployed in Cumberland and Portsmouth. All RIE's LNG facilities are peak shavers, and the Portsmouth LNG facility also serves as a backup for Aquidneck Island in the case of a major contingency. CH_4 and CO_2 have the potential to leak from LNG facilities through small perforations in equipment and blowdown events. DEM obtained all LNG storage data from PHMSA and communication with RIE.

Meter and Regulator Stations

Custody of gas transfers from the transmission system to the distribution system at meter and regulator (M&R) stations, also known as "city gate" stations. RIE operates a total of 190 M&R stations across Rhode Island that are connected to the AGP or the TGP (*high confidence*). M&R stations vary by pressure, size, and are located within fenced-in aboveground areas or in belowground vaults. To reach customers, RIE must reduce the pressure of the gas in the transmission system to flow into the distribution system. 15 gate stations operate at pressures greater than 300 psi, while one (1) operates between 100 psi and 300 psi. All other regulators operate at pressures ranging from 300 psi to less than 40 psi. Natural gas has the potential to leak at M&R connection points, especially at stations that operate under higher pressures. DEM obtained all information on M&R stations from communication with RIE. At the recommendation of RIE, 2024's M&R station count was used as a proxy back to 1990 due to challenges accessing historical data (*medium confidence*).

Distribution Mains and Services

Figure 6: Example of a plastic natural gas distribution main. Credit: Rhode Island Office of Energy Resources.

Once natural gas is flowing through the distribution system, it can be routed to homes, businesses, factories, and other customers via underground mains. As of 2023, RIE operated a total of 3,223 miles of natural gas mains in Rhode Island (*high confidence*). The majority (1,797 miles) are made of plastic, such as the example in Figure 6 (*high confidence*). Protected steel (585 miles), unprotected steel (264 miles), cast iron (565 miles), and ductile iron (12 miles) mains also delivered gas to customers within the RIE service area in 2023 (*high confidence*). Since 1990, the distribution system's network of gas mains has grown by 412 miles – up from 2,811 in 1990. The addition of 1,382 miles of plastic mains have replaced many of the antiquated cast iron and unprotected steel mains in the last 33 years. Specifically, 474 miles of cast iron, 333 miles of unprotected steel, and 163 miles of protected steel mains have been removed or abandoned since 1990. Most gas mains are buried under roads, sidewalks, or other "gray infrastructure", which makes LPP replacement difficult and costly. Natural gas enters private property via gas services, which connect individual buildings to the main. A total of 195,158 services existed in Rhode Island as of 2023 (*high confidence*). Most services are made of plastic (147,078), while smaller amounts are made from unprotected steel (40,643), protected steel (6,487), and other materials, including copper and cast iron (950) (*high confidence*). Each service varies in length due to distance of the building from the main underneath the street. DEM estimated the combined length of all mains and services in Rhode Island equals approximately 5,551 miles – up from 4,962 miles in 1990 (+11.9%). This estimate considers the average service length reported by Bristol & Warren Gas, Providence Gas, and Valley Gas before they were consolidated in the early 2000s. DEM obtained all mains and services data from PHMSA.

Customer Meters

Natural gas that enters homes, businesses, factories, and other buildings at the end of the service must be read or "metered" to bill customers. The total number of meters by end use (residential, commercial, or industrial) provides a simple overview of how many individual entities consume natural gas. Apartment complexes, commercial buildings, and industrial buildings often have more than one meter since multiple customers occupy the same space. Thus, the *number of customer meters* should not be equated with the *number of buildings* that consume natural gas. In 1990, 195,100 residential meters, 17,765 commercial meters, and 1,135 industrial meters existed in Rhode Island (*medium confidence*). By 2023, the number of residential meters grew to 249,454 (+28%) and the number of commercial meters increased to 24,731 (+39%) (*high confidence*). Economic and demographic changes have sharply declined Rhode Island's manufacturing industry in the past 34 years. The number of industrial meters has fallen to 290 (-75%) despite the significant growth of the gas distribution system. It is possible some industrial meters were reclassified as commercial meters between 1990 and 2000, thus there is only *medium confidence* in this metric. Since many meters are situated outside buildings, they are prone to the effects of weathering and may leak gas at connection points. DEM obtained all customer meter data from the U.S. Department of Energy's Energy Information Administration (EIA).

Figure 7: Example of a typical natural gas meter. Credit: U.S. Department of Energy.

Post-Meter Equipment

Natural gas is used in a variety of ways once it enters a building. Residential customers use natural gas for space heating (boilers, furnaces, and fireplaces), water heating, cooking (ovens, ranges, and stoves), and occasionally clothes washing and drying. Commercial customers purchase natural gas for these end-uses and for CHP generators. Industrial customers consume natural gas for CHP generators and some also combust it in manufacturing processes. While appliances in the 21st century are significantly more energy efficient than their 20th century predecessors, nothing is perfectly constructed. Post-meter leaks from residential and commercial appliances are estimated with customer meter data as a proxy due to lack of available data on individual appliances (*low confidence*). Industrial and electric power generation equipment leaks are estimated with EIA natural gas consumption data (*low confidence*). Detailed information about the number of


Figure 8: Example of post-meter gas equipment.

residential and commercial space heating, water heating, and cooking appliances in Rhode Island would be required to estimate emissions more robustly from post-meter leaks. DEM is not currently aware of this data and chose to follow the methodology employed by EPA in the U.S. GHGI.

Table 1: Natural Gas Systems Infrastructure Data by Decade

	1990	**2000**	**2010**	**2022**
Transmission and Storage				
Miles of Pipeline	87	89	95	95
Compressor Stations	1	1	2	2
Reciprocating Compressors	3	3	3	1
Centrifugal Compressors	2	2	3	4
Pneumatic Devices	32	38	48	46
LNG Stations	3	3	3	3
Distribution				
Miles of Main	2,811	3,024	3,132	3,222
Cast Iron	1,051	979	895	604
Unprotected Steel	597	482	592	276
Protected Steel	748	817	601	582
Plastic	415	746	1,044	1,759
Services	163,644	185,306	188,405	194,862
Unprotected Steel	108,977	96,096	59,800	42,210
Protected Steel	13,898	13,553	11,206	6,569
Plastic	40,481	75,423	115,718	145,093
Copper	288	234	1,681	990
M&R Stations	190	190	190	190
Customer Meters	214,000	237,683	248,502	272,426
Residential	195,100	214,474	225,204	247,508
Commercial	17,765	22,592	23,049	24,636
Industrial	1,135	317	249	282

Emissions Factors

All sectors of the GHGI are estimated via a “bottom-up” method as opposed to a “top down” method. Compared with nascent “top down” satellite-based approaches to observe and quantify emissions, “bottom up” calculations require knowledge about the physical characteristics of the system and the rate at how quickly and intensively emissions occur. The more scientifically robust the emissions "factor", the more accurate the emissions estimate will be. DEM proposes to use the emissions factors employed by EPA in the U.S. GHGI to estimate all components of natural gas systems emissions. EPA leveraged the two most comprehensive studies ever taken to understand U.S. natural gas system emissions to create the emission factors used in the U.S. GHGI.

1996 EPA/Gas Research Institute Study

The landmark study *Methane Emissions from the Natural Gas Industry* was contracted to Radian International, LLC of Austin, TX on behalf of the Gas Research Institute (GRI) and EPA in 1996.[20] For close to 15 years, this study was the authoritative source for all information related to fugitive emissions from natural gas systems in the United States. All segments of the natural gas industry were studied extensively for the first time. EPA primarily undertook this study to understand whether the economy-wide switch from coal and oil to natural gas would meaningfully reduce U.S. emissions. Since natural gas is almost entirely composed of CH_4, forgone CO_2 emissions from switching to natural gas could theoretically be offset by fugitive CH_4 emissions. Scientists theorized a relatively small quantity of leaked CH_4, compared to avoided CO_2 from combustion, could result in little-to-no reduction in atmospheric warming since CH_4 is 28 times more powerful than CO_2 over 100 years and 84 times more powerful over 20 years.

The complexity of the U.S. natural gas industry required most of the 1996 EPA/GRI study to be dedicated towards developing methodologies for estimating fugitive emissions for the first time. Accuracy was not the primary objective, though the final emissions calculations included an assessment of accuracy. This report is often regarded as outdated because significantly better leak-detection technology has emerged since the late 1990s. Many of the emissions factors in this study remain useful for estimating emissions in older years (i.e., 1990-1993) because they are more reflective of the condition of the pipeline and equipment at the time. For example, this study's emission factors for cast iron distribution mains are more representative of early years because they are more reflective of this type of pipeline before efforts to seal leaks started in the 2000s (*medium confidence*).

EPA Greenhouse Gas Reporting Program

After 2010, EPA's GHGRP regulation generated a significant amount of facility-level data on fugitive emissions from natural gas systems. The GHGRP's "Subpart W: Petroleum and Natural Gas Systems" details how facilities estimate their fugitive emissions from natural gas equipment.[22] EPA developed unique emissions factors for many components of natural gas systems based on year specific GHGRP data starting in 2011. Relevant to Rhode Island, the emissions factors EPA developed with GHGRP data for compressor stations accurately reflects the AGP compressor station in Burrillville since it reports to the GHGRP (*medium confidence*). EPA also configured emissions factors for transmission pipeline venting based on GHGRP data after 2016 (*medium confidence*). Both instances are examples of the GHGRP regulation ensuring the U.S. GHGI is reflective of current science. The absence of a similar regulation at the state-level in Rhode Island was another reason DEM chose to leverage the emissions factors from the U.S. GHGI.

2015 Lamb et al. Local Distribution Company Study

The most advantageous aspect of the U.S. GHGI's emissions factors is the use of much newer methods for analyzing distribution system gas leaks. Lamb et. al., published in 2015, was the first comprehensive examination of local distribution company (LDC) fugitive emissions since the 1996 EPA/GRI study.[21] This study took direct measurements of CH_4 leaks from underground pipelines and M&R stations across 13 LDCs to create emission factors to replace those from the 1996 EPA/GRI study. Although there are over 1,400 LDCs in the U.S., the 13 LDCs that voluntarily participated in the Lamb et al. study comprised ~16% of total U.S. natural gas deliveries in 2011, thus representing a significant share. The 13 LDCs in the Lamb et al. study had similar LPP replacement rates to the U.S. average (*high confidence*), though this rate may be lower than RIE's annual average (*low confidence*).

Lamb et al. used a high-flow gas sampling method to measure emissions and a downwind tracer-ratio method to quality control the results. 230 individual leaks of different sizes from mains and services were measured to create the new emissions factors, over twice as many samples as the 1996 EPA/GRI study. The emission factors created by Lamb et al. are also more than twice as low as the 1996 EPA/GRI study, though small methodology differences exist. The 1996 EPA/GRI study measured leak rates by unearthing pipe sections and correcting for CH_4 oxidized in the soil. Notably, the soil oxidation correction was nearly 40% of measured emissions for cast iron mains. Lamb et al. did not unearth any pipes during their study and did not need to correct for soil oxidation. Hendrick et al., published in 2016, also agreed with Lamb et al., noting their log-normal mean leak rate was consistent with the emission factor for cast iron mains reported by Lamb et al.[9] Additionally, plastic mains were found by Lamb et al. to leak 85% less than those recorded in the 1996 EPA/GRI study. This finding was comparable to a study conducted by the Gas Technology Institute (GTI) in 2013.[22]

Lamb et al. created new emission factors for M&R stations to replace those from the 1996 EPA/GRI study (*low confidence*). A comparison will not be discussed here since M&R stations are a new addition to the GHGI. Lamb et al. acknowledges the substantial difference between top-down vs. bottom-up emissions quantification studies, especially the McKain et al. study. This reiteration underscores the importance for (1) a top-down study to be undertaken in the Providence area and (2) for Federal agencies such as NASA to aid in the reconciliation of top-down and bottom-up emissions estimates. Until more guidance emerges, DEM advises caution comparing top-down and bottom-up emissions estimates. The emissions factors created by Lamb et al., though more scientifically sound than the 1996 EPA/GRI study, still exhibit significant uncertainty given the different results presented in academic literature.

Table 2: Comparison of Emissions Factors for Natural Gas Distribution

	1996 EPA/GRI	**2015 Lamb et al.**
Mains – Cast Iron	4,597.4 kg/mile/year	1,157.3 kg/mile/year
Mains – Unprotected Steel	2,122.3 kg/mile/year	861.3 kg/mile/year
Mains – Protected Steel	59.1 kg/mile/year	96.7 kg/mile/year
Mains – Plastic	190.9 kg/mile/year	28.8 kg/mile/year
Services – Unprotected Steel	32.8 kg/service/year	14.5 kg/mile/year
Services – Protected Steel	3.4 kg/service/year	1.3 kg/mile/year
Services - Plastic	0.2 kg/service/year	0.3 kg/mile/year
Services – Copper	4.9 kg/service/year	4.9 kg/mile/year

Other Sources

The U.S. GHGI continues to rely on the 1996 EPA/GRI report for other understudied segments of natural gas systems. Interstate transmission pipelines, compressor stations (1990-1992), pneumatic devices (1990-1992), pipeline venting (1990-2015), compressor station venting, LNG facility blowdowns, M&R stations (1990-1992), routine distribution pipeline maintenance, and distribution pipeline mishaps all continue to be estimated with emission factors from the 1996 EPA/GRI study (*medium confidence*). Segments of the natural gas industry that rely on the 1996 EPA/GRI study for early years in the timeseries (1990-1992) will likely always use these emission factors since this study was more reflective of the industry at the time. Emission factors for customer meter leaks were calculated with data from the 1996 EPA/GRI study and studies undertaken in 2009 and 2019 by the Gas Technology Institute (GTI). Post-meter leak emission factors are based on a study conducted in 2018 by Fisher et al. For commercial, industrial, and electric power generation post-meter leaks, the U.S. GHGI leverages emissions factors provided by the IPCC and detailed in the *2019 Refinement to the 2006 Guidelines for National Greenhouse Gas Inventories*, *Volume 2: Energy* [25] (*low confidence*). EPA may update these emission factors if research conducted in the U.S. demonstrates they are substantially different from those provided by the IPCC.

Natural Gas Systems Emissions Results

All emissions calculations were completed with the format used by EPA in the U.S. GHGI. DEM leveraged "Annex 3.6: Methodology for Estimating CH_4, CO_2, and N_2O Emissions from Natural Gas Systems (.xlsx)" of the 1990-2022 U.S. GHGI to create its internal workbook.[27] Natural gas systems emissions are grouped into three main categories: transmission and storage, distribution, and post-meter. As expected, distribution was the largest source of fugitive emissions from natural gas systems in 1990 (86.3% of total) and in 2022 (56.5% of total) (*medium confidence*). Post-meter leaks contributed 25.9% and transmission and storage comprised 17.7% of natural gas system emissions in 2022 (*medium confidence*). Table 3 exhibits emissions from all three segments disaggregated into individual components. Please note, this table does not seek to provide a complete account of each emissions source or fully detail the 1990-2022 timeseries.

Table 3: Natural Gas Systems Emissions by Decade, All Units in MMTCO_2e

	1990	2000	2010	2022
Transmission & Storage	0.03	0.03	0.03	0.03
Pipeline Leaks	0.00003	0.0003	0.0003	0.0003
Compressor Stations	0.02	0.01	0.02	0.01
Pneumatic Devices	0.003	0.002	0.001	0.0005
Pipeline Venting	0.001	0.002	0.002	0.001
Compressor Station Venting	0.002	0.002	0.005	0.003
LNG Storage Facilities	0.01	0.01	0.01	0.01
Distribution	0.32	0.22	0.11	0.08
Pipeline Leaks - Mains	0.17	0.11	0.05	0.03
Pipeline Leaks - Services	0.10	0.07	0.03	0.02
Meter/Regulators	0.01	0.01	0.002	0.001
Customer Meters	0.02	0.02	0.03	0.03
Routine Maintenance	0.0003	0.0002	0.0002	0.0002
Upsets	0.004	0.004	0.005	0.005
Post-Meter	0.02	0.03	0.04	0.04
Residential	0.01	0.01	0.01	0.02
Commercial	0.002	0.002	0.003	0.003
Industrial	0.001	0.002	0.003	0.003
Electricity Generating Units	0.003	0.02	0.02	0.02
Total	**0.37**	**0.28**	**0.18**	**0.14**

Analysis of emissions from all segments highlight a few nascent takeaways:

1. Transmission and storage emissions have remained relatively flat over the last 32 years (*high confidence*).
2. Customer meters contributed a larger share of 2022's distribution segment emissions (33.7%) than 1990 (6.25%), though this is largely a proportional increase because of the reduction in distribution system emissions (*medium confidence*).
3. Post-meter emissions have roughly doubled since 1990, especially fugitive emissions from electricity generating units (*low confidence*).

Transmission and Storage

Inclusion of CO_2 and CH_4 emissions from transmission and storage was important to assess the effects interstate pipelines, compressor stations, and LNG storage facilities have on the state's collective emissions. Rhode Island's location near the end of the AGP and the TGP amounts to a relatively small amount of transmission and storage infrastructure compared to other states. Natural gas transmission and storage produced 0.03 $MMTCO_2e$ in 2022 (*medium confidence*). The majority (0.02 $MMTCO_2e$) originated from compressor stations and a smaller amount (0.01 $MMTCO_2e$) was produced by LNG storage facilities. Few additions to pipeline infrastructure and LNG storage facilities kept emissions nearly flat from 1990 to 2022 (*medium confidence*). Between 2002 and 2009, transmission and storage emissions peaked at 0.04 MMTCO2e. The addition of TGP's small compressor station in 2002 temporarily raised emissions until lower emissions factors from Zimmerle et al., 2015 were utilized for compressor stations starting in 2011.[27] Transmission and storage emissions are expected to remain stable unless sections of interstate pipeline are abandoned, a compressor station closes, or an LNG storage facility retires. DEM will inventory the state's transmission and storage infrastructure each year to ensure emissions are correctly estimated for this segment.

Distribution

Leaks from natural gas mains and services produced 0.08 $MMTCO_2e$ in 2022 and represented 58.9% of distribution segment emissions (*low confidence*). In 1990, mains and services caused 86.9% of distribution segment emissions due to the state's high percentage of LPP. The replacement of cast iron and unprotected steel gas mains with protected steel and plastic mains, especially after 2010, sharply decreased the distribution segment's emissions. This is notable considering the overall mileage of mains and services has grown by 589 miles in the last 32 years. Efforts to seal and modernize antiquated pipelines, mathematically expressed through the linear interpolation of old and new emission factors, also contributed to the 28.0% drop in distribution emissions since 1990 (*low confidence*). DEM expects estimated emissions from mains and services to continue a downward trend with more investment in LPP replacement program.

Customer meters produced 33.7% of distribution segment emissions in 2022 (0.03 $MMTCO_2e$) (*medium confidence*). Fugitive emissions from customer meters have increased alongside the number of customers that consume gas. Rhode Island has 54,354 more residential users and 6,966 more commercial users of natural gas in 2022 compared to 1990 (*medium confidence*). Despite the loss of ~845 industrial customers since 1990, emissions from customer meters have grown by ~50% (*low confidence*). DEM believes estimated emissions from this category will continue to increase unless a significant percentage of customers completely transition to renewable heating fuels, such as electric heat pumps. M&R stations, routine maintenance of mains and services, and pipeline upsets produced the remaining 7.4% of distribution system emissions in 2022 (*low confidence*).

Post-Meter

Behind-the-meter gas leaks from residential, commercial, and industrial customers caused 57.0% of all post-meter emissions in 2022 (*low confidence*). Gas-fired heating equipment, cooking equipment, and clothes dryers are the most probable sources of post-meter fugitive emissions. DEM estimated Rhode Island's four natural gas power plants produced the remaining 43.0% of post-meter fugitive emissions (*low confidence*). Only CH_4 was estimated, as the U.S. GHGI does not provide emissions factors to estimate post-meter fugitive CO_2. CH_4 leaks from natural gas vehicles were not estimated due to the lack of available data from the Rhode Island Division of Motor Vehicles. Vehicles are likely a small source of fugitive CH_4 emissions considering the small number of natural gas vehicles registered in Rhode Island. DEM may be able to confirm this if data becomes available through a future heavy-duty vehicle inspection and maintenance regulation. DEM expects post-meter fugitive emissions to follow the trajectory of customer meter emissions, industrial natural gas consumption, and electric power plant natural gas consumption.

Reconciliation with Distribution System Unaccounted for Gas

The distribution segment is a complex network that was built over time. As previously discussed, the entire system is not perfectly sealed, and gas is marked as lost or "unaccounted for" each year:

1. **"Gross" Unaccounted for Gas** = Gas into System – Gas out of System
2. **"Net" Unaccounted for Gas** = Gross Unaccounted for Gas – Estimated Atmospheric Leaks

Gross unaccounted for gas (UFG) is simply the amount of gas RIE purchased less the amount of gas recorded on their customer's meters. In 2023, gross unaccounted for gas comprised 3.38% of RIE's total send out.[30] RIE attempts to estimate where *some* of this gas went by calculating the quantity of **net UFG**, which considers how much gas was fugitively emitted to the atmosphere. RIE uses the same data and methods as the GHGI (i.e., infrastructure data and emissions factors from EPA) to estimates their system's atmospheric leakage rate. The net UFG percentages in Figure 9 were calculated with the 1996 EPA/GRI study emissions factors and thus are not directly comparable to the results of this study. RIE estimated net UFG comprised 2.70% of its total send out in 2023.[30] In other words, it is unknown where 2.70% of the total gas RIE purchased in 2023 went *after* considering how much leaked to the atmosphere. From 2013 to 2023, RIE estimated an average leak rate of 0.76%. Note: this estimate (0.76%) is not comparable to the 2.70% (± 0.6%) leak rate estimated by McKain et al. because it only includes distribution, whereas McKain et al. included the transmission and storage, distribution, and post-meter segments.[10]

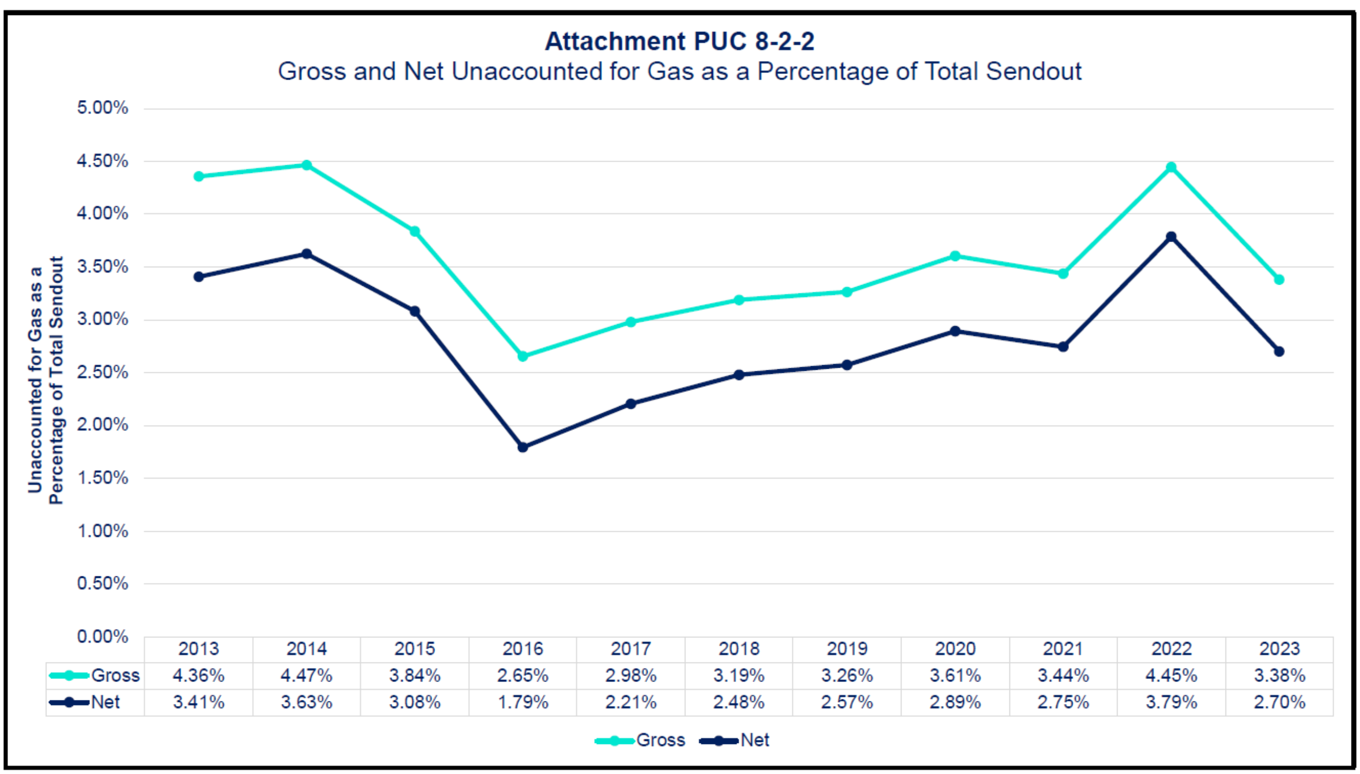

Figure 9: 2013-2023 RIE Unaccounted for Gas Calculations.

Aside from atmospheric leaks, there are other reasons to explain the 2.70% of net UFG estimated in 2023. Daily operation of the gas system contributes to UFG through pipeline abandonment. When a section of pipeline is abandoned, all the gas within that main and/or service is directly vented to the atmosphere. Since this gas never reaches a customer meter, it is marked as UFG. *Note: this is accounted for in this study's proposed methodology under the distribution segment "routine maintenance" and "upsets" components*. Another potential explanation is meter slippage, where a customer meter reads incorrectly and contributes to the net UFG total through accounting differences. Theft of gas, which is illegal in Rhode Island, also could contribute to the net UFG total.

Ideal Gas Law

$$PV = nR^*T$$

- P = pressure of natural gas
- V = volume of natural gas
- n = number of kilomoles in sample
- R* = universal gas constant (8,314.5 $JK^{-1}kmol^{-1}$)
- T = temperature of natural gas

The most probable explanation for RIE's net unaccounted for gas is differences in pressure and temperature that operators must induce upon the system to adhere to environmental conditions and customer demand. Variations in pressure and temperature result in changes in overall volume delivered to customers. This principle is illustrated by the ideal gas law. If pressure (P) or temperature (T) are adjusted, volume (V) will automatically change. Small deviations in pressure and temperature over time lead to differences in the volume of gas sent out and the volume of gas read on customer meters. RIE likely applies a correction factor to account for differences in temperature and pressure in UFG, though its efficacy is unknown.

Stakeholders have remarked all distribution system net unaccounted for gas should be treated as emitted to the atmosphere given the high rates of leakage reported in Hendrick et al.[9], McKain et al.[10], and Sargent et al.[24] This approach would be an oversimplification since other factors contribute to RIE's net UFG total. While RIE's UFG estimates are subject to significant uncertainty, as are the results of this report, there is a correlation between age, quality of pipeline materials, and UFG. This publication attempts to reconcile this correlation with the proposed emissions accounting methodology.

Conclusion

Fugitive emissions from the natural gas industry are particularly harmful to Earth's climate system since natural gas is primarily composed of CH_4. To estimate emissions, DEM collected a plethora of current and historical infrastructure data from Federal agencies and State-regulated facilities. DEM also leveraged the full suite of emissions factors from EPA's U.S. GHGI to estimate each natural gas systems segment. The results confirm a long-held belief that fugitive emissions from distribution, particularly LPP, are the largest contributor to Rhode Island's emissions from natural gas systems. For the first time, DEM estimated fugitive emissions from the transmission, storage, and post-meter segments. The combination of these three segments were found to leak nearly as much as distribution in 2022, which is a novel finding.

Rhode Island's complex and evolving natural gas system presents unique challenges to estimate fugitive CO_2 and CH_4 emissions. Numerous studies around Boston, MA suggest much higher rates of fugitive CH_4 from natural gas infrastructure in urban environments.[9,10] The similarities between the Boston and Providence gas distribution systems (i.e., age, composition, climate zone) raise the question of whether fugitive CH_4 emissions are underestimated in this report. The complexity of comparing atmospheric-based "top-down" studies with activity data-based "bottom-up" studies are not well understood, especially for small geographic regions such as Rhode Island. Ongoing work through the U.S. Greenhouse Gas Center, a collaboration between NASA and other Federal agencies, may shed light on this issue in the future. DEM cautions comparisons between these studies and the emissions estimates in this report until street-level CH_4 emissions are thoroughly studied in the Providence metro area.

The data presented in this report and the emissions factors from EPA's U.S. GHGI are believed to best represent emissions from natural gas systems in Rhode Island. Accurate quantification of emissions in this sector will help the EC4 chart a more cost-effective and equitable path towards economy-wide net zero emissions by 2050. Additionally, official guidance on natural gas systems emissions accounting by DEM will aid RIE and the PUC on reconciling gross unaccounted for gas figures with atmospheric leak rates. More accurate data and emissions factors may become available as the Federal government and other state agencies investigate pathways to decarbonize buildings in Rhode Island. DEM will strive to incorporate local data and relevant emissions factors into the GHGI when reasonable and scientifically justifiable.

References

1. 2021 Act on Climate, R.I. Gen. Laws § 42-6.2-9 (2021). http://webserver.rilin.state.ri.us/Statutes/TITLE42/42-6.2/42-6.2-9.htm
2. IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.
3. Public Utilities Commission Docket No. 24-55-NG. The Narragansett Electric Co. d/b/a Rhode Island Energy FY 2026 Gas Infrastructure, Safety, and Reliability Plan Compliance Filing (filed 3/31/25). https://ripuc.ri.gov/sites/g/files/xkgbur841/files/2025-04/24-55-NG%20-%20Gas%20ISR%20FY2026%20-%20Compliance%20Filing%20-%20PUC%203-21-2025.pdf
4. Rhode Island Department of Environmental Management. (2013). *2010 Rhode Island Greenhouse Gas Emissions Inventory*. State of Rhode Island, Department of Environmental Management. https://dem.ri.gov/sites/g/files/xkgbur861/files/climate/pdf/gginv2010.pdf
5. IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. [Core Writing Team, R.K. Pachauri, and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
6. EPA Office of Atmospheric Protection. (2024). *Greenhouse Gas Reporting Program (GHGRP)*. [Data set]. U.S. Environmental Protection Agency, Office of Atmospheric Protection. https://www.epa.gov/ghgreporting
7. Mandatory Greenhouse Gas Reporting Subpart W – Petroleum and Natural Gas Systems. 40 C.F.R. § 98.230 – 98.238 (2024). https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98/subpart-W
8. Veysey, J., Roberts, J.T., Traver, D., Cotler, B., Gross, B., & Kim, A. (2019*). Deeper Decarbonization in the Ocean State: The 2019 Rhode Island Greenhouse Gas Reduction Study*. Stockholm Environment Institute and Brown University Climate and Development Lab. https://www.sei.org/wp-content/uploads/2019/09/deeper-decarbonization-in-the-ocean-state.pdf
9. Hendrick, M.F., Ackley, R., Sanaie-Movahed, B., Tang, X., & Phillips, N.G. (2016). Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments. *Environmental Pollution, 213.* 710-716. ISSN 0269-7491. https://doi.org/10.1016/j.envpol.2016.01.094.
10. McKain, K., Down, A., Raciti, S. M., Budney, J. W., Hutyra, L. R., Floerchinger, C., Herndon, S. C., Nehrkorn, T., Zahniser, M. S., Jackson, R. B., Phillips, N., & Wofsy, S. C. (2015). Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts. *Proc. Natl. Acad. Sci. U.S.A., 112(7),* 1941–1946. https://doi.org/10.1073/pnas.1416261112.
11. Rhode Island Department of Environmental Management (2023). *2020 Rhode Island Greenhouse Gas Emissions Inventory*. State of Rhode Island, Department of Environmental Management. https://dem.ri.gov/sites/g/files/xkgbur861/files/2024-06/RIDEM-ghg-inventory-2020.pdf
12. EPA Office of Research and Development. (1996). *Methane Emissions from the Natural Gas Industry, Volume 9: Underground Pipelines*. U.S. Environmental Protection Agency, Office of

Research and Development. https://www.epa.gov/sites/default/files/2016-08/documents/9_underground.pdf

13. EPA Office of Atmospheric Protection. (2024). *Inventory of U.S. Greenhouse Gas Emissions and Sinks by State*. U.S. Environmental Protection Agency, Office of Atmospheric Protection. https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals
14. EPA Office of Atmospheric Protection. (2024). *Inventory of U.S. Greenhouse Gas Emissions. Natural Gas and Petroleum Systems in the GHG Inventory: Additional Information on the 1990-2022 GHG Inventory (published April 2024)*. U.S. Environmental Protection Agency, Office of Atmospheric Protection. https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2022-ghg
15. Argonne National Laboratory. (2007). National Pipeline Technology Overview. (ANL/EVS/TM/08-5). U.S. Department of Energy, Argonne National Laboratory. https://corridoreis.anl.gov/documents/docs/technical/apt_61034_evs_tm_08_5.pdf
16. Messersmith, D. (2015). *Understanding Natural Gas Compressor Stations*. The Pennsylvania State University. https://extension.psu.edu/understanding-natural-gas-compressor-stations
17. Natural Gas STAR Program. (2024, July). *Compressor Station Blowdowns*. U.S. Environmental Protection Agency, Natural Gas STAR Program. https://www.epa.gov/natural-gas-star-program/compressor-station-blowdowns
18. Excelerate Energy. (n.d.) *Northeast Gateway Deepwater Port*. Excelerate Energy, Inc. Retrieved January 16, 2025, from https://excelerateenergy.com/projects/northeast-gateway-deepwater-port/
19. National Grid. (n.d.). Fields Point – Domestic Liquified Natural Gas (LNG) in New England. Retrieved January 16, 2025, from https://www.nationalgridus.com/Fields-Point/
20. EPA Office of Research and Development. (1996). *Methane Emissions from the Natural Gas Industry, Volume 1: Executive Summary*. U.S. Environmental Protection Agency, Office of Research and Development. https://www.epa.gov/sites/default/files/2016-08/documents/1_executiveummary.pdf
21. Lamb, B.K., Edburg, S.L., Ferrara, T.W., Howard, T., Harrison, M.R., Kolb, C.E., Townsend-Small, A., Dyck, W., Possolo, A., & Whetstone, J.R. (2015). Direct Measurements show decreasing methane emissions from natural gas local distribution systems in the United States. *Environmental Science & Technology 49 (8)*, 5161-5169. https://doi.org/10.1021/es505116p.
22. Gas Technology Institute. (2013). *Improving Methane Emission Estimates for Natural Gas Distribution Companies: Phase II-PE Pipes*. Report No. 21044; OTD Project Number 7.10.c [White Paper].
23. Greenhouse Gas Reporting Rule: Revisions and Confidentiality Determinations for Petroleum and Natural Gas Systems, 89 F.R. 42062 (proposed May 14, 2024) (to be codified at 40 C.F.R. § 98). https://www.federalregister.gov/documents/2024/05/14/2024-08988/greenhouse-gas-reporting-rule-revisions-and-confidentiality-determinations-for-petroleum-and-natural#p-985
24. Sargent, M.R., Floerchinger, C., McKain, K., Budney, J., Gottlieb, E.W., Hutyra, L.R., Rudek, J., & Wofsy, S.C. (2021). Majority of US urban natural gas emissions unaccounted for in inventories. *Proc. Natl. Acad. Sci. U.S.A., 118 (44)*, e2105804118. https://doi.org/10.1073/pnas.2105804118.

25. IPCC. (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Calvo Buendia, E., Tanabe, K., Krankc, A., Baasansuren, J., Fukunda, M., Ngarize S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds). Published: IPCC, Switzerland.
26. EPA Office of Atmospheric Protection. (2024). Natural Gas and Petroleum Systems in the GHG Inventory: Additional Information on the 1990-2022 GHG Inventory (published April 2024). U.S. Environmental Protection Agency, Office of Atmospheric Protection. https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2022-ghg
27. Zimmerle, D.J., Williams, L.L., Vaughn, T.L., Quinn, C., Subramanian, R., Duggan, G.P., Wilson, B., Opsomer, J.D., Marchese, A. J., Martinez, D. M., & Robinson, A.L. (2015). Methane emissions from the natural gas transmission and storage system in the United States. *Environmental Science & Technology 49 (15)*, 9374-9383. https://doi.org/10.1021/acs.est.5b01669
28. Strahan, D. (2019, May 28). *Pelham Street, Newport, Rhode Island.* Lost New England. https://lostnewengland.com/2019/05/pelham-street-newport-rhode-island/
29. Kuffner, A. (2017, May 5). Danger below: R.I.'s gas-pipe network leaks like a sieve. *The Providence Journal*. https://www.providencejournal.com/story/news/environment/2017/05/05/ris-aging-gas-lines-leaks-still-problem-despite-repairs/10464166007/
30. Public Utilities Commission Docket No. 23-49-NG. The Narragansett Electric Co. d/b/a Rhode Island Energy FY 2025 Gas Infrastructure, Safety, and Reliability (ISR) Plan (filed 12/21/23). Responses to PUC Data Requests – Set 8. https://ripuc.ri.gov/Docket-23-49-NG

Recommended Citation (APA):

Rhode Island Department of Environmental Management. (2025). *Fugitive Greenhouse Gas Emissions from Natural Gas Systems*. [White Paper]. State of Rhode Island, Department of Environmental Management. https://dem.ri.gov/ghg-inventory.