New York State Oil and Gas Sector: Methane Emissions Inventory

Final Report | Report Number 23-28 | December 2023

NEW YORK STATE | NYSERDA

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Advance clean energy innovation and investments to combat climate change, improving the health, resiliency, and prosperity of New Yorkers and delivering benefits equitably to all.

New York State Oil and Gas Sector: Methane Emissions Inventory

Final Report

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Abstract

Methane (CH_4) is a greenhouse gas that is second only to carbon dioxide (CO_2) in its contribution to global climate change. Fossil fuel production and consumption—including the extraction and processing of natural gas as well as the distribution of natural gas to homes and businesses—is a significant source of anthropogenic CH_4 emissions. The goal of this project was to support CH_4 emission reduction efforts in New York State by improving the State's understanding of CH_4 emissions and CH_4 emission-accounting methodologies for its oil and natural gas sector, including upstream, midstream, and downstream sources within New York State. Informed by a literature review and guided by identified best practices, a 1990–2021 geospatially resolved, bottom-up CH_4 emissions inventory for the oil and natural gas sector was developed. In 2021, CH_4 emissions from oil and natural gas activity in the State totaled 176,051 metric tons (MT) CH_4, equivalent to 14,788,258 $MTCO_2e$ (AR5 GWP_{20}). Downstream emissions totaled 5.850 $MMTCO_2e$ in 2021 (39.6%), midstream emissions totaled 6.137 $MMTCO_2e$ (41.5%) and upstream sources emitted 2.800 $MMTCO_2e$ (18.9%). These results demonstrate that the State is largely a consumer of natural gas and, as such, the midstream and downstream source categories drive the majority of CH_4 emissions.

Keywords

Methane, oil, natural gas, emissions, inventory, greenhouse gas inventory, emission factors, methane inventory, downstream emissions, upstream emissions, midstream emissions, natural gas emissions, natural gas production, New York State methane inventory

Acknowledgments

The NYSERDA project team expresses its appreciation to the members of the Project Advisory Committee during the first iteration of the project and to the New York Department of Public Service and the New York State Department of Environmental Conservation during the second and third iterations of the project for their guidance, expertise, and time.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AR4	Fourth Assessment Report of the IPCC (2007)
AR5	Fifth Assessment Report of the IPCC (2014)
bbl	barrels. 1 oil barrel = 42 U.S. gallons
Bcf	billion cubic feet
BHFS	Bacharach Hi Flow® Sampler
BOE	barrels of oil equivalent
BOEM	Bureau of Ocean Energy Management
Bscf	billion standard cubic feet
Btu	British thermal unit
BU	bottom-up
CAP	criteria air pollutants
CBM	coal-bed methane
CenSARA	Central States Air Resource Agencies
cf	cubic feet
CFR	Code of Federal Regulation
CH_4	methane
CI	confidence interval
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CS	compressor station
D-J	Denver-Julesburg
EDF	Environmental Defense Fund
EF	emissions factor
EIA	Energy Information Administration
EPA	United States Environmental Protection Agency
ESOGIS	Empire State Organized Geologic Information System
EU	European Union
EU Inventory	Annual European Union Greenhouse Gas Inventory 1990-2016 and Inventory Report 2018
FLIGHT	Facility Level Information on GreenHouse gases Tool
g	gram
Gg	gigagram
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program

GRI	Gas Research Institute
GWP	global warming potential
GWP_{20}	global warming potential (20 year)
GWP_{100}	global warming potential (100 year)
H_2S	hydrogen sulfide
HAP	hazardous air pollutants
hp	horsepower
hr	hour
HVHF	high-volume hydraulic fracturing
IPCC	Intergovernmental Panel on Climate Change
ITRC	Interstate Technology and Regulatory Council
Kg	kilogram
lb	pound
LAUF	lost and unaccounted for
LNG	liquefied natural gas
Mcf	thousand cubic feet
Mg	megagram
MMBTU	million British thermal unit
MMcf	million cubic feet
MMT	million metric ton (1 MMT = 1 teragram)
M&R	metering and regulating
MT	metric ton
NAICS	North American Industry Classification System
N_2O	nitrous oxide
NG	natural gas
NEI	National Emissions Inventory
NSPS	New Source Performance Standards
NYS	New York State
DEC	New York State Department of Environmental Conservation
Oil and Gas Tool	Nonpoint Oil and Gas Emission Estimation Tool
PAC	Project Advisory Committee
PHMSA	Pipeline and Hazardous Materials Safety Administration
psi	pounds per square inch
psig	pounds per square inch gauge
SCC	Source Classification Code

scf	standard cubic foot
scfd	standard cubic feet per day
SCFM	standard cubic foot per minute (1 SCFM = 19.2 $gCH_4.min^{-1}$)
SEDS	State Energy Data System
SIT	State Inventory Tool
SNCR	selective non-catalytic reduction
TD	top-down
UNFCCC	United Nations Framework Convention on Climate Change
VOC	volatile organic compound

Summary

Methane (CH_4) is a greenhouse gas that is second only to carbon dioxide (CO_2) in its contribution to global climate change. Driven by human activity, CH_4 emissions are increasing in the atmosphere. CH_4 is particularly problematic because its impact on climate change is 84 times greater than CO_2 over a 20-year period, according to the Fifth Assessment Report (AR_5) of the Intergovernmental Panel on Climate Change (IPCC). Fossil fuel production and consumption, including the extraction and processing of natural gas and the distribution of natural gas to homes and businesses, is a significant source of anthropogenic CH_4 emissions.

In 2019, New York State passed the Climate Leadership and Community Protection Act (the Climate Act). The Climate Act is among the most ambitious climate laws in the world and requires the State to reduce economy-wide greenhouse gas emissions 40% by 2030 and no less than 85% by 2050 from 1990 levels. The goal of this project is to support CH_4 emission reduction efforts in New York State, as well as achievement of the Climate Act goals, by improving the State's understanding of CH_4 emissions and CH_4 emission-accounting methodologies for the oil and natural gas sector. The use of improved accounting methodologies to develop an activity-driven, site-level, CH_4 emissions inventory for upstream, midstream, and downstream sources is needed to inform mitigation strategies and measure progress on fugitive CH_4 emissions reductions from the oil and natural gas sector as the State moves toward its ambitious climate goals.

The inventory developed under this project occurred in three iterations. The project's first iteration incorporated findings from empirical research and utilized the most accurate, current, and inventory-appropriate available data sources at the time. The application of state-of-the-art practices and emissions factors (EFs) represented a significant methodological advancement over other available tools, since those tools are often based on out-of-date EFs that do not reflect the modern oil and natural gas sector. By applying established best practices based on a thorough review of the literature and expert consultation, the inventory established a rigorous and robust CH_4 emissions baseline in New York State. The development of this inventory focused on the following best practices: (1) the use of appropriately scaled activity data, (2) inclusion of state-of-the-science EFs, (3) geospatial resolution of activities and emissions, and (4) application and reporting of uncertainty factors, including high-emitting sources. The original iteration of this project sought to update the New York State Greenhouse Gas Inventory 1990–2015 and implement these best practices to improve and develop an activity-driven, geospatially-resolved, CH_4 emissions inventory for the oil and natural gas sector. To ensure project rigor, a six-member Project Advisory Committee (PAC) comprised of experts with knowledge on air pollutant emissions from the oil and natural gas sector was established to provide technical oversight and peer review throughout the duration of the first iteration of this project. The original report for the initial iteration was published in 2019 and included data years 1990–2017.

Following the best practices established during the first iteration of the project, the second iteration focused on updating activity data and emissions factors to the latest found in the literature and extending the latest year to 2020. During the second iteration, additional source categories were also added to the inventory to begin addressing identified gaps in the inventory. In addition, the Climate Act required the State to report emissions in CO_2 equivalents (CO_2e) using the most recent IPCC Assessment Report (AR5) 20-year global warming potential (20-year GWP, GWP_{20}) rather than AR4 100-year global warming potential (GWP_{100}) values, which are typically used in national and state inventories and was used in the first iteration of the project. Using GWP_{20} further emphasizes the contribution of methane to global climate change.

The inventory is now updated on a yearly basis, with the current inventory estimating emissions through 2021. The current report represents the most recent inventory, where updates were made to the prior inventory to bring the data through the year 2021 and make improvements to emissions factors and additional sources based on more recent data and scientific studies. These inventory results provide important resources for supporting rulemaking and regulations to reduce CH_4 emissions from the oil and natural gas sector. This inventory lays the foundation for a geospatially refined inventory that can capture the impacts of future mitigation strategies for CH_4 emissions from the oil and natural gas sector as well as the impacts of current regulations, such as EPA’s proposed changes to the 2016 New Source Performance Standards for the oil and gas industry or EPA’s 2022 Inflation Reduction Act. In addition, the inventory provides New York State with the flexibility to revise the current inventory, or generate future inventories, by updating activity data and EFs as improved data become available and as future advancements in the industry lead to technological changes.

Table S-1 below compares emissions from key inventory years from the first New York State Greenhouse Gas Inventory (1990–2015) to the first iteration of the New York State Oil and Gas Sector Methane Emissions Inventory (1990–2017), the second iteration of the New York State Oil and Gas Sector Methane Emissions Inventory (1990–2020), and the most recent iteration (1990–2021). In the first iteration of the project, CH_4 emissions in 2015 totaled 112,870 metric tons (MT) CH_4 or approximately

2.82 million metric tons (MMT) CO_2e (AR4 GWP_{100}). Results of the first iteration estimated CH_4 emissions to be 27% higher than previous estimates of CH_4 emissions from natural gas systems (2.22 MMT CO_2e, AR4, GWP_{100} in 2015), based on prior inventories developed by the State and using 2015 as the most recent common year. In the first iteration of the NYS Oil and Gas Methane Emissions Inventory 2017 emissions totaled 2.66 $MMTCO_2e$ (AR4 GWP_{100}), or 8.951 $MMTCO_2e$ (AR5 GWP_{20}). The second iteration of the inventory estimates emissions to total 14.7 $MMTCO_2e$ (AR5 GWP_{20}) in 2017. Thus, the improvements made to the inventory between the first and second iteration resulted in an emissions increase of 64%. The increase is due to the addition of beyond-the-meter sources and updates to distribution emission factors and conventional production emission factors. The second iteration of the inventory estimates emissions to be approximately 113.5% higher than estimates from the original, 2015 inventory, when estimates from the 2015 inventory are converted to AR5 GWP_{20} and using 2015 as the most recent common year.

Table S-1. Comparison of Emissions Across Key Inventory Years with AR4 and AR5 GWP_{100} and GWP_{20} Values Applied from the Three Inventories

Inventory	AR4 GWP_{100}	AR4 GWP_{20}	AR5 GWP_{100}	AR5 GWP_{20}
1990				
New York State Greenhouse Gas Inventory, 1990–2015	2.8	8.06	3.14	9.41
New York State Oil and Gas Methane Emissions Inventory, 1990–2017	2.74	7.88	3.07	9.21
New York State Oil and Gas Methane Emissions Inventory, 1990–2020	5.17	14.89	5.80	17.40
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	5.42	15.60	6.07	18.20
2005				
New York State Greenhouse Gas Inventory, 1990–2015	3.5	10.07	3.93	11.76
New York State Oil and Gas Methane Emissions Inventory, 1990–2017	3.52	10.12	3.95	11.83
New York State Oil and Gas Methane Emissions Inventory, 1990–2020	6.15	17.72	6.93	20.73
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	6.42	18.48	7.19	21.56
2015				
New York State Greenhouse Gas Inventory, 1990–2015	2.22	6.39	2.49	7.46
New York State Oil and Gas Methane Emissions Inventory, 1990– 2017	2.82	8.12	3.16	9.48
New York State Oil and Gas Methane Emissions Inventory, 1990– 2020	4.74	13.65	5.31	15.92
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	4.98	14.34	5.58	16.73

CH_4 emissions from oil and natural gas activity in New York State in 2021 totaled 176,051 $MTCH_4$, equivalent to 14.8 $MMTCO_2e$ (AR5 GWP_{20}). Figure S-1 shows CH_4 emissions by source category broken out by upstream, midstream, and downstream source categories using AR5 GWP_{20} units. Downstream emissions totaled 5.850 $MMTCO_2e$ in 2021, accounting for 39.6% of total CH_4 emissions. Cast iron steel mains are the largest downstream single-source category, followed by unprotected steel mains and services. Midstream emissions totaled 6.137 $MMTCO_2e$, accounting for 41.5% of emissions, with compressors (storage and transmission) comprising the largest source categories in the inventory. In fact, storage and transmission compressor stations are two of the largest single-source categories identified in New York State. Upstream sources, dominated by conventional gas wells, emitted 2.800 $MMTCO_2e$, accounting for 18.9% of total CH_4 emissions. These results reflect the fact that the State is largely a consumer of natural gas and, as such, the midstream and downstream source categories drive the majority of CH_4 emissions.

Figure S-1. CH_4 Emissions by Source Category and Grouped by Upstream, Midstream, and Downstream Stages in New York State in 2021

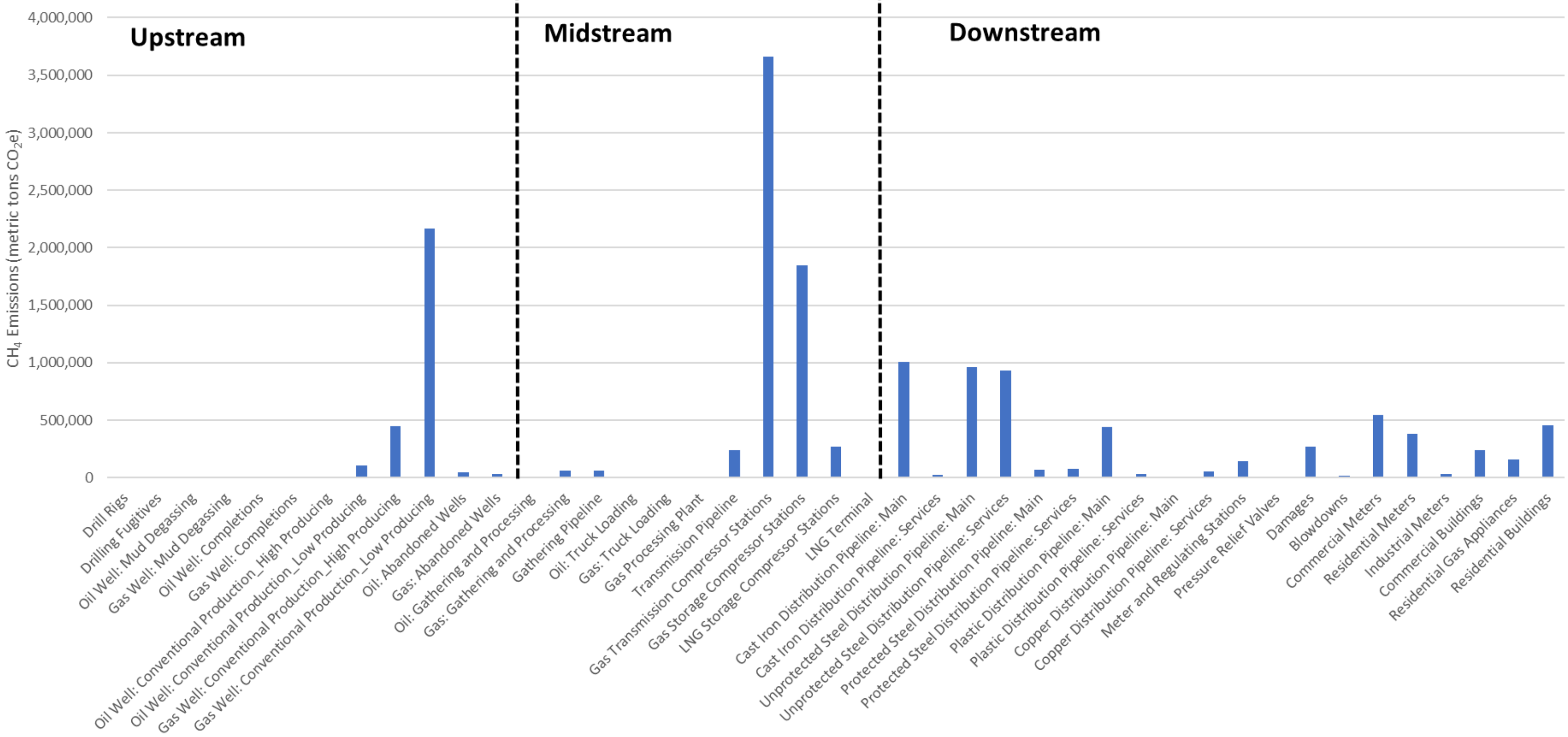


Figure S-2 shows the distribution of emissions by county. The counties with the largest emissions correspond to the high oil and natural gas exploration and production areas in Western New York and to areas of high population, gas services, and consumption around New York City and Long Island. Downstream emissions in counties that correspond to New York City and Long Island (New York, Kings, Bronx, Richmond, Queens, Nassau, and Suffolk) total 4.44 MMTCO$_2$e, which is approximately 75.8% of total downstream emissions. As shown in Figure S-2, Erie County had the highest total CH$_4$ emissions in 2021, accounting for 10.5% of statewide CH$_4$ emissions from the oil and natural gas sector, followed by Chautauqua (10.1%). Erie County had the second-highest conventional gas production from low producing wells in New York State, as well as the largest miles of transmission pipeline (378 miles) and second-highest number of compressor stations (five gas transmission compressor stations and six gas storage compressor stations), resulting in high-midstream emissions. Chautauqua County ranked highest in gas gathering and processing and in low producing conventional gas production resulting in high upstream and midstream emissions. The top five counties (Erie, Chautauqua, Kings, Steuben, and Queens) accounted for 40% of statewide CH$_4$ emissions in 2021.

Figure S-2. Map of CH$_4$ Emissions by County in New York State in 2021 (AR5 GWP$_{20}$)

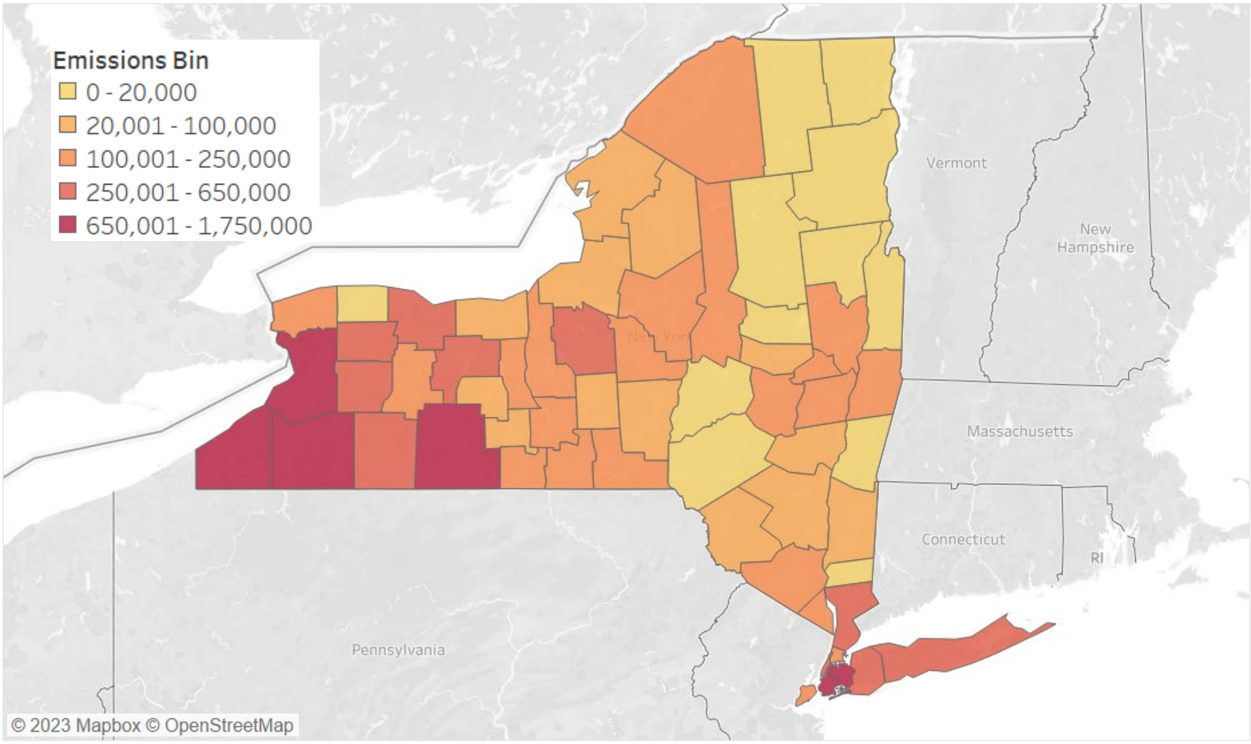
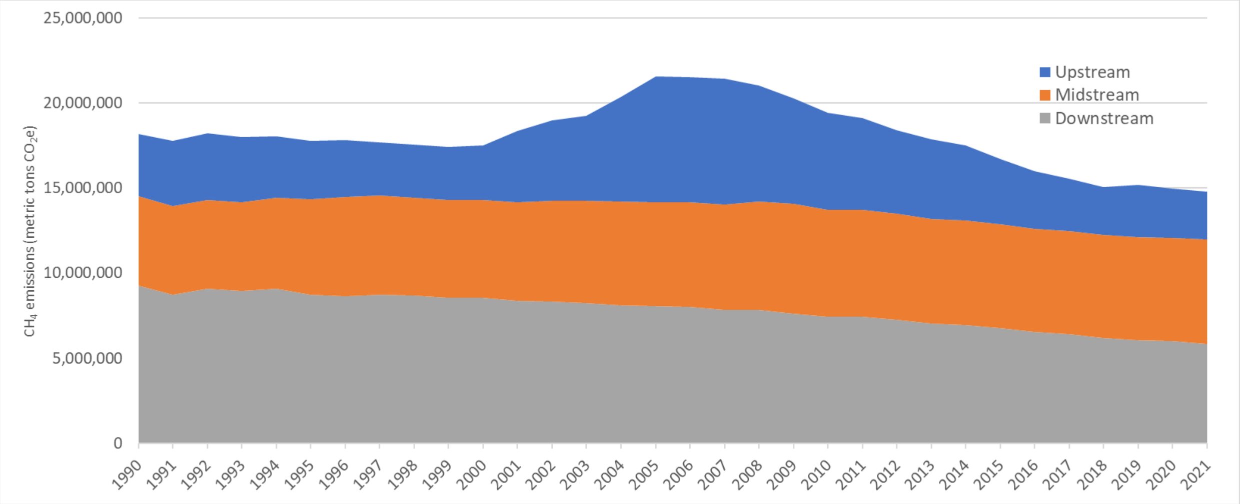


Figure S-3 shows that total CH_4 emissions in New York State from 1990–2021 followed a generally increasing trend from 1990 until peaking at 21.564 $MMTCO_2e$ in 2005. Since 2005 CH_4 emissions have decreased each year with the exception of a small increase in 2019. Total CH_4 emissions decreased 31.4% since their peak in 2005.

Figure S-3. Total CH_4 Emissions in New York State from 1990–2021 (AR5 GWP_{20})

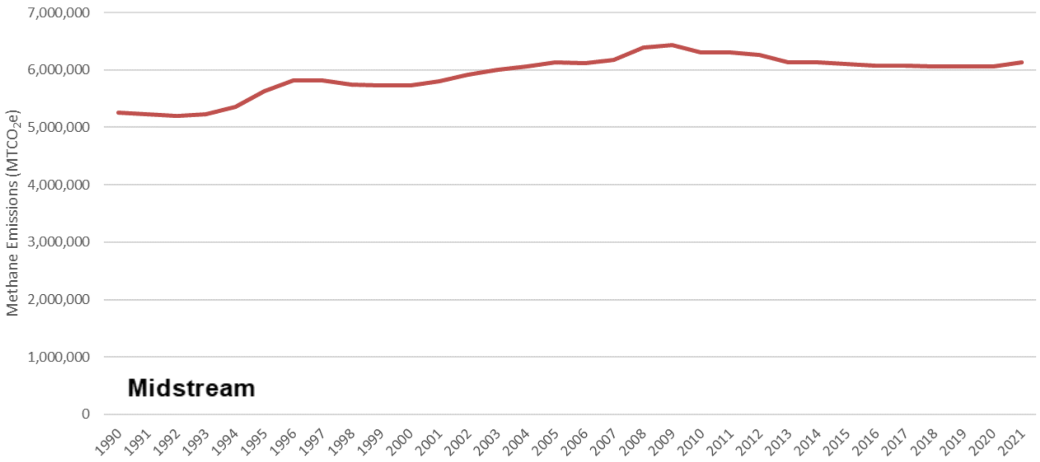


Upstream CH_4 emissions (Figure S-4), though smaller in magnitude than midstream and downstream emissions, have shown greater variation over time, more closely mirroring the cyclical nature of oil and gas exploration and well completions in the State. Upstream CH_4 emissions peaked at 7.416 $MMTCO_2e$ in 2007, corresponding with the observed peak in natural gas prices and production and well completions. Since 2007, well completions have fallen to zero and natural gas production is around one-fifth of the peak production, resulting in an overall decline in emissions associated with upstream source categories. Overall upstream emissions decreased 24% from 1990–2021, and by 62.2% from 2007–2021.

Figure S-4. Upstream CH_4 Emissions in New York State (AR5 GWP_{20})

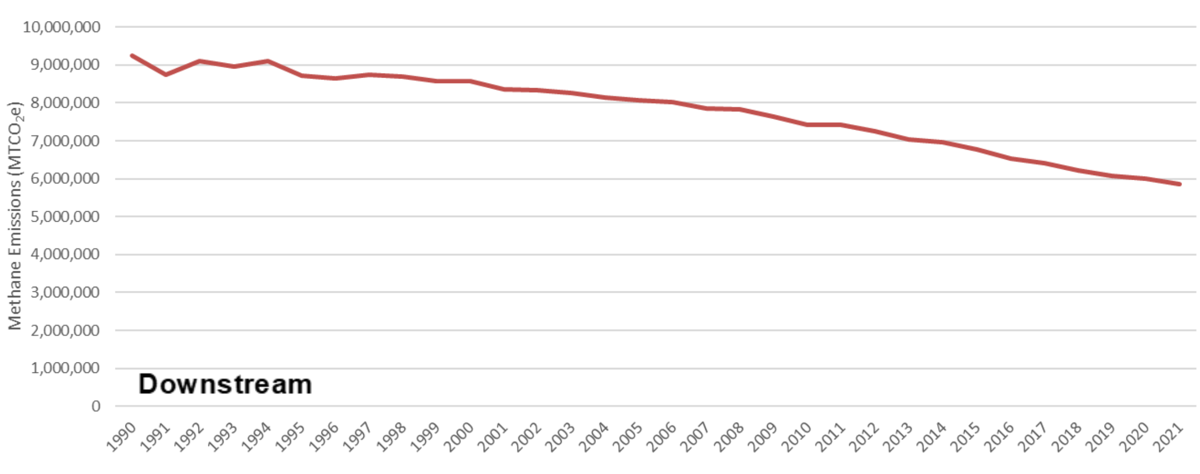
Midstream CH_4 emissions (Figure S-5) increased from 1990–2021 by 16.8%. Midstream emissions are largely a function of transmission and storage compressor stations and transmission pipelines. New York State Department of Environmental Conservation (DEC) data, used to verify compressor station counts in this inventory, show increasing compressor counts and transmission pipeline miles, resulting in increasing midstream CH_4 emissions. Although natural gas production in New York State has declined since 2006, natural gas consumption in the State has risen by 22% from 1,080 Bcf in 2005 to 1,317 Bcf in 2021. Correspondingly, midstream emissions peaked in 2009 from the addition of transmission compressor stations and transmission pipelines but have declined by 4.6% since then as a result of declining natural gas production and subsequent natural gas gathering in the State.

Figure S-5. Midstream CH_4 Emissions in New York State (AR5 GWP_{20})



Downstream CH_4 emissions (Figure S-6) decreased by 36.8% from 1990–2021. The two largest source categories in downstream emissions, cast-iron and unprotected steel distribution main pipelines, have both decreased since 1990, since they have largely been replaced with plastic distribution mains. Plastic mains have much lower leak rates and therefore a lower emissions factor, resulting in the downward trend observed in Figure S-6. Though increasing consumption in New York State has driven increases in the number of residential services and meters, any increase in emissions from these components is outweighed by the transition from cast-iron and unprotected steel distribution lines to plastic.

Figure S-6. Downstream CH_4 Emissions in New York State (AR5 GWP_{20})



The identified activity patterns correspond to national trends in CH_4 emissions. To validate this emission inventory, comparisons were made with EPA's nationwide inventory and with adjacent state inventories. Comparison to the national inventory shows New York State CH_4 emissions to be equivalent to 6.39% of the total national oil and natural gas inventory. Comparison with inventories from adjacent states shows New York State oil and gas emissions to be approximately one-third of emissions from the same source categories in Pennsylvania, which has much higher upstream production and similar downstream consumption.

1 Introduction

In 2019, New York State passed the Climate Leadership and Community Protection Act (the Climate Act). The Climate Act is among the most ambitious climate laws in the world and requires the State to reduce economy-wide greenhouse gas (GHG) emissions 40% by 2030 and no less than 85% by 2050 from 1990 levels. The goal of this project is to support CH_4 emission reduction efforts in New York State (NYS), and achievement of the Climate Act goals, by improving the State's understanding of CH_4 emissions and CH_4 emissions-accounting methodologies for the oil and natural gas sector. The use of improved accounting methodologies to develop an activity-driven, site-level, CH_4 emissions inventory for upstream, midstream, and downstream sources is needed to inform mitigation strategies and measure progress on fugitive CH_4 emission reductions from the oil and natural gas sector as the State moves toward its ambitious climate goals. Consequently, the inventory developed under this project incorporates findings from the most current empirical research and utilizes the most accurate, current, and inventory-appropriate available data sources to develop an activity-driven, site-level, CH_4 emissions inventory.

The inventory developed under this project occurred in three iterations. The project's original iteration sought to update the New York State Greenhouse Gas (NYS GHG) Inventory 1990–2015 and implement the following best practices to improve and develop an activity-driven, geospatially-resolved, CH_4 emissions inventory for the oil and natural gas sector: (1) the use of appropriately scaled activity data, (2) inclusion of state-of-the-science EFs, (3) geospatial resolution of activities and emissions, and (4) application and reporting of uncertainty factors, including high-emitting sources. To ensure project rigor, a six-member Project Advisory Committee (PAC) comprised of experts with knowledge on air pollutant emissions from the oil and natural gas sector was established to provide technical oversight and peer review throughout the duration of the first iteration of this project. The report for the initial iteration was published in 2019 and included data years 1990–2017. The report for the second iteration was published in 2022 and included data years 1990–2020. The current report represents the third iteration of this project, where updates are made to the 2020 inventory to bring the data up to date through the current inventory year (2021), make improvements to emissions factors, and incorporate additional sources.

Specific objectives of first iteration of this project, completed in 2019, included (1) assessing the State's previous oil and natural gas sector CH_4 emissions inventory (NYSERDA and DEC 2018), (2) performing a literature review of CH_4 emission-accounting methodologies and associated analyses and studies, (3) developing an improved CH_4 emission-accounting methodology, and (4) implementing the methodology to create an improved CH_4 emissions inventory for the oil and natural gas sector in the State.

For Iteration 2, further updates were made after the initial assessment and development of the NYS oil and gas methane inventory. For more details on the improvements made, please see Appendix A. Additional objectives during the second and third iterations of the project included (1) assessing NYS's oil and natural gas sector CH_4 emissions inventory for areas of improvement, (2) performing a literature review of latest data on fugitive oil and gas methane emissions in NYS, and (3) incorporating the latest data to create an updated CH_4 emissions inventory for the oil and natural gas sector in NYS.

2 Characterization of New York State's Oil and Natural Gas Sector

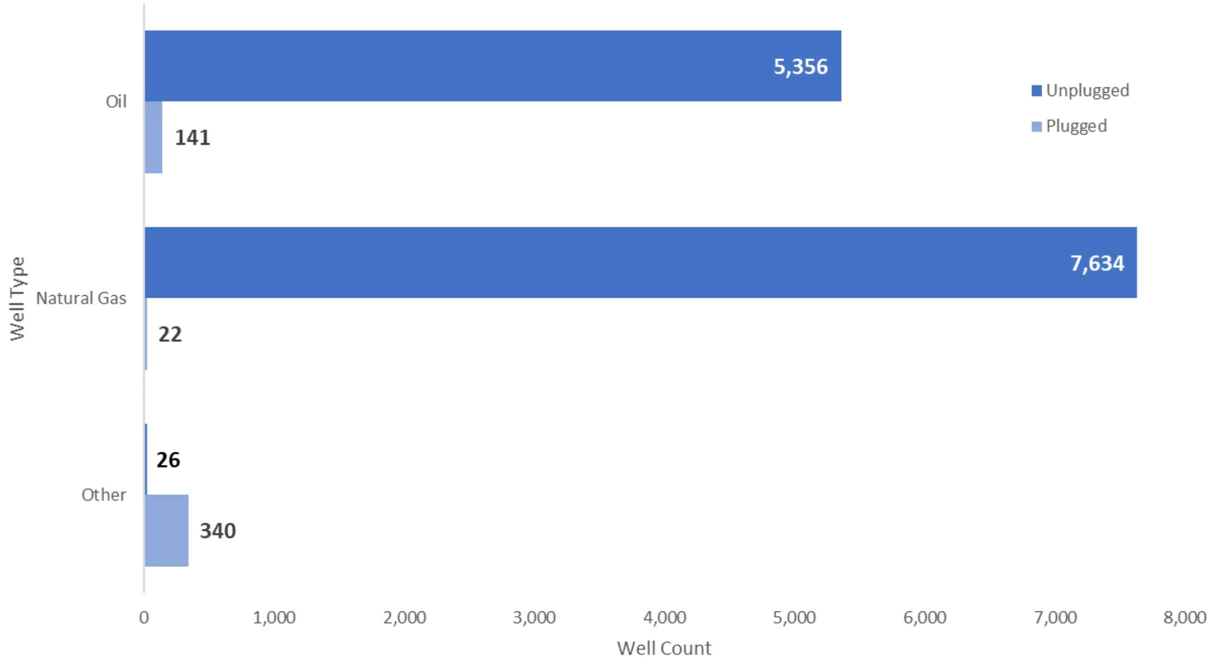
The following section begins with a characterization of oil and gas wells, then moves into a discussion of oil and gas production and concludes with an overview of associated oil and gas infrastructure.

2.1 Oil and Gas Wells in New York State

In 2021, New York State had a total of 13, 519 oil and gas wells. New York State had 7,634 unplugged natural gas wells and 22 unplugged gas wells (DEC 2022). In addition, the State had 5,356 unplugged oil wells, 141 plugged oil wells (Figure 1), 26 unplugged wells of other types, and 340 plugged wells of other types. (Plugged wells are wells that are no longer in use and the borehole has been plugged with cement or another impermeable substance to isolate and prevent the underlying hydrocarbon formation from contaminating the environment.)

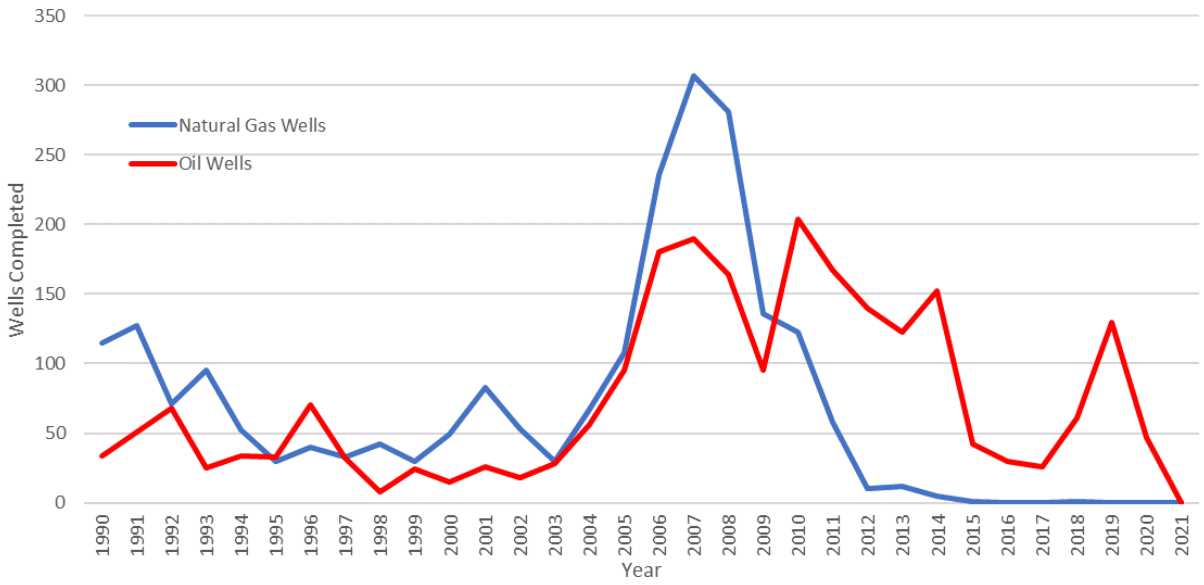
Figure 1. Number of Open Hole and Plugged Wells in New York State in 2021

Source: New York State Department of Environmental Conservation (DEC) downloadable well data.



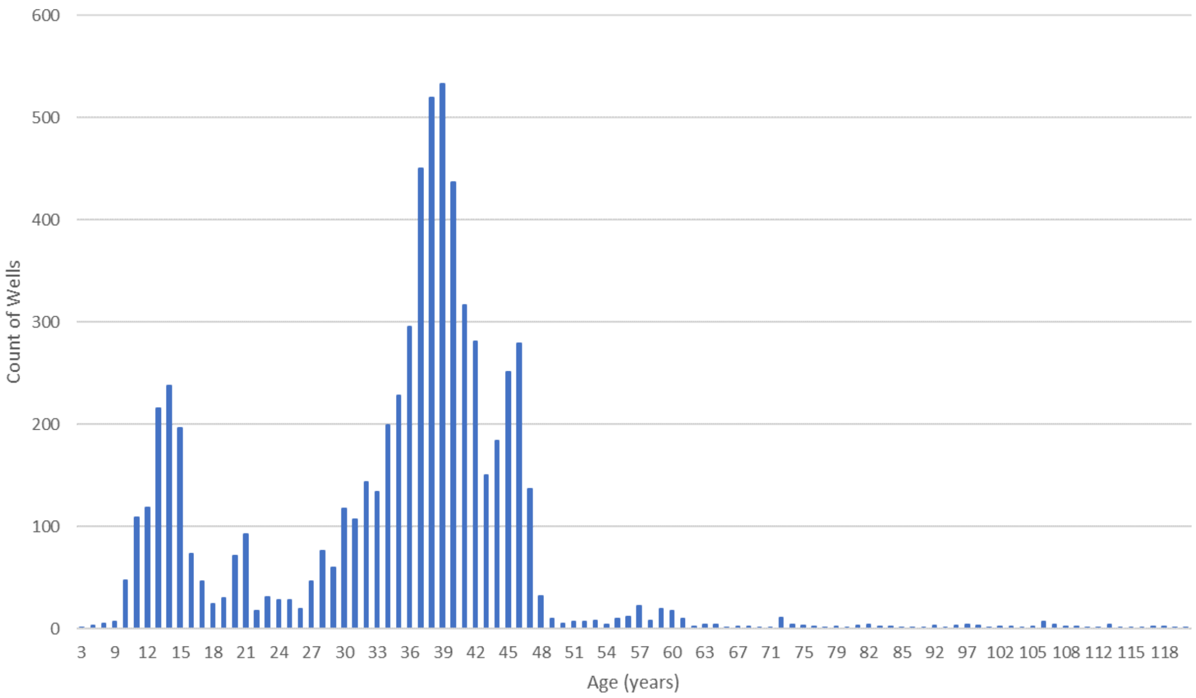
Gas well development in New York State increased significantly in the 1970s, reaching a peak in 1982 when 611 wells were drilled and put into production, followed by a decline in activity until the mid-2000s. There was a secondary spike in installations from 2006–2008 (Figure 2). After 2008, natural gas well completions fell to fewer than 10 per year. High-volume hydraulic fracturing (HVHF), or fracking, was banned in the State in 2014. Oil well completions also followed a cyclical pattern, with increased activity from 1973–1985 and again from 2006–2014. Oil well completion activity follows oil and natural gas price patterns, with higher activity during periods of high-fuel prices, and lower activity during periods of low-fuel prices. The deregulation of oil and natural gas markets also played a role in increasing production and consumption of natural gas while reducing prices.

Figure 2. Number of Oil and Natural Gas Wells Completed per Year in New York State



The age distribution of natural gas wells producing in New York State in 2021 (Figure 3) followed a similar bimodal pattern to that seen in Figure 2. Well count data for 2021 show a primary peak of wells aged around 12 and 13 years old, and a secondary peak of wells aged between 37 and 38 years old. Comparing Figure 2 and Figure 3, age and completions follow a similar bimodal pattern, with peaks in age corresponding to peaks in completions, indicating that older wells can remain in production for a long time. Well age data showed that, although there were far more completions in the 1970s and 1980s, 14.7% of currently operational wells were completed in the last 15 years, with 88.4% of wells under 45 years old.

Figure 3. Age Distribution of Gas Wells Producing in 2021



2.2 New York State Oil and Natural Gas Production

Natural gas production far outweighs oil production in New York State, as shown in Figure 4. Natural gas production peaked at 55.34 billion cubic feet (Bcf) or 9.78 million barrels of oil equivalent (BOE) in 2006 (1 BOE = 5.65853 thousand cubic feet, Mcf), while oil production peaked at 386,192 barrels (bbl) in 2008. Natural gas production declined from 55.34 Bcf in 2006 to 9.72 Bcf, or 1.72 million BOE in 2021. Oil production has also declined in the State from the 2008 peak to 260,254 bbl in 2021. Since there are no in-state oil refineries, all the oil produced is refined out of State, primarily in Pennsylvania (DEC 2006).

As shown in Figure 5, 600 out of 9,220 wells (6.51%) accounted for 50% of natural gas production in New York State in 2021, 22.6% of the wells accounted for 75% of natural gas production, and almost all (99%) of natural gas production came from 6,707 (73%) of wells. These data demonstrate that a comparatively small number of wells produce the majority of natural gas, and that production is not evenly distributed across those wells. Oil wells also showed a similarly skewed distribution, with 270 out of 3,391 (8%) wells accounting for 50% of production, 754 (22.2%) wells accounting for 75% of production, and 2,389 (70.4%) wells accounting for 99% of production in 2021.

Figure 4. Oil and Natural Gas Production in New York State

The axis scale for natural gas production (left) is 10x larger than the axis scale for oil production (right).

1 BOE = 5.65853 Mcf natural gas[1]

Source: (DEC 2022)

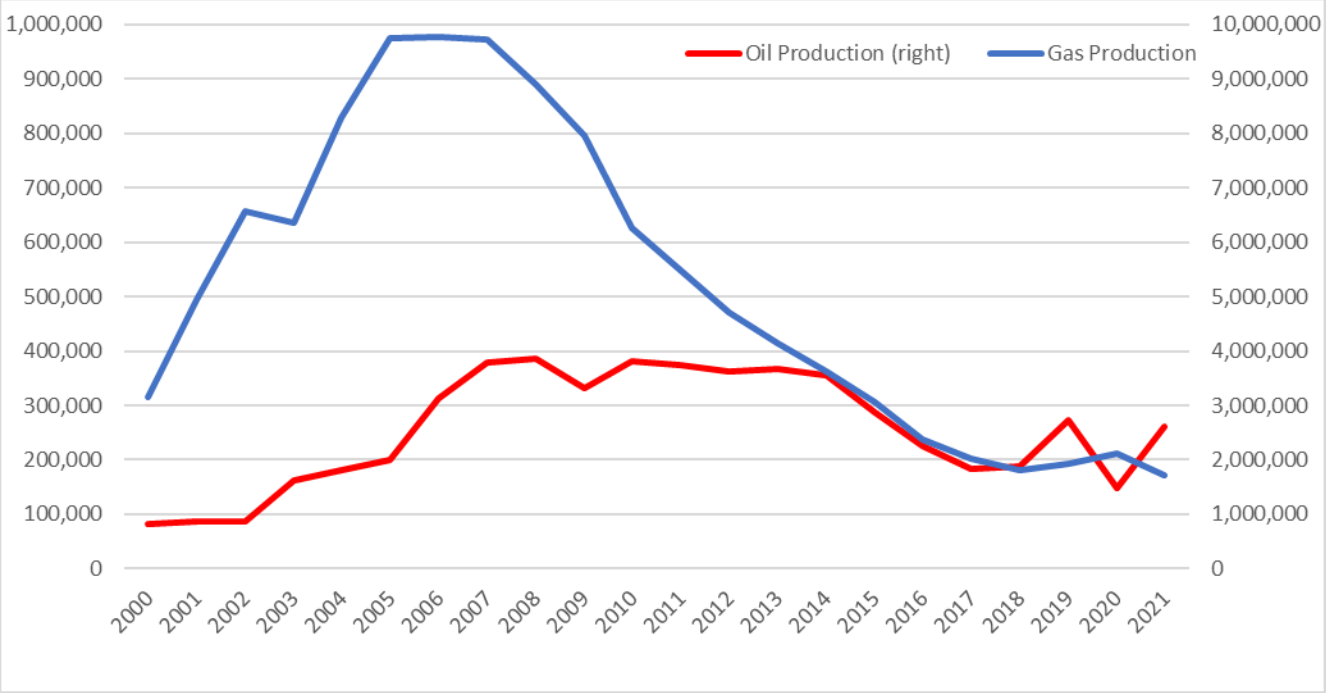
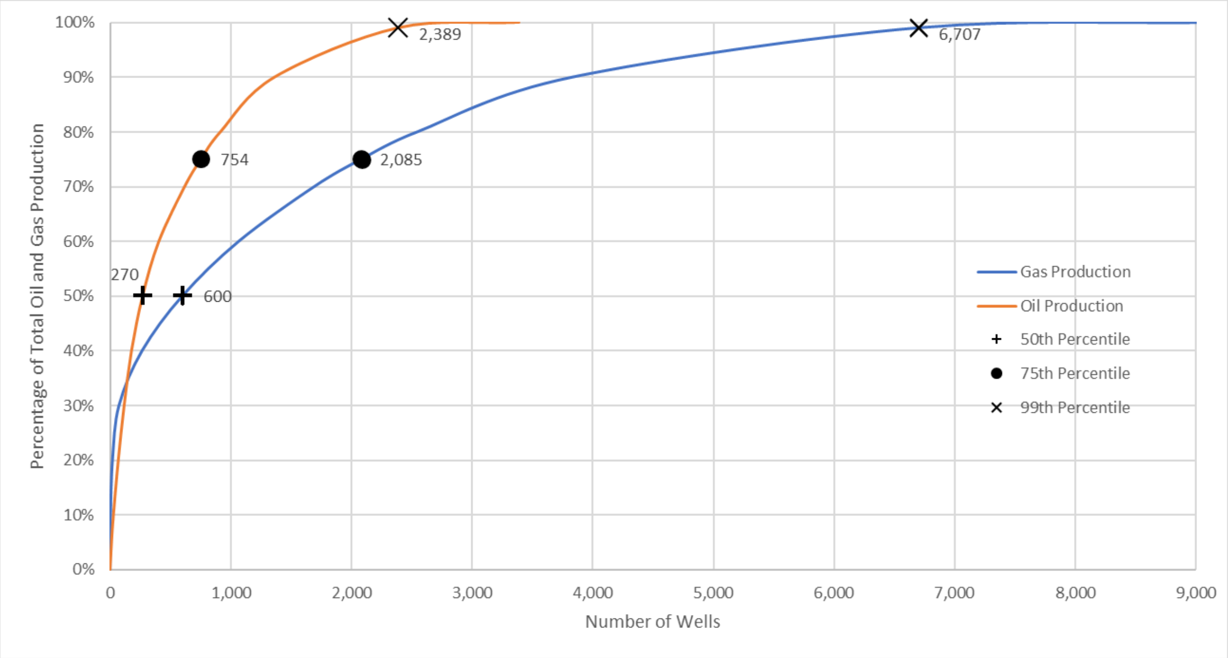


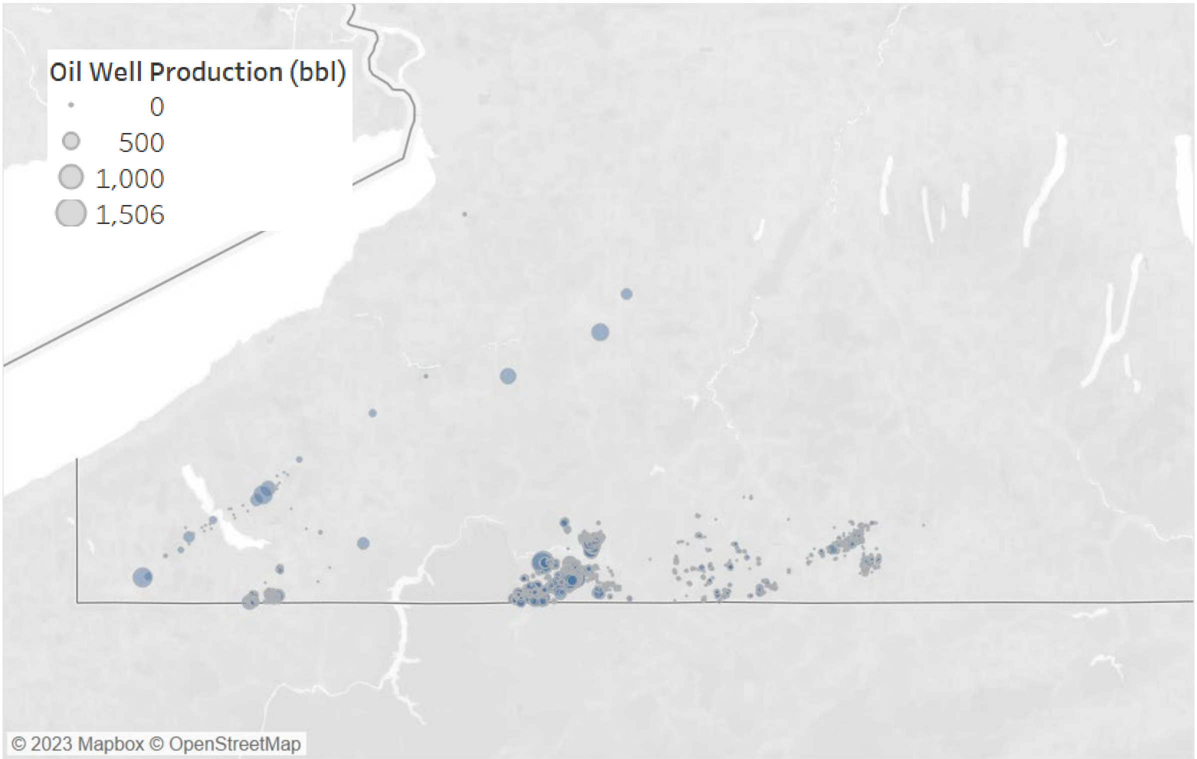
Figure 5. Relationship between Percent of Total Cumulative Oil and Natural Gas Production in 2021 and the Number of Wells in New York State



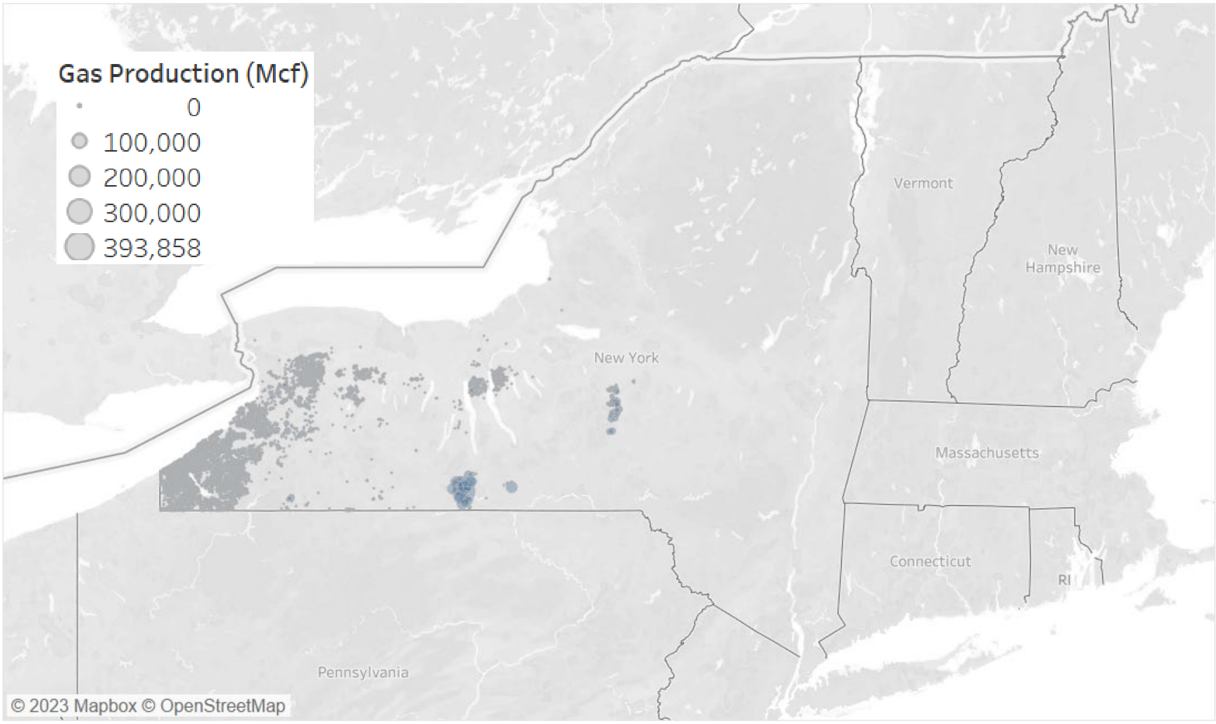
As shown in , oil and natural gas production occur largely in Western New York, west of the line delineating the eastern boundary of Broome, Chenango, Madison, Oneida, and Lewis counties. Oil production is concentrated in the far west of New York State, in Allegany, Cattaraugus, Chautauqua, Erie, and Steuben counties.

Figure 6. Oil and Natural Gas Well Locations and Production in New York State in 2021

(Oil): *There are no oil producing wells located outside of western New York.



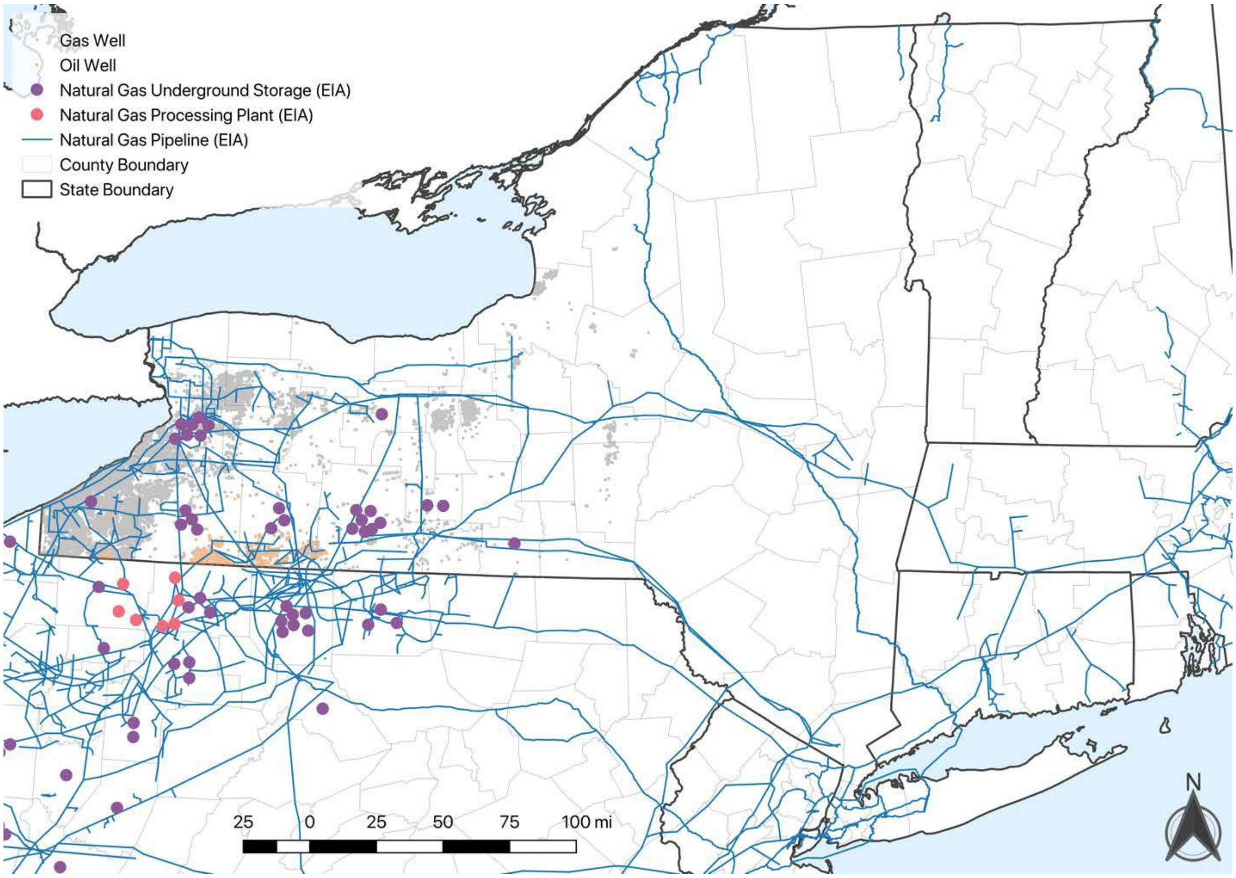
(Natural Gas)



2.3 New York State Oil and Natural Gas Infrastructure

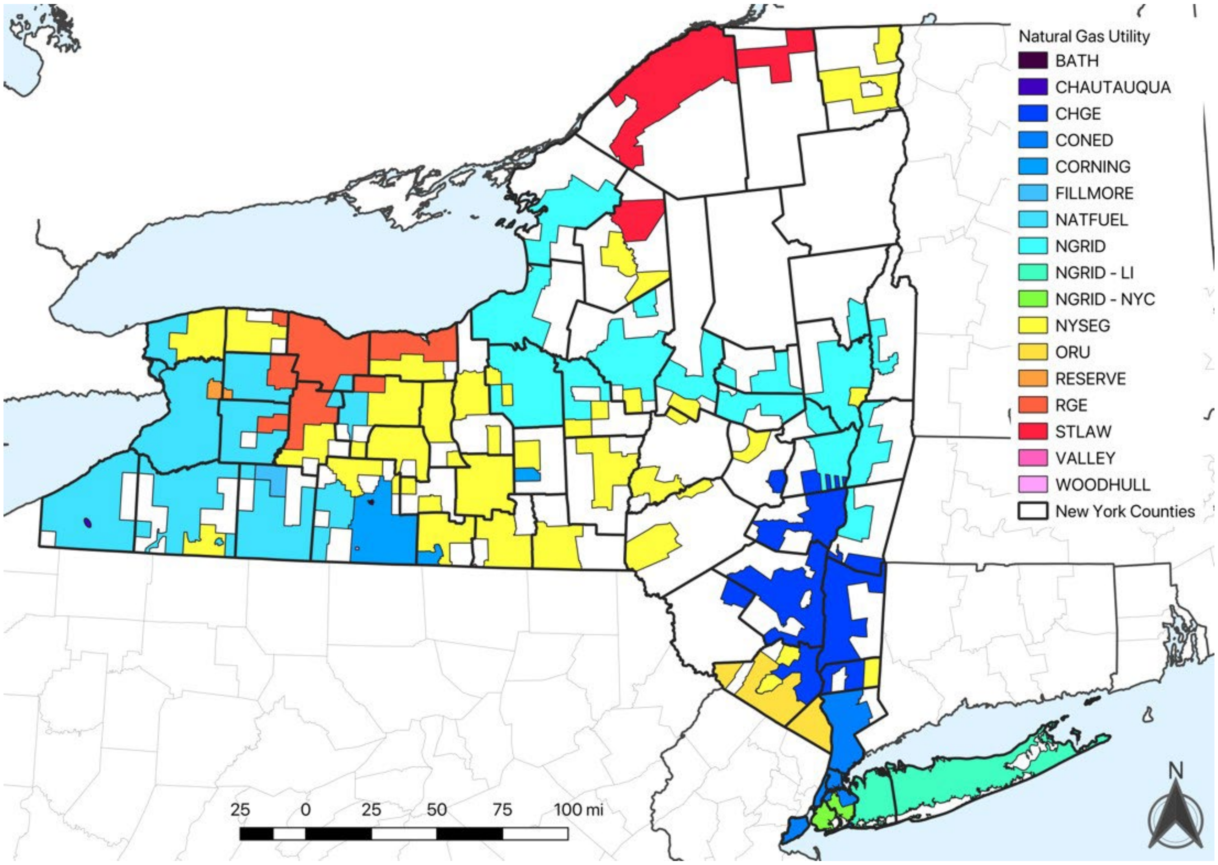
As shown in Figure 7, oil and natural gas activities are concentrated in the western portion of the State. Western NY has the greatest density of wells and underground natural gas storage facilities. Storage fields are located in former solution salt caverns and depleted reservoirs. The Energy Information Administration (EIA) data lists no natural gas processing plants in New York State, with the closest processing plants located in northwestern Pennsylvania. The greatest density of interstate and intrastate natural gas transmission pipelines, as identified by EIA, is in Western New York near the production and storage wells for removal and delivery. Transmission pipelines are well-connected to Pennsylvania and have linkages to Canada in the west and north. Two main pipeline trunks extend east-west across the State, with one along the southern Pennsylvania border, connecting to pipelines in the New York City Metropolitan Area and the other connecting farther north to pipelines in the Albany and Buffalo regions.

Figure 7. Locations of Oil and Natural Gas Wells, Natural Gas Processing Plants, Natural Gas Pipelines, Natural Gas Underground Storage, and Shale Plays in New York State and Surrounding States



New York State has 17 natural gas utility service territories (Figure 8). These service territories cover around 94% of the households identified by the United States (U.S.) Census Bureau. According to the Census, 54% of households inside natural gas utility service areas use natural gas as their primary home heating source. In addition, EIA data[2] show 430,368 commercial and industrial end users of natural gas in the State. Based on census data, which show 537,369 registered businesses in 2020 with 96.9% of businesses within natural gas utility service areas, 80.1% of businesses inside natural gas utility service areas use natural gas.

Figure 8. New York State Gas Utility Service Territories



3 Methane Emissions Inventory Development

3.1 Methane Emissions Literature Review

3.1.1 Overview

The following section provides the results of a literature review, primarily conducted during Iteration 1 of the project, aimed at uncovering best practices for CH_4 inventory development and inputs to inform improvements in the State's inventory models in the future.

As part of Iteration 1, a literature review was conducted that included peer-reviewed articles, reports, and tools describing state-of-the-art CH_4 inventory development in the United States and internationally, with a focus on emissions in the oil and natural gas sector. While over 100 documents on oil and natural gas emissions were carefully reviewed, specific attention was paid to three sources of information: (1) EPA's GHGRP (Greenhouse Gas Reporting Program) Subpart W, (2) EPA's FLIGHT (Facility Level Information on GreenHouse gases Tool), and (3) the Environmental Defense Fund's (EDF) 16 Study Series. The European Union's (EU) most recent inventory report (European Environment Agency 2018) was also reviewed to explore differences between international and U.S.-centric inventory methodologies.

The literature review highlights the rapid advancement of state-of-the-art CH_4 inventory development. In just the last decade, new data now allow for more geographic-specific inventory development and greater certainty of emissions, ranging from routine leaks to episodic releases. The literature has also advanced on identifying the role of high-emitting sources, which have previously been ignored in conventional CH_4 inventories, but which can play an important part in a region's overall emission levels. The literature review was used to inform the first iteration of the New York State Oil and Gas Methane Emissions Inventory (NYSERDA 2019).

Section 3.1.2 presents key terminology so that readers may better understand subsequent sections. Section 3.1.3 reviews existing methane inventory approaches for oil and natural gas systems. Section 3.1.4 discusses key findings on emission factors, spatial variability, and high-emitting sources. Section 3.2 provides a review of the methods and data used to develop this inventory including a summary of best practices, assessment of emissions factor confidence, an activity data summary, and a review of emission factor development for the upstream stages, midstream stages, and downstream stages.

3.1.2 Key Terminology

3.1.2.1 Oil and Natural Gas Supply Chain

The U.S. oil and natural gas supply chain can be broken into nine main segments. For oil development, CH_4 emissions occur across the following four stages: (1) exploration, (2) production, (3) gathering and boosting, and (4) transmission. For natural gas development, CH_4 emissions occur across the following nine stages: (1) exploration, (2) production, (3) gathering and boosting, (4) processing, (5) transmission, (6) underground storage, (7) LNG import and export terminals, (8) LNG storage, and (9) distribution, as shown in Figure 9 (Howarth 2014; Harrison et al. 1997a). These stages are divided into three major groups: (1) upstream, (2) midstream, and (3) downstream stages.

3.1.2.2 Upstream Stages

- **Exploration** includes well drilling, testing, and completions. The predominant sources of emissions from exploration are well completions and testing.
- **Production** involves taking crude oil or raw natural gas from underground formations, whether using conventional drilling or unconventional drilling techniques. Sources of emissions during the oil production stage typically include leaks, pneumatic devises, storage tanks, and flaring of associated gases. Sources of emissions during the natural gas production stage depend on the technologies employed for gas extraction, but typically include leaks, pneumatic controllers, unloading liquids from wells, storage tanks, dehydrators, and compressors. Many wells co-produce oil and natural gas; therefore, the distinction between oil production and gas production is not always clear.
- **Gathering and boosting** stations receive natural gas from production sites/wells and via gathering pipelines, and then transfer the gas to transmission pipelines and/or processing facilities and distribution systems. Compression, dehydration, and sweetening (removal of foul-smelling sulfur containing compounds) occur in this segment. Sources of emissions in this segment include gathering stations, pneumatic controllers, natural gas engines, gathering pipelines, liquids unloading, and flaring.

3.1.2.3 Midstream Stages

- **Natural gas processing** includes the process of removing impurities and other hydrocarbons, including liquids, from raw natural gas, resulting in pipeline grade natural gas. Emissions from the processing stage originate from reciprocating and centrifugal compressors, blowdowns, venting, and leaks.

- The **transmission and compression** stage is the transfer of natural gas from gathering lines and processing plants to the city gate or to high-volume industrial users through main transmission lines. Compressor stations located along the pipelines maintain high pressure and move the gas throughout the system. Sources of emissions in this segment include compressor stations, venting from pneumatic controllers, uncombusted engine exhaust, unburned and pipeline venting.
- **Underground storage** involves injecting natural gas into underground formations during periods of low demand; and the natural gas is withdrawn, processed, and redistributed during periods of high demand. Compressors and dehydrators are the primary emission sources from the storage segment.
- **LNG import/export terminal activities** involve the receipt and delivery of LNG for storage and ultimately delivery.
- **LNG storage** involves the storage of LNG while it awaits final distribution.

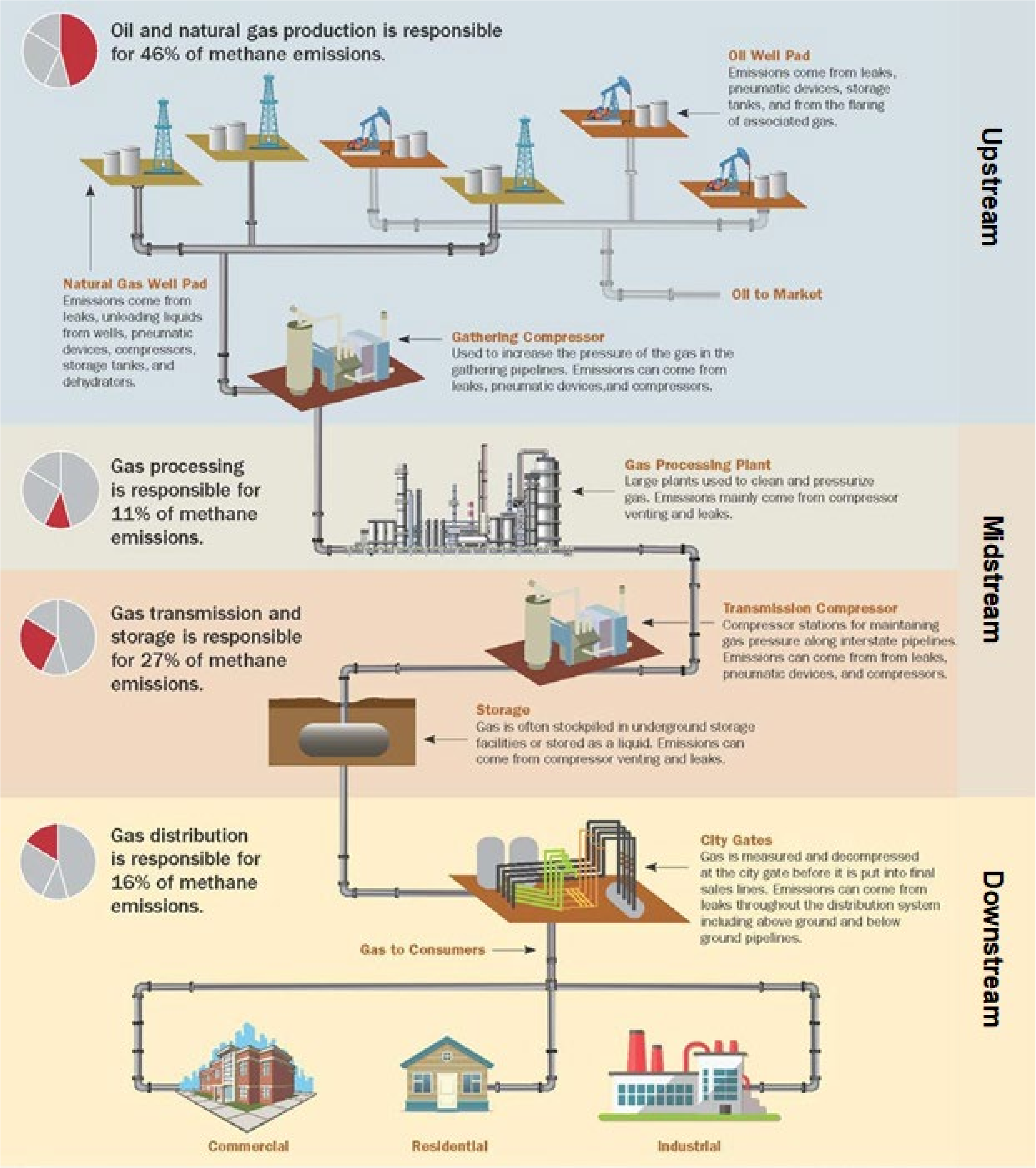
3.1.2.4 Downstream Stage

- The **distribution** stage represents the delivery of natural gas to end users through distribution mains and service pipelines. Distribution pipelines receive high-pressure gas from the transmission pipelines at city gate stations, where the pressure is reduced, and the gas is distributed through predominantly underground main and service pipelines to the customer’s meter, where the downstream stage ends. Primary sources of emissions from the distribution segment are leaks from pipes and metering and regulating (M&R) stations. Fugitive emissions after the customer meter are not considered here since those emissions should be accounted for in the residential or commercial sector inventory.
- **Beyond-the-meter** end use sources are those downstream of meters, and account for end-uses such as natural gas appliances and commercial and residential buildings. Discrepancies between top-down and bottom-up methodologies (see section 3.1.2.6) suggest that beyond-the-meter sources are a significant contribution to methane emissions.

Figure 9. Oil and Natural Gas System Depicting the Upstream, Midstream, and Downstream Grouping of Stages

The fraction of emissions is based on the 2014 EPA U.S. GHG Inventory.

Source: McCabe et al. 2015.



Oil and natural gas production is responsible for 46% of methane emissions.

Oil Well Pad
Emissions come from leaks, pneumatic devices, storage tanks, and from the flaring of associated gas.

Natural Gas Well Pad
Emissions come from leaks, unloading liquids from wells, pneumatic devices, compressors, storage tanks, and dehydrators.

Gathering Compressor
Used to increase the pressure of the gas in the gathering pipelines. Emissions can come from leaks, pneumatic devices,and compressors.

Gas processing is responsible for 11% of methane emissions.

Gas Processing Plant
Large plants used to clean and pressurize gas. Emissions mainly come from compressor venting and leaks.

Gas transmission and storage is responsible for 27% of methane emissions.

Transmission Compressor
Compressor stations for maintaining gas pressure along interstate pipelines. Emissions can come from from leaks, pneumatic devices, and compressors.

Storage
Gas is often stockpiled in underground storage facilities or stored as a liquid. Emissions can come from compressor venting and leaks.

Gas distribution is responsible for 16% of methane emissions.

City Gates
Gas is measured and decompressed at the city gate before it is put into final sales lines. Emissions can come from leaks throughout the distribution system including above ground and below ground pipelines.

3.1.2.5 Emission Source Categories

Emissions from oil and natural gas production systems fall into three main categories: fugitive emissions, vented emissions, and combustion emissions (Kirchgessner 1997). Definitions of these categories are as follows:

- **Fugitive emissions** represent unintended emissions from equipment leaks (such as those from compressor stations, meters, pressure regulating stations, malfunctioning pneumatic controllers, and various parts of the production process) and pipeline leaks due to deteriorating pipelines or poor pipeline connectors.
- **Vented emissions** represent purposeful releases (i.e., by design) of CH_4 (e.g., through pneumatics, dehydrator vents, regular maintenance, and chemical injection pumps).
- **Combustion emissions** represent unburned CH_4 emitted during any fossil fuel combustion component of the production process (e.g., compressor exhaust emissions or flares).

These different types of emissions are discussed in the context of inventory development in the following sections.

3.1.2.6 Bottom-Up versus Top-Down Methodologies

CH_4 emissions from the oil and natural gas sector are typically quantified using either top-down (TD) or bottom-up (BU) methodologies. Definitions of these methodologies are as follows:

- **TD** studies calculate CH_4 emission levels using observational techniques, including airborne measurements, satellites, mobile measurement devices, and stationary sensors. These approaches estimate aggregate CH_4 emissions from all sources in a given region, and then attempt to apportion those emissions to different source categories. Allen (2014) notes that the challenges of estimating emissions using TD methods include separating anthropogenic emissions from natural emissions, and identifying legacy emission sources such as abandoned wells and nonoperational infrastructure. TD estimates are typically generated at the area-level.
- **BU** studies generate emission estimates by applying EFs to different activities in the oil and natural gas sector. The generation of EFs can be challenging and usually involve laboratory or in situ measurements of emissions that are then extrapolated and applied broadly to develop overall emission inventories. As Allen (2014, 2016) notes, one of the primary challenges with BU studies is obtaining a representative sample of a large, geographically dispersed, and diverse population of equipment and activities. Other uncertainties are due to inaccurate activity data, malfunctioning equipment, or poorly operated equipment (Allen 2016). Furthermore, emissions from various sources are not normally distributed, and so the use of an "average" EF may lead to both overestimation and underestimation (Littlefield et al. 2017). BU inventories are typically estimated at the component or site level. BU estimates are particularly challenging when estimating emissions from high-emitting sources, as an accurate estimate requires either prior understanding of which sources are likely to be high-emitting sources; or obtaining a statistically representative sample, which is itself not easily determined without a large

sample size. Lastly, because BU methods calculated at the component level only capture source emissions for known and well-defined sources, they typically underestimate actual emissions, which include emissions from unknown or ill-defined sources (Heath et al. 2015; Adam R Brandt, Heath, and Cooley 2016; A R Brandt et al. 2014; Miller et al. 2013; Alvarez et al. 2018).

- **Site-level** estimates use a similar methodology to TD estimates, often estimating emissions from atmospheric concentrations, but then apply those estimates in a BU approach. Site-level estimates are generated for each site (e.g., well head, compressor station) and are at a smaller geographic scale than TD estimates—and at a greater scale than component-level BU estimates.

In both BU and TD approaches, uncertainty exists and the literature suggests that CH_4 inventories at the national level are likely under representing actual emissions by 50% or more (Miller et al. 2013; A R Brandt et al. 2014). At a regional level, Miller et al. (2013) suggest that fossil fuel extraction and processing emissions could be three to seven times higher than reported. Zavala-Araiza et al. (2015a) also show that CH_4 emissions from oil and gas production are almost twice as large as reported by the EPA and represent approximately 1.5% of natural gas production. This 1.5% may also be on the low range; other authors have observed regional losses of 2–12% or more in the Natural Gas sector, implying CH_4 emissions nationally could be three times higher than the EPA reports (Pétron et al. 2012; A. Karion et al. 2013; Caulton et al. 2014). The ceiling for fugitive emissions can be considered as the delta between aggregated meter readings in the distribution segment and the input of gas into the system from production and gathering.

3.1.3 Review of Existing Methane Inventory Approaches for Oil and Natural Gas Systems

3.1.3.1 EPA’s Greenhouse Gas Reporting Program Subpart W

EPA’s GHGRP [codified at 40 Code of Federal Regulation (CFR) Part 98] requires large emitters of GHGs to report their emissions through a centralized database accessible by the public (EPA n.d.). Data collection began in 2011 and covers sources emitting over 25,000 MT of CO_2e per year, using the GWP_{100} from AR4 (IPCC 2006) for converting CH_4 and other GHGs to CO_2e. These facilities self-identify and report annually. The owners and operators of these facilities are tasked with calculating CO_2e emissions, filing their results with the EPA, and maintaining records.

Subpart W of the GHGRP is focused specifically on facilities operating in oil or gas sectors (EPA 2018a). This includes emission sources in the following segments of the oil and natural gas system. Subpart W facility definitions differ across segments and are defined in parentheses.

- Onshore Oil and Natural Gas Production (Company or Basin)
- Offshore Oil and Natural Gas Production (Company or Basin)
- Natural Gas Gathering and Boosting (Company or Basin)
- Natural Gas Processing (Site)
- Natural Gas Transmission Compression (Site)
- Natural Gas Transmission Pipeline (Site)
- Underground Natural Gas Storage (Site)
- LNG Import/Export (Site)
- LNG Storage (Site)
- Natural Gas Distribution (Company or State)

In 2016, 2,248 Subpart W facilities reported emissions totaling 282.9 MMTCO$_2$e, of which 186.7 MMTCO$_2$e was CO$_2$, 96.0 MMTCO$_2$e was CH$_4$, and 0.2 MMTCO$_2$e nitrous oxide (N$_2$O). Note that although the GHGRP data and the U.S. national GHG Inventory are not directly comparable, total emissions in the U.S. for all sectors in 2016 was 6,511 MMTCO$_2$e (EPA 2018a), so the Subpart W emitters contributed about 4.3% of total emissions nationally.

GHGRP facilities are required to report emissions greater than 25,000 MTCO$_2$e for specific source categories. Facilities report emissions data to the EPA through an electronic submission. A review of the spreadsheet tool used by the EPA for this purpose, herein called the “Subpart W Tool,” was conducted. The Subpart W Tool is a BU approach that captures emissions of different components of the oil and natural gas system. The Subpart W forms are embedded in a Microsoft Excel spreadsheet and require facilities to provide input on equipment at an operational level. For example, Subpart W forms ask for input on the quantity of oil and natural gas produced, the quantity of oil and natural gas stored, the number and type of pneumatic devices and pumps, the number and types of dehydrators, the amount of well venting for liquids unloading, blowdown vent stacks, well completions, atmospheric storage units, flare stacks, and estimates of non-planned emission leaks.

The value of the Subpart W form for inventory development is its library of EFs, which provide specific values for a host of equipment and operations. For example, onshore production facilities that use natural gas pneumatic devices will find EFs (standard cubic feet/hour/device) for high-bleed pneumatic devices, intermittent-bleed pneumatic devices, and low-bleed pneumatic devices of 37.9, 13.5, and 1.39, respectively. This level of detail is useful for others constructing BU emission inventories.

3.1.3.2 EPA's Facility-Level Information on Greenhouse Gas Tool

EPA's FLIGHT provides access to GHG data reported to the EPA through the previously mentioned Subpart W reporting system and other GHGRP subparts. Aside from providing data access in geospatial, graphical, and tabular formats, FLIGHT does not provide any additional advancements with respect to inventory methodology.[3]

Data included in FLIGHT are submitted to the EPA periodically under the GHGRP (typically in March following the reporting year), as reported by over 8,000 facilities, including Subpart W and non-Subpart W facilities. These data are submitted by large emitters (> 25,000 $MMTCO_2e.yr^{-1}$) and cover an estimated 85–90% of total GHG emissions in many sectors in the U.S., including power plants and landfills, but less than 50% of the oil and natural gas sector. GHGRP data are available at the national, state, local, sector, and facility levels (EPA 2018c).

Emission sources available in FLIGHT relevant to CH_4 inventory accounting include point sources, onshore oil and gas production, onshore oil and gas gathering and boosting, local distribution, and onshore gas transmission pipelines. Sectors available in FLIGHT are power plants, petroleum and natural gas systems, refineries, chemicals, other, minerals, waste, metals, and pulp and paper.

EPA's Envirofacts, which draws on data from EPA's GHGRP and provides an alternate path to accessing FLIGHT data, shows that CH_4 emissions from all sources in New York State in 2016 totaled 3,082,129 $MTCO_2e$ (using IPCC AR4 GWP_{100} values), of which 1,334,090 $MTCO_2e$ of CH_4 were emitted from the oil and natural gas sector, and 1,716,960 $MTCO_2e$ were emitted from waste facilities, primarily landfills (the agriculture sector was not included). Together, these two sectors account for 98.98% of non-agriculture based CH_4 emissions reported in the State (43.28% and 55.70%, respectively).

3.1.3.3 EPA's Greenhouse Gas Emissions Inventory

EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016 provides an overview of U.S. GHG emissions, including CH_4 emissions from oil and natural gas systems (EPA 2018a). The approach for calculating emissions for natural gas systems generally involves the application of EFs to activity data. For most sources, the approach uses technology specific EFs or EFs that vary over time and consider changes to technologies and practices, which are used to calculate net emissions directly. For others, the approach uses what are considered "potential methane factors" and reduction data to calculate net emissions.

Key references for EFs for CH_4 emissions from the U.S. oil and natural gas sector include a 1996 study published by the Gas Research Institute (GRI) and the EPA (EPA/GRI 1996). The EPA/GRI study developed over 80 CH_4 EFs to characterize emissions from the various components within the operating stages of the U.S. natural gas system. The EPA/GRI study was based on a combination of process engineering studies, a collection of activity data, and measurements at representative gas facilities conducted in the early 1990s.

In the production segment, EPA's GHGRP data (EPA 2017) were used to develop EFs used for all years for well testing, gas well completions and workovers with and without hydraulic fracturing, pneumatic controllers and chemical injection pumps, condensate tanks, liquids unloading, and miscellaneous flaring. In the processing segment, for recent years of the times series, GHGRP data were used to develop EFs for fugitives, compressors, flares, dehydrators, and blowdowns/venting. In the transmission and storage segment, for recent years of the times series, GHGRP data were used to develop factors for pneumatic controllers. Other data sources used for CH_4 EFs include Marchese et al. (2015) for gathering stations, Zimmerle et al. (2015) for transmission and storage station fugitives and compressors, and Lamb et al. (2015) for recent years for distribution pipelines and meter/regulator stations. When changes are made to the EPA GHG Inventory methodology, the EPA adjusts inventories from prior years to be consistent with the updated methodology.

3.1.3.4 Environmental Defense Fund's 16 Study Series

The Environmental Defense Fund (EDF) has been a leader in undertaking investigations into CH_4 emissions in the oil and natural gas sector (EDF 2018). Through this work, EDF has drawn attention to factors such as leakage rates from aging equipment or poor operations, episodic emissions due to equipment failures, and high-emitting sources. EDF has also been a leading proponent of considering alternative GWP values when conducting GHG emission analyses, noting that the selection of an appropriate GWP depends on the types of environmental problems one is trying to address, and that the relatively arbitrary selection of a GWP_{100} may be inferior to a GWP_{20}, especially when considering the importance of short-term climate impacts (Alvarez et al. 2018).

With respect to supply chain analysis, EDF has been working since 2012 on a number of projects aimed at providing a peer reviewed, scientific basis for assessing CH_4 emissions in natural gas supply systems. The research program is divided into 16 different areas, hence the “16 Study Series” moniker. This section of the report summarizes the results to date from EDF’s work. A summary of each of the 16 studies is shown in Table 1. These studies are useful in helping identify important issues, EFs, and areas of uncertainty for future inventory work for New York State.

Table 1. List of Studies Included in Environmental Defense Fund's 16 Study Series (2018)

Study Area/Title	Overview of Results	References
	Production Studies	
Natural Gas Production Site Emissions	Conducted measurements of CH_4 emissions at natural gas production sites (conventional and hydraulically fractured wells). Found that CH_4 emissions over an entire completion flowback event ranged from less than 0.1 megagram (Mg) to more than 17 Mg, with a mean of 1.7 Mg [0.67-3.3 Mg with a 95% Confidence Interval (CI)]. Results show that wells with CH_4 capture and/or control devices captured 99% of the potential emissions, and that 3% of the wells account for 50% of estimated emissions during unloading.	Allen et al. 2013
	Identified that due to a possible malfunction, the Bacharach Hi Flow® Sampler (BHFS) may underestimate CH_4 emissions by as much as 40-80%. The authors constrained the potential underestimate and, given differences in flow rates and CH_4 content across different sites, they estimate that emissions from the Natural Gas Production sector may be 7–14% greater than initially thought, with total supply chain emissions being 2–5% greater.	Alvarez et al. 2016
Production Site Emissions Additional Data	Reviewed emissions from 377 gas actuated (pneumatic) controllers at natural gas production sites and a small number of oil production sites. Found that 19% of devices accounted for 95% of entire gas emission rates, with significant geographic variation. Gulf Coast CH_4 emission rates were the highest [10.61 standard cubic foot (scf)/hr] followed by mid-continent (4.87 scf/hr), Appalachian (1.65 scf/hr), and Rocky Mountain (0.67 scf/hr) emission rates. The highest-emitting devices were shown to be behaving in a manner inconsistent with their design specifications.	Allen, Pacsi, et al. 2015
	Investigated CH_4 emissions from wells during liquid unloading events. Liquid unloadings to clear wells of accumulated liquids to increase production may be necessary when a gas well also produces water. Wells with plunger lifts are triggered to unload far more frequently than wells without plunger lifts (thousands of times per year versus less than 10 times per year). Though wells without plunger lifts emit more CH_4 per unloading event (0.4–0.7 Mg) than wells with plunger lifts (0.02–0.2 Mg), the frequency of unloading events means that wells with plunger lifts account for the majority of CH_4 emissions from liquid unloading. Twenty percent of wells sampled with plunger lifts account for 83% of emissions. With plunger lifts, 20% of wells account for 65–72% of annual emissions (manual and automatically triggered, respectively).	Allen, Sullivan, et al. 2015
	Production Studies	
Production Data Analysis	Developed a multivariate linear regression to test the relationship of well age, gas production, and oil or condensate production to CH_4 emissions: $\log(\mathrm{CH_4}) = \beta\beta_1 \log(\mathrm{gas}) + \beta\beta_2 \log(\mathrm{oil}) + \beta\beta_3 \,\mathrm{age}$ Age was not significantly correlated with CH_4 production while gas production was significantly positively correlated [\beta_1 = 0.25 (p < 0.001)], and oil production was significantly negatively correlated [\beta_2 = -0.08 (p = 0.01)]. Emissions showed significant geographical variation by basin.	Brantley et al. 2014

Table 1 Continued

Study Area/Title	Overview of Results	References
Midstream Studies		
Gathering and Processing Study	Measurements at 114 gathering facilities and 16 processing plants showed CH_4 emissions ranging from 0.7 to 700 kg/hr^{-1}. Thirty percent of gathering facilities contributed 80% of total emissions, and normalized emissions are negatively correlated with facility throughput, though higher throughput is positively correlated with CH_4 emissions. Venting from liquids storage tanks occurred at ~ 20% of facilities, which showed four times the emission rates of similar facilities without substantial venting.	Mitchell et al. 2015
	Marchese et al. (2015) used the results from Mitchell et al. (2015), combined with state and national facility databases, to develop a Monte Carlo simulation to estimate CH_4 emissions from U.S. natural gas gathering and processing operations. Total annual CH_4 emissions of 2,421 (+245/-237) gigagrams (Gg) were estimated for all U.S. gathering and processing operations, representing a CH_4 loss rate of 0.47% (± 0.05%) when normalized by annual CH_4 production. Ninety percent of those emissions are attributed to normal operation of gathering facilities. CH_4 from gathering facilities are substantially higher than prior EPA estimates and are equivalent to ~ 30% of total net CH_4 emissions from natural gas systems in the current GHG Inventory. Results showed substantial variation in losses by state, with the highest loss rates in Oklahoma (0.94%) and the lowest in Pennsylvania (0.19%). A facility-level EF for gathering stations (42.6 kg/hr/facility) and estimated number of U.S. gathering stations (4,459 facilities) from this study were incorporated into the EPA GHG Inventory in April 2016.	Marchese et al. 2015
Transmission and Storage Study	Data from 45 compressor stations in the Transmission and Storage sector showed highly skewed site-level CH_4 emissions, with 10% of sites contributing 50% of CH4 emissions. The range in emissions observed is 1.7 ± 0.2 standard cubic foot per minute (SCFM) to 880 ± 120 SCFM, with the highest emissions generated by two high-emitting sites. Sites with reciprocating compressors showed typically greater emissions than sites with only centrifugal compressors.	Subramanian et al. 2015
	Evaluated CH_4 emissions from the Transmission and Storage sector. The largest emission sources were high-emitting sources, which showed site-level emission rates that were much higher than their aggregate component-level emission rates. In this instance, these high-emitting sources showed anomalous operations, such as leaking isolation valves, etc. Overall, on a per-station level, emissions from underground storage compressor stations were 847 Mg·station^{-1}·yr^{-1} (+53%/-35%) and transmission stations were 670 Mg·station^{-1}·yr^{-1} (+53%/-34%). Sup er-emitters contribute 39% of transmission fugitives and 36% of storage station fugitives, highlighting the importance of observing high-emitting sources, and modeled sup er-emitters are better modeled as frequency of occurrence rather than based on equipment counts.	Zimmerle et al. 2015

Table 1 continued

Study Area/Title	Overview of Results	References
Local Distribution Studies		
Multi-City Local Distribution Study	Direct measurements of 230 underground pipeline leaks and 229 metering/regulating facilities showed that emissions from leaks are generally lower (~ 2 times) than those described earlier in 1992, with a similar pattern in M&R facilities. Annual CH_4 emissions were calculated by multiplying the number of leaks in each category by the appropriate EF. Leaks in cast-iron and unprotected steel pipe account for 70% of eastern emissions and almost half of total U.S. emissions.	Lamb et al. 2015
Boston Study	Atmospheric study that showed overall emissions of 18.5 ± 3.7 g CH_4 m-2 r^{-1}. Natural gas emissions rate is 2.7 ± 0.6% of consumed natural gas in Boston, which is ~ 2-3 times greater than prior estimates.	McKain et al. 2015
Indianapolis Study	Atmospheric study with observed emissions from distribution, metering, regulating, and pipeline leaks showed 48% of emissions were from biogenic sources, and 52% of emissions from natural gas usage. Mean observed leak rates from pipelines were 2.4 g min^{-1} (range of 0.013 g min^{-1} to 22.3 g min^{-1}).	Lamb et al. 2015
Methane Mapping	Mobile analysis using vehicle-based sensors showed cities with a greater prevalence of corrosion-prone distribution lines (~ 25 times larger). Eliminating 8% of leaks would reduce gas pipeline emissions by up to 30%, and the largest 20% of leaks account for half of all emissions.	Von Fischer et al. 2017
Basin-Specific Studies		
Denver- Julesburg (D-J) Basin	Using ground-based and airborne measurements of the D-J Basin, study showed that non-oil and gas sources contribute around 7.1 ± 1.7 MT CH_4 h^{-1} (May 29) and 6.3 ± 1.0 MT CH_4 h^{-1} (May 31) or 24-27.5% of total measurement based CH_4 emissions. Non-oil and gas sources include animals, animal waste, landfills, municipal wastewater plants, and industrial wastewater plants.	Pétron et al. 2014
Barnett Study	Extensive set of work that used air and ground measurements to develop CH_4 emission estimates for oil and gas wells in the Barnett Shale in Texas. Results indicated emissions were 50–90% higher than would have been predicted using EPA's GHG Inventory model.	Yacovitch et al. 2015 Rella et al. 2015 Nathan et al. 2015 Harriss et al. 2015 Lyon et al. 2015 Zavala-Araiza, Lyon, Alvarez, Palacios, et al. 2015 Smith et al. 2015 Johnson, Covington, and Clark 2015 Lavoie et al. 2015 Townsend-Small et al. 2015 Zavala-Araiza, Lyon, Alvarez, Davis, et al. 2015a Zavala-Araiza et al. 2017

Table 1 continued

Study Area/Title	Overview of Results	References
Basin-Specific Studies		
Flyover Study: Barnett Shale	Involved aircraft measurements of hydrocarbons over the Barnett Shale to quantify regional CH_4 emissions.	Karion et al. 2015
Other Studies		
Pump-to- Wheels	Assessed CH_4 emissions from medium- and heavy-duty vehicles operating on natural gas. The research also included assessments of CH_4 emissions through liquefied and compressed natural gas refueling. CH_4 emissions from vehicle tailpipes (30%) and crank cases (39%) were the dominate emission sources, while refueling emissions were relatively low (12% of transport segment emissions).	Clark et al. 2017
Pilot Projects	EDF funded a number of pilot projects that helped informed the research threads included in this table Although no references are given for these pilot projects *per se*, the results of the projects are embedded in the work referenced throughout this table.	NA
Filling Gaps, Including Super-Emitters	Identified high-emitting sources from a set of 8,000 well pads using aerial flyovers and to estimate the contribution of CH_4 emissions by abandoned wells using a set of 138 abandoned oil and gas wells in 4 basins. These high-emitting sources represent sources that disproportionately contribute to emission inventories. Lyon et al. (2016) concluded that high-emitting sources are “widespread and unpredictable” but easily identifiable with appropriate monitoring systems. Townsend-Small et al. (2016) estimated that abandoned wells contribute less than 1% to regional CH_4 emissions in the study areas.	Lyon et al. 2016 Townsend-Small et al. 2016
Project Synthesis	A synthesis of the current state of knowledge around CH_4 emissions from natural gas production, with input from numerous stakeholders, was conducted; the conclusions indicate that actual emissions of CH_4 may be ~ 60% higher than currently reported in official U.S. inventories, and that 2.3% of the CH_4 in natural gas is emitted between extraction and delivery.	Littlefield et al. 2017 Alvarez et al. 2018

3.1.3.5 European Union's Greenhouse Gas Inventory

A review was performed on the inventory approaches implemented by the EU, as discussed in the Annual European Union Greenhouse Gas Inventory 1990–2016 and Inventory Report 2018 (EU Inventory) through the European Environment Agency 2018.[4] The EU Inventory applies methodologies outlined by the IPCC in 2006 and uses GWP information contained in AR4.[5] The EU Inventory is essentially an amalgamation of inventories for each of the 28 EU member nations plus Iceland. Each nation is allowed flexibility in its methodological approach, as long as it follows IPCC guidance. That guidance outlines three tiers of methodologies, representing increasing complexity and certainty. For example, Tier 1 methods are TD and apply average EU EFs (e.g., gCO_2e/MBTU natural gas) to national activity data (e.g., MBTU of natural gas consumed). Upon review of the EU Inventory and country specific EFs, the data show that using EFs from the U.S. is more applicable to the New York State context. Tier 2 applies more nationally focused EFs and activity data, but still represents a TD approach, and Tier 3 represents significant BU analysis, where production and consumption systems are well-defined at the equipment level, and emissions are calculated through equations that depict activity at the micro-level, similar to the Subpart W analysis previously mentioned (IPCC 2006, Vol 2, Ch. 4). Tier 1, 2, and 3 approaches are described in more detail in the following passages.

The EU Inventory estimates gaseous emissions in four source categories in IPCC's Common Reporting Framework Source Category 1.B related to fossil fuel extraction, handling, and consumption. These are Coal Mining and Handling (1.B.1.a), Oil (1.B.2.a), Natural Gas (1.B.2.b), and Venting and Flaring (1.B.2.c). Source category 1.B.2 (a and b) is the EU equivalent to the U.S. Oil and Natural Gas Production and Infrastructure sector. The EU GHG Inventory reports that 70.6% of emissions from Source Category 1.B are from fugitive CH_4 emissions, while 29.3% are fugitive CO2 emissions.

The Tier 1 methodology involves the application of appropriate default EFs to a representative activity parameter, often natural gas throughput, to each segment or subcategory of the country's oil and natural gas industry. The set of equations applied here is a simple scaling of activity estimates by an EF, summed across industry segments. A major flaw of this approach is that emission intensities are fixed relative to activity levels and do not reflect changes in emissions that may result from efficiency improvements and infrastructure upgrades over time.

The Tier 2 methodology applies the same general approach as Tier 1 but applies country-specific EFs that were developed from studies and measurement programs specific to the country's infrastructure. Best practices suggest that Tier 2 EFs be updated periodically. Where reliable venting and flaring data are available, a country may use an alternative Tier 2 approach, which also factors in emissions due to venting and flaring through a set of defined equations (IPCC 2006). This alternative approach may be used to estimate emissions due to venting and flaring from oil production.

The Tier 3 methodology applies a rigorous BU assessment of primary emission sources at the facility level. This approach requires a high level of detail on facilities, wells, flare and vent processes, production, reported and measured releases (planned and unplanned), and country-specific EFs. These inventories require a significant level of effort, and it is common among EU countries to periodically produce Tier 3 inventories, and then use these detailed studies to back-calculate the EFs, which can then be used in interim years' Tier 2 studies.

Data from the EU Inventory indicate that fugitive CH_4 emissions from natural gas (Source Category 1.B.2.b) account for 0.6% of total EU – 28 + ISL (28 EU countries, plus Iceland) GHG emissions, and account for 30% of all fugitive emissions. Fugitive sources include exploration, production, processing, transmission, and storage and distribution of natural gas. Fugitive CH_4 emissions from oil (Source Category 1.B.2.a) account for 0.1% of total EU – 28 + ISL GHG emissions and 4% of all fugitive emissions. Fugitive emissions from oil are associated with exploration, production, transmission, upgrading and refining of crude oil, and distribution of crude oil products.

Data for Source Category 1.B.2.b were calculated at the EU country level using a range of methodologies, from Tier 1 to Tier 3 methods, as prescribed by the IPCC in 2006 (IPCC 2006). Data for Source Category 1.B.2.a were calculated at the EU country level using Tier 1 and Tier 2 methods. The decision trees provided by the IPCC for determining which methodology to apply for each source category are shown in Figure 10 and Figure 11. The decision trees are provided here because they may offer useful guidance as the State considers different approaches to inventory development.

Figure 10. Decision Tree for Determining Natural Gas System Fugitive CH_4 Emissions Estimation Methodology

Source: Figure 4.2.1 from IPCC (2006).

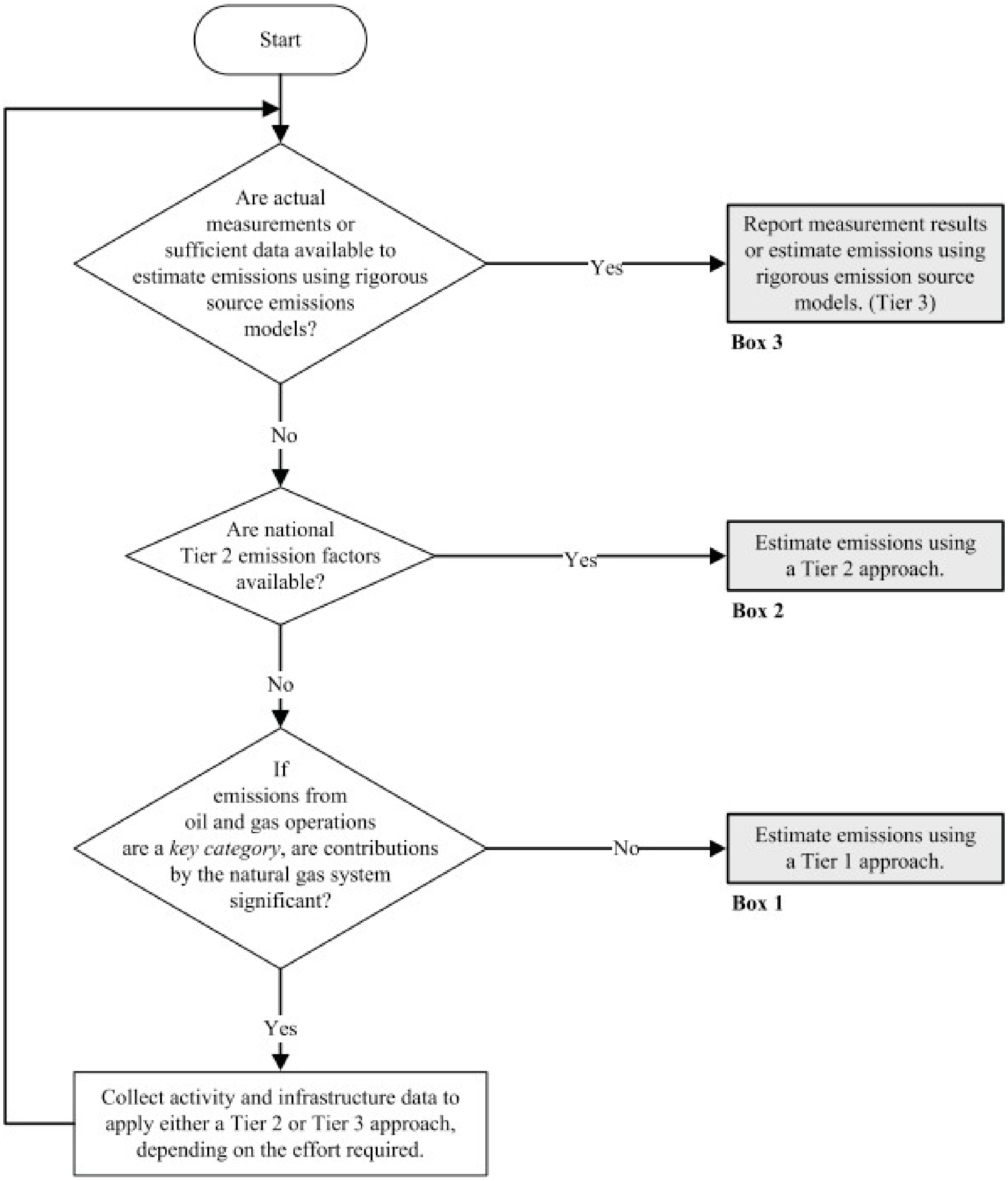
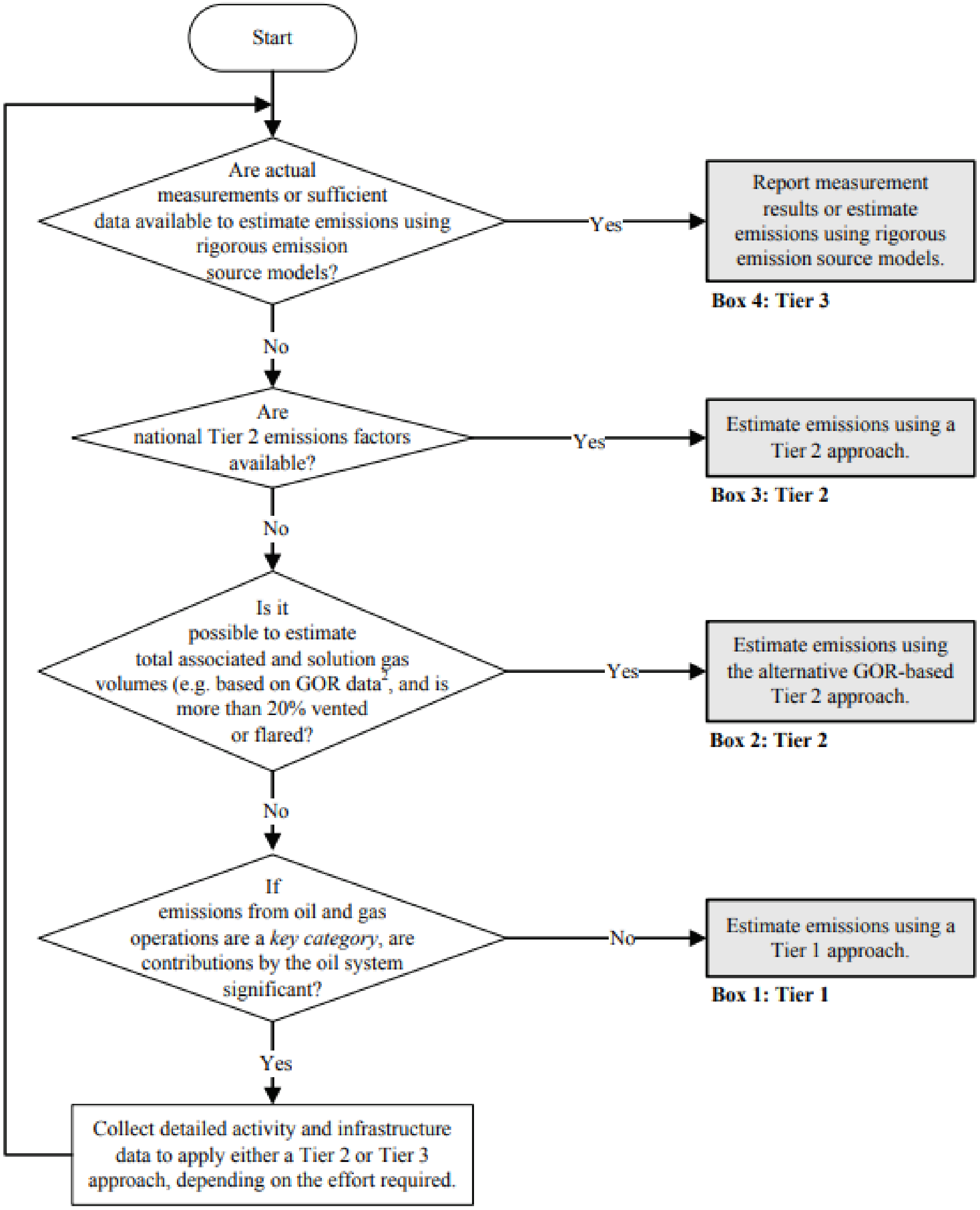


Figure 11. Decision Tree for Determining Oil System Fugitive CH_4 Emissions Estimation Methodology

Source: Figure 4.2.2 from IPCC (2006).



3.1.4 Emission Factors, Spatial Variability, and High-Emitting Sources

3.1.4.1 Emission Factors

One of the most important inputs for CH_4 inventories is the identification of appropriate EFs for BU analyses. These EFs are applied to different activities to calculate emission inventories at either (1) a national, regional, or state basis, or Tier 2 analyses, or (2) a process and system level, or Tier 3 analyses.

In its simplest form, an example of a Tier 2 type of calculation is shown in the following equation, where $E_{s,i}$ is the emissions of type i for period s, NG_s is the natural gas consumption (or throughput) in period s in SCF, and EF_i is the EF for emissions of type i in mass·SCF^{-1}.

Equation 1 $$\boldsymbol{E_{s,i} = NG_s \cdot EF_i}$$

Tier 2 approaches allow reporting facilities or organizations to easily prepare inventories in cases where limited data exist. EFs for Tier 2 analyses are generally estimated by sampling or testing a set of devices, processes, and facilities; generating EFs at a component level; and then synthesizing those EFs so that they can be applied more widely. Although simple to use, the drawback is that EFs for Tier 2 analyses are averages based on sample testing and may not reflect the actual emissions of the particular facility or region under study.

Tier 3 analyses are more site-specific and estimate emissions at a facility level by incorporating data at an operational level. An example of a type of Tier 3 analysis is shown in the following equation, which is used by facilities to estimate emissions from three types of pneumatic devices using EPA’s Subpart W inventory tool mentioned previously.

Equation 2 $$\boldsymbol{E_{s,i} = \sum_{t=1}^{3} N_t \cdot EF_t \cdot GHG_i \cdot T_t}$$

where:

- $E_{s,i}$ is emissions of type i for year period s
- N_t is the number of devices of type t
- EF_t is the EF for device of type t measured in SCF·hr^{-1}·device^{-1}
- GHG_i is the concentration of GHG of type i in natural gas as a percent
- T_t is the average number of hours during the period the devices were operating

Although Tier 3 analyses use more specific facility and operational data (i.e., activity data) when calculating emissions, the EFs used may not reflect actual EFs for the facility. Thus, in both Tier 2 and Tier 3 analyses, the selection of an appropriate EF is critically important, as emissions are directly and proportionally related to these values.

What has emerged in the literature is an evolution of EFs over time, informed by ongoing research, testing, and demonstration projects. As an example of that variability, data from Howarth (2014) that summarize CH_4 emissions as a percentage of natural gas throughput by process stage (upstream/downstream) and type of natural gas extraction (conventional/unconventional) are reproduced in Table 2.

Table 2. Information on EFs (as a percentage loss) for Upstream, Downstream, and Total Based on Data in Howarth (2014)

Source	Upstream Conventional (%)	Upstream Unconventional (%)	Downstream (%)	Total (%)
Kirchgessner 1997; Harrison et al. 1997b	0.54		0.88	1.42-0.47
Hayhoe et al. 2002	1.4		2.5	3.9
Jaramillo, Griffin, and Matthews 2007	0.2		0.9	1.1
Howarth, Santoro, and Ingraffea 2011	1.4	3.3	2.5	3.9-5.8
EPA 2011	1.6	3.0	0.9	2.5-3.9
Venkatesh et al. 2011	1.8	--	0.4	2.2
Jiang et al. 2011	--	2.0	0.4	2.4
Stephenson, Valle, and Riera-Palou 2011	0.4	0.6	0.07	0.47-0.67
Hultman et al. 2011	1.3	2.8	0.9	2.2-3.7
Burnham et al. 2012	2.0	1.3	0.6	1.9-2.6
Cathles et al. 2012	0.9	0.9	0.7	1.6

More recent work by Alvarez et al. (2018) and Littlefield et al. (2017) synthesize a set of source-specific and site-specific analyses to derive EFs for certain parts of the natural gas supply chain. Littlefield et al. (2017) synthesize component-based data from other studies on well completion, pumps, and equipment leaks (Allen et al. 2013), pneumatic controllers (Allen, Pacsi, et al. 2015), liquids unloading (Allen, Sullivan, et al. 2015), general production (Zavala-Araiza, Lyon, Alvarez, Davis, et al. 2015a), gathering and processing (Marchese et al. 2015), transmission and storage (Zimmerle et al. 2015), and local distribution systems (Lamb et al. 2015). Alvarez et al. (2018) provide the most comprehensive assessment to date of CH_4 emissions from the natural gas supply chain, demonstrating that site-based analyses show CH_4 emission levels that are 1.2 to 2 times higher than EPA's estimates. The EFs derived in this literature provide additional inputs for BU inventory development for New York State.

During the second iteration of this project, a literature review was conducted to identify data that could be used to incorporate beyond-the-meter sources into the inventory. More information can be found in appendix A.2.2.

3.1.4.2 Spatial Variability

CH_4 missions from natural gas production and distribution are also affected by location. This can be seen most obviously in Table A-13, which is derived from Alvarez et al. (2018) and shows estimated CH_4 emissions from oil and natural gas production across nine different production basins. Emissions, as a percentage of total production, vary considerably from 0.4% (northeast Pennsylvania) to 9.1% (west Arkoma).

Allen (2016) explains variability due to the different characteristics of the reservoir, the production systems used to extract oil or natural gas, and the air quality regulations that are in place for the region, to name a few. This variability is also reflected in BU analyses that evaluate emissions from equipment and devices, and that can vary by an order of magnitude across different regions (Daniel Zavala-Araiza, Allen, et al. 2015).

In addition to production variability, other sources of variability by region occur throughout the natural gas supply chain. For example, some regions of the county have old distribution systems that may exhibit much higher leakage rates than what national average values would imply (Brandt et al. 2016). For this reason, BU analyses need to be cognizant of regional variability and address that variability in inventory development.

3.1.4.3 Comparison across Historical Methane Loss Rates

Kirchgessner (1997) provides a review of past papers that provide a window into historical assumed loss rates, which is useful for considering hindcasting of emissions using updated methodology. Assumed loss rates, generally measured as unaccounted for gas in the 1970s varied between 1–3% and 6–10%, which was considered an exceptionally high leakage rate. Through the 1980s the assumed CH_4 loss rates were generally 2–4%, with additional considerations for vented and flared CH_4. Considering total natural gas marketed production of 18,712 billion standard cubic feet (Bscf) and estimated CH_4 emissions of 314 Bscf in 1992, Kirchgessner's (1997) estimate of CH_4 loss in 1992 was 1.678% of total production. Given the variation seen in these historical loss rates, it is difficult to determine any trend toward increasing or decreasing CH_4 loss rates from the oil and natural gas sector over the 1968–1992 time period.

3.1.4.4 High-Emitting Sources

An area that has received recent attention in the inventory literature is related to high-emitting sources, sometimes referred to in the literature as "super-emitters."[6] High-emitting sources represent a small group of emission sources that contribute a disproportionately high amount of emissions across the supply chain (Allen 2016). However, high-emitting source status may vary over time and may be better thought of as a statistical status across the entire set of sites and components. That is, if a set of hundreds of sites were observed instantaneously, a fraction of them may be high-emitting sources. If that same set of sites were observed on another occasion, one might expect to see similar rates of high-emitting sources, but not necessarily correlated to the same prior high-emitting sources.

These high-emitting sources may be planned and episodic (e.g., during certain high-emitting liquid unloadings), where planned activity emissions can be "equivalent to a thousand or more wells in routine operation" (Allen, Sullivan, et al. 2015); or can occur due to unplanned events such as equipment malfunction (Allen 2016; Conley et al. 2016).

To illustrate the potential impact of high-emitting sources, consider an example provided by Allen (2016) regarding the venting of CH_4 during liquid unloadings. EPA has reported that ~ 50,000 wells in the U.S. conduct this type of venting, amounting to 259 $Gg{\cdot}yr^{-1}$ of CH_4 emissions (EPA 2018a). It is believed that 3–5% of these wells account for ~ 50% of these emissions. Similar effects are observed for pneumatic controllers (where 20% of the controllers are thought to emit 95% of emissions) and other equipment and processes in the natural gas supply chain (Allen, Pacsi, et al. 2015). Table 10 summarizes other studies on high-emitting sources.

Table 3. Example Cases of High-Emitting Sources from the Literature, Demonstrating the Disproportionate Level of Emissions Coming from a Small Subset of the Natural Gas Production Supply Chain

Source: Ona Papageorgiou, DEC, personal communication, October 2018.

Citation	Segment	Sample Size	Result
Robertson et al. 2017	Oil & Gas Producing Wells	160 wellpads	51/16/30 wellpads in Upper Green River/DJ/Uinta, respectively. 20% of the wellpads contributed ~ 72-83% of emissions. 53 wellpads in Fayetteville; 20% of the wellpads contributed ~ 54% of emissions.
Brandt, Heath, and Cooley 2016	All	15,000 previous measurements	Aggregated 15,000 measurements from 18 prior studies, finding that 5% of leaks contribute over 50% of total leakage volume.
Zavala-Araiza et al. 2017	Gas Producing Wells	17,000 wellpads	Highest emitting 1% and 10% of sites accounted for roughly 44% and 80%, respectively, of total CH4 production emissions from ~ 17,000 production sites.
Franken berg et al. 2016	Gas Producing Wells, Gas Processing Plants, Gas Gathering Lines, Gas Transmission Pipelines	250-point sources	10% of emitters accounted for ~ 50% of observed point source emissions, roughly ~ 25% of total basin emissions.
Lyon et al. 2016	Oil and Gas Producing Wells	8,000 well pads	Of 8,000 well pads, 4% of sites had high-emitting sources (detection threshold was 1-3 g/s).
Schade and Roest 2016	Gas Producing Wells		Eagle Ford Region “routine” ethane 4-5 x background; “upsets” ethane ~ 100 x background.
Hendrick et al. 2016	Distribution Mains	100 natural gas leaks from cast- iron distribution main	7% of leaks contributed 50% of emissions measured.
Omara, Sullivan, Li, Subramian, et al. 2016	Gas Producing Wells	35 well pads	Of 13 unconventional routinely operating well pads, 23% of sites accounted for ~ 85% of emissions; of 17 conventional well pads, 17% of sites accounted for ~ 50% of emissions.
Zavala-Araiza, Lyon, Alvarez, Davis, et al. 2015a	Gas Producing Wells, Gas Processing Plants, Gas Transmission Compressor Stations	413 sites	2% of facilities are responsible for 50% of the emissions, and 10% of facilities are responsible for 90% of the emissions.
Zimmerle et al. 2015	Gas Transmission Compressor Stations, Gas Underground Storage	New measurements from 677 facilities, activity data from 922 facilities	Authors note that “equipment-level emissions data are highly skewed.”
Lamb et al. 2015	Distribution Mains/Services, Regulators & Meters	257 pipe leakage measurements, 693 metering and regulator measurements	3 large leaks accounted for 50% of total measured emissions from pipeline leaks.

Table 3 continued

Citation	Segment	Sample Size	Result
Rella et al. 2015	Oil and Gas Producing Wells	182 well pads	~ 6% of sites accounted for 50% of emissions, and 22% of sites accounted for 80% of emissions.
Yacovitch et al. 2015	Oil and Gas Producing Wells, Gas Gathering & Boosting Compressor Stations, Gas Transmission Compressor Stations, Gas Processing Plants	188 emissions measurements	7.5% of emitters contributed to 60% of emissions.
Marchese et al. 2015	Gas Gathering & Boosting Compressor Stations	114 compressor stations (CSs)	25 CSs vented > 1% of gas processed, 4 CSs vented > 10% of gas processed.
Mitchell et al. 2015	Gas Gathering & Boosting Compressors, Gas Processing Plants	114 gathering facilities, 16 processing plants	Of 114 CSs, 30% of sites were responsible for ~ 80% of emissions; of 16 gas processing plants, 45% of sites were responsible for ~ 80% of emissions.
Subramanian et al. 2015	Gas Transmission Compressor Stations	47 compressor stations	Of 45 CSs, 10% of sites accounted for ~ 50% of emissions.
Kang et al. 2014	Abandoned Wells	19 abandoned wells	Of 19 abandoned wells, 3 had flow rates 3x larger than the median flow rate.
Allen, Pacsi, et al. 2015	Gas Producing Wells	377 pneumatic controllers	20% of devices accounted for 96% of emissions.
Allen, Sullivan, et al. 2015	Gas Producing Wells	107 wells with liquids unloading	Without plunger lift, 20% of wells accounted for 83% of emissions; with plunger lift and manual, 20% of wells accounted for 65% of emissions; with plunger lift and automatic, 20% of wells accounted for 72% of emissions.

3.1.5 Conclusion

This comprehensive literature review identified five major issues with the original 2015 inventory that were addressed to improve the CH_4 emissions inventory for the oil and natural gas sector and develop the 2017 inventory.

- First, the literature stresses the importance of an activity-based, component-level analysis. These methodologies meet the highest standards laid out by the IPCC and EPA.
- Second, this review has shown the importance of identifying appropriate EFs for the systems that are in place in the geographic region. EFs can vary significantly by region due to differences in gas pressure and gas composition, as well as equipment type, material, and age. Thus, using region-specific EFs provide the most accurate results.

- Third, geospatial allocation of emissions is important for planners and regulators to identify hotspots and to link emission inventories with chemical fate and transport and health models.
- Fourth, the literature demonstrates significant uncertainty in estimating emissions, stressing the need to incorporate uncertainty analysis into the emissions inventory methodology.
- Fifth, there is a clear and pressing need to consider high-emitting sources, their causes, and the role that they play in overall emission inventories.

The fact that the literature presents a large variability in inventory calculations further argues for the need to customize emission inventories for the State's geography and infrastructure. In addition, the information learned from this literature review can be used to inform similar reviews for other major sources of CH_4, including agriculture, landfills, wastewater management, and wetlands.

3.2 Methods and Data

3.2.1 Overview

This section contains a detailed accounting of the emissions inventory development methodology, informed by the initial assessment and literature review and the enhancements identified during the updates for 2020. Sources included in the inventory are listed in Table 4. For each source section, the section contains the following subsections: (1) a source category description, (2) a discussion of EFs, (3) a discussion on activity data, (4) geospatial data and any allocation methodologies, (5) sample calculations, (6) limitations and uncertainties, and (7) potential areas of improvement.

In addition, the general equation for emissions estimation is:

Equation 3 $$E = A \times EF$$

where:

- E = emissions
- A = activity
- EF = emissions factor

EFs in the published literature typically are averages of available data of acceptable quality and are assumed to represent long-term averages for similar facilities. However, variations among facilities, such as operational conditions and emission controls, can significantly affect emissions. Whenever possible, the development of local, source-specific EFs is highly desirable.

Table 4. Sources of CH_4 Emissions Included in the Improved New York State Inventory

Section	Category	Segment	Source
1	Upstream	Onshore Exploration	Drill Rigs
2	Upstream	Onshore Exploration	Fugitive Drilling Emissions
3	Upstream	Onshore Exploration	Oil Well: Mud Degassing
	Upstream	Onshore Exploration	Gas Well: Mud Degassing
4	Upstream	Onshore Exploration	Oil Well: Completions
	Upstream	Onshore Exploration	Gas Well: Completions
5	Upstream	Onshore Production	Oil Well: Conventional Production
	Upstream	Onshore Production	Gas Well: Conventional Production
	Upstream	Onshore Production	Oil Well: Unconventional Production
	Upstream	Onshore Production	Gas Well: Unconventional Production
6	Upstream	Onshore Production	Oil: Abandoned Wells
	Upstream	Onshore Production	Gas: Abandoned Wells
7	Midstream	Gathering and Boosting	Oil: Gathering and Processing
	Midstream	Gathering and Boosting	Gas: Gathering and Processing
8	Midstream	Gathering and Boosting	Gathering Pipeline
9	Midstream	Crude Oil Transmission	Oil: Truck Loading
	Midstream	Natural Gas Transmission and Compression	Gas: Truck Loading
10	Midstream	Natural Gas Processing	Gas Processing Plant
11	Midstream	Natural Gas Transmission and Compression	Transmission Pipeline
12	Midstream	Natural Gas Transmission and Compression	Gas Transmission Compressor Stations
13	Midstream	Underground Natural Gas Storage	Gas Storage Compressor Stations
	Midstream	Underground Natural Gas Storage	Storage Reservoir Fugitives
14	Midstream	LNG Storage	LNG Storage Compressor Stations
15	Midstream	LNG Import/Export	LNG Terminal
16	Downstream	Natural Gas Distribution	Cast-Iron Distribution Pipeline: Main
	Downstream	Natural Gas Distribution	Cast-Iron Distribution Pipeline: Services
	Downstream	Natural Gas Distribution	Unprotected Steel Distribution Pipeline: Main
	Downstream	Natural Gas Distribution	Unprotected Steel Distribution Pipeline: Services
	Downstream	Natural Gas Distribution	Protected Steel Distribution Pipeline: Main
	Downstream	Natural Gas Distribution	Protected Steel Distribution Pipeline: Services
	Downstream	Natural Gas Distribution	Plastic Distribution Pipeline: Main
	Downstream	Natural Gas Distribution	Plastic Distribution Pipeline: Services
	Downstream	Natural Gas Distribution	Copper Distribution Pipeline: Main
	Downstream	Natural Gas Distribution	Copper Distribution Pipeline: Services
17	Downstream	Natural Gas Distribution	Pressure Relief Valves
18	Downstream	Natural Gas Distribution	Blowdowns
19	Downstream	Natural Gas Distribution	Damages
20	Downstream	Natural Gas Distribution	Metering and Regulating Stations
21	Downstream	Natural Gas Distribution	Meters (Residential, Commercial, Industrial)
22	Downstream	Beyond the meter	Residential Natural Gas Appliances
23	Downstream	Beyond the meter	Residential Buildings
24	Downstream	Beyond the meter	Commercial Buildings

3.2.2 Summary of Best Practices

The original New York State approach for constructing the statewide CH_4 inventory had its limitations. Although the nature of the highly aggregated, sectoral, analysis is consistent with the U.S. national GHG

Inventory and in some sense captures all source activities, in another sense it does not provide detailed information about those source activities in a meaningful and actionable way. An alternative approach would include a level of data refinement and spatial and temporal resolution that more accurately reflects State conditions, accounts for uncertainty, and has results that allow New York State to focus programs and policies on parts of the system where the greatest emission reductions may be realized.

In summary, characteristics of the New York State oil and natural gas industry differ from the national average. Therefore, using national estimates of the fraction of emissions attributed to each stage in the oil and natural gas system derives potentially spurious results, and highlights the importance of performing a BU, activity-driven, component-level CH_4 emissions inventory for the State. The development of such an inventory should focus on the (1) use of appropriately scaled activity data, (2) inclusion of state-of-the-science EFs, (3) geospatial resolution of activities and emissions, and (4) application and reporting of uncertainty factors, including high-emitting sources.

All iterations of the New York State Oil and Gas Sector Methane Emissions Inventory follow these best practices.

Table 5. Summary of Best Practice Recommendations, Implementation of Best Practices, and Areas for Future Inventory Improvements

✓	**Recommendation No. 1** New York State should develop a more detailed set of activity data, including site- and component-level data, for its CH_4 inventory in order to create an inventory with the detail needed to capture the impacts of CH_4 mitigation strategies targeted at the site- or component-level. **Implementation in Current Inventory:** Applied the best available activity data, using publicly available inputs as well as data provided by New York State agencies. **Areas for Future Improvement:** • Collect/compile data on the number and location of transmission and storage compressor stations in the State, including stations that only have electric compressors. • Collect/compile data on the county-level miles of distribution pipeline by pipeline material. • Collect/compile data on the county-level number of residential and commercial/industrial gas meters. • Identify additional sources of methane emissions to include in the inventory and collect/compile data on county-level activity.
✓	**Recommendation No. 2** New York State should estimate and apply EFs for upstream and downstream oil and gas activities in the State using best available data, validated by both bottom-up and top-down studies, and specific to geographic location. **Implementation in Current Inventory:** Applied the best available EFs from the published literature. **Areas for Future Improvement:** • Develop New York State-specific EFs for well pads during production. • Develop New York State-specific EFs for transmission and storage compressor stations. • Develop an EF for fugitive emissions from storage reservoirs. • Identify EFs for other types of commercial buildings, industrial buildings, and additional residential appliances.

Table5 continued

✓	**Recommendation No. 3** New York State should align available geospatial data with inventory data as much as possible to create a geospatial emissions inventory that allows greater consideration of identifying hot spots and air quality concerns as well as verification of emission inventories with empirical data. **Implementation in Current Inventory**: Results are presented geospatially, allocated to the county-level, with the ability to produce sub-county results for many segments. **Areas for Future Improvement:** • Collect air quality data on ambient CH_4 concentrations throughout New York State and use the observed concentrations to verify emission estimates. • As data become available, compare top-down measurements of methane emissions to the inventory to verify inventory and identify areas for potential improvement.
✓	**Recommendation No. 4** New York State should conduct uncertainty analysis when calculating and reporting its CH_4 inventory. At a minimum, that uncertainty analysis should account for uncertainties in published EFs, but it could also include an assessment of high-emitting sources across the State. New York State should develop and apply models that help account for the existence of high-emitting sources either in cases where emission releases are known (e.g., reported leakage) or in cases where emission releases are not known (e.g., estimated leakage based on pipeline age or material). **Implementation in Current Inventory:** Assessed uncertainty in the applied EFs to identify the most likely range of CH_4 emission from the oil and natural gas sector. With better information on the statistical distribution of high-emitting sources, this inventory methodology may also be applied to explicitly include high-emitting sources. **Areas for Future Improvement:** • Develop a better understanding of the distribution of high-emitting sources and the frequency of operation in the high-emitting state.

3.2.3 Emissions Factor Confidence

EFs used in this inventory are derived from a comprehensive search of the literature and selected based on expert judgment and best available data. In most cases, EFs are transferred from studies performed at sites outside of New York State, which have varying methodologies and are not all peer reviewed. In addition, some of the EFs applied in this inventory are derived from empirical studies or engineering estimates performed well in the past and may not reflect current conditions. As such, it is important to describe the certainty of the EF in being applied to the State. In order to address EF certainty, this section outlines the four metrics used to evaluate the EF applied: geography, recency, study methodology, and publication status. Each metric is presented equally and independently with no judgments as to weighting of the four categories.

3.2.3.1 Geography

Geography is an important consideration when evaluating EFs. Selecting EFs that most closely reflect local conditions will result in the most robust estimates, as they are likely to share similar local environmental conditions and regulations, which can influence average EFs. As discussed in appendix A.4.3 and section 3.1.4.1, site-level EFs show significant geographic variation varying from 0.4% of production in the Marcellus Basin, to 9.1% of production in the West Arkoma Basin, highlighting the need to select EFs that are as geographically local as possible.

New York State	**Marcellus/Appalachian Basin**	**Rest of the Country**

3.2.3.2 Recency

Many of the EFs employed in the EPA Oil and Gas Tool and SIT are derived from older studies, with some values originating from studies first published in 1977. The oil and natural gas sector has changed a good deal since that time, transitioning toward plastic pipelines with lower leak rates, and centrifugal compressors with greater throughput than reciprocating, and lower leak rates, among other changes to the sector. As such, it is important to use EFs that most closely reflect the current state of the industry when evaluating the inventory.

Study Age ≤ 5 Years	**5 < Study Age ≤ 15 Years**	**15 < Study Age**

3.2.3.3 Study Methodology

The EFs in this inventory are derived using a variety of methodologies. At their simplest, EF estimates are derived from engineering estimates, which take assumptions about equipment throughputs and leak rates to estimate EFs, in the absence of empirical observations. More sophisticated methodologies apply component or site-level sampling methods to empirically observe emission rates. Empirical observations of EFs represent best available practices, as they reflect real-world operations and uncertainties that may not be captured by engineering estimates.

Empirical Observation	**Engineering Estimate**

3.2.3.4 Publication Status

EFs in this inventory are derived from two primary sources: grey and peer-reviewed literature. Grey literature estimates are typically from government publications and reports, which are prepared by experts and in many cases provide a wealth of information on clearly documented EFs, but do not undergo a formal external peer review. The second source of EFs is the peer-reviewed literature. These EFs are subject to peer review prior to publication, indicating that they have been thoroughly vetted, are derived using robust scientific methodologies, and represent the best available data.

Peer-Reviewed	**Grey Literature**

3.2.3.5 Summary Table

Table 6 summarizes the EF confidence assessment by CH_4 emissions source for EFs used in developing the improved New York State inventory.

Table 6. Emission Factor Confidence Assessment for Emission Factors Used in the Improved New York State Inventory

Emissions Source	EF			EF Unit	Geography	Recency	Methodology	Status	Source
	Low	Mid	High						
Drill Rigs	0.003	0.004	0.006	g/hp-hr	🟨	🟨	🟨	🟨	EPA NONROAD 2008 Model
Fugitive Drilling Emissions	-	0.0521	-	MTCH$_4$ well^{-1}	🟥	🟥	🟨	🟨	EPA 2018b, Annex 3.6-2
Oil Well: Mud Degassing	0.2605	0.324	0.38	MTCH$_4$ drillingday^{-1}	🟥	🟥	🟨	🟨	EPA Oil and Gas Tool
Gas Well: Mud Degassing	0.2605	0.324	0.38	MTCH$_4$ drillingday^{-1}	🟥	🟥	🟨	🟨	EPA Oil and Gas Tool
Oil Well: Completions	0.67	1.7	3.3	MTCH$_4$ completion^{-1}	🟨	🟨	🟦	🟦	Allen et al. (2013)
Gas Well: Completions	0.67	1.7	3.3	MTCH$_4$ completion^{-1}	🟨	🟨	🟦	🟦	Allen et al. (2013)
Oil Well: Conventional Production	9.4	25.4	60.7	% of throughput	🟨	🟨	🟦	🟦	≤ 10 MSCFD (top) > 10 MSCFD (bottom) Omara et al (2016)
	4.1	7.2	13.7						
Gas Well: Conventional Production	9.4	25.4	60.7	% of throughput	🟨	🟨	🟦	🟦	≤ 10 MSCFD (top) > 10 MSCFD (bottom) Omara et al (2016)
	4.1	7.2	13.7						
Oil Well: Unconventional Production	0.1	0.15	0.26	% of throughput	🟨	🟨	🟦	🟦	≤ 10,000 MSCFD (top) > 10,000 MSCFD (bottom) Omara et al (2016)
	0.018	0.03	0.178						
Gas Well: Unconventional Production	0.1	0.15	0.26	% of throughput	🟨	🟨	🟦	🟦	≤ 10,000 MSCFD (top) > 10,000 MSCFD (bottom) Omara et al (2016)
	0.018	0.03	0.178						

Table 6 continued

Emissions Source	EF			EF Unit	Geography	Recency	Methodology	Status	Source
	Low	Mid	High						
Oil: Abandoned Wells	0	0.09855	0.1971	$MTCH_4$ well^{-1} yr^{-1}	🟨	🟨	🟦	🟦	Kang et al. (2014)
Gas: Abandoned Wells	0	0.0878	0.196	$MTCH_4$ well^{-1} yr^{-1}	🟥	🟨	🟦	🟦	Townsend-Small et al. (2016)
Oil: Gathering and Processing	303.1	373.2	460.8	% of throughput	🟨	🟨	🟦	🟦	Marchese et al. (2015)
Gas: Gathering and Processing	303.1	373.2	460.8	$MTCH_4$ facility^{-1}-yr^{-1}	🟨	🟨	🟦	🟦	Marchese et al. (2015)
Gathering Pipeline	0.036	0.4	0.044	$MTCH_4$ mile^{-1} yr^{-1}	🟥	🟥	🟨	🟨	EPA SIT Natural Gas and Oil Module
Oil: Truck Loading	0	33.7	-	$mgCH_4$ L^{-1} crude oil	🟥	🟥	🟨	🟨	AP-42: Compilation of Air Emission Factors
Gas: Truck Loading	-	-	-	-	-	-	-	-	-
Gas Processing Plant	832.2	919.8	1,016.2	$MTCH_4$ plant^{-1} yr^{-1}	🟨	🟨	🟦	🟦	Marchese et al. (2015)
Transmission Pipeline	0.394	0.62	1.01	$MTCH_4$ mile^{-1} yr^{-1}	🟥	🟥	🟨	🟨	EPA SIT Natural Gas and Oil Module
Gas Transmission Compressor Stations	442.2	670	1,018.4	$MTCH_4$ station^{-1} yr^{-1}	🟨	🟨	🟦	🟦	Zimmerle et al. (2015)

Table 6 continued

Emissions Source	EF			EF Unit	Geography	Recency	Methodology	Status	Source
	Low	Mid	High						
Gas Storage Compressor Stations	550.6	847	1,295.1	MTCH_4 station^{-1} yr^{-1}	🟨	🟨	🟦	🟦	Zimmerle et al. (2015)
Storage Reservoir Fugitives	-	-	-	-	-	-	-	-	-
LNG Storage Compressor Stations	920	1,077.48	1,234.9	MTCH_4 facility^{-1} yr^{-1}	🟨	🟨	🟨	🟨	EPA 2016 GHG Inventory, Dr. A. Marchese
LNG Terminal	Not Applicable to New York State								
Cast Iron Distribution Pipeline: Main	1.1573	1.1573	4.5974	MTCH_4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021
Cast Iron Distribution Pipeline: Services	1.1573	1.1573	4.5974	MTCH_4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021
Unprotected Steel Distribution Pipeline: Main	0.8613	0.8613	2.1223	MTCH_4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021
Unprotected Steel Distribution Pipeline: Services	1.1987	1.1987	2.7116	MTCH_4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021

Table 6 continued

Emissions Source	EF			EF Unit	Geography	Recency	Methodology	Status	Source
	Low	Mid	High						
Protected Steel Distribution Pipeline: Main	0.0589	0.0589	0.0967	MTCH4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021
Protected Steel Distribution Pipeline: Services	0.0946	0.0946	0.2474	MTCH4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021
Plastic Distribution Pipeline: Main	0.0288	0.0288	0.1909	MTCH4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021
Plastic Distribution Pipeline: Services	0.0136	0.0136	0.0136	MTCH4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021
Copper Distribution Pipeline: Main	-	-	-	-	-	-	-	-	Note: There are no copper distribution mains in NYS.
Copper Distribution Pipeline: Services	0.4960	0.4960	0.4960	MTCH4 mile^{-1} yr^{-1}	🟦	🟦	🟦	🟦	Lamb et al. 2015; EPA 2018b; EPA, 2021
Pressure Relief Valves	-	0.96	-	kg CH_4 mile^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Blowdowns	-	1.96	-	kg CH_4 mile^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023

Table 6 continued

Emissions Source	EF			EF Unit	Geography	Recency	Methodology	Status	Source
	Low	Mid	High						
Damages	-	30.62	-	kg CH_4 mile^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – M&R >300	-	2,142.70	-	kg CH_4 station^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – M&R 100-300	-	995.40	-	kg CH_4 station^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – M&R <100	-	727.20	-	kg CH_4 station^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – Reg >300	-	868.90	-	kg CH_4 station^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – R-vault >300	-	50.60	-	kg CH4 station-1 year-1	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – Reg 100-300	-	143.40	-	kg CH4 station-1 year-1	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – R-vault 100-300	-	50.60	-	kg CH4 station-1 year-1	🟥	🟦	🟦	🟨	EPA 2023

Table 6 Continued

Emissions Source	EF			EF Unit	Geography	Recency	Methodology	Status	Source
	Low	Mid	High						
Metering and Regulating Stations – Reg 40-100	-	163.70	-	kg CH_4 station^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – R-vault 40-100	-	50.60	-	kg CH_4 station^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Metering and Regulating Stations – Reg <40	-	22.40	-	kg CH_4 station^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Meters: Residential	-	0.0015	-	MTCH_4 meter^{-1} yr^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Meters: Commercial	-	0.0097	-	MTCH_4 meter^{-1} yr^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Industrial Meters	-	105.00	-	kg CH_4 meter^{-1} year^{-1}	🟥	🟦	🟦	🟨	EPA 2023
Residential Appliances – NG Furnace	0.14	0.22	0.51	kg CH4 appliance^{-1} year^{-1}	🟦	🟦	🟦	🟦	Merrin and Francisco 2019
Residential Appliances – NG Boiler	0.15	0.32	0.75	kg CH4 appliance^{-1} year^{-1}	🟦	🟦	🟦	🟦	Merrin and Francisco 2019

Table 6 Continued

Emissions Source	EF			EF Unit	Geography	Recency	Methodology	Status	Source
	Low	Mid	High						
Residential Appliances – NG Storage Water Heater	0.02	0.077	0.084	kg CH_4 appliance^{-1} year^{-1}	🟦	🟦	🟦	🟦	Merrin and Francisco 2019
Residential Appliances – NG Tankless Water Heater	0.98	1.2	41	kg CH_4 appliance^{-1} year^{-1}	🟦	🟦	🟦	🟦	Merrin and Francisco 2019
Residential Appliances – NG Stove	0.04	0.056	0.071	kg CH_4 appliance^{-1} year^{-1}	🟦	🟦	🟦	🟦	Merrin and Francisco 2019
Residential Appliances – NG Oven	0.11	0.13	0.14	kg CH_4 appliance^{-1} year^{-1}	🟦	🟦	🟦	🟦	Merrin and Francisco 2019
Residential Buildings	0.0011	0.0018	0.0035	MTCH_4 housing unit^{-1} year^{-1}	🟥	🟦	🟦	🟦	Fischer et al. 2018a, Fischer et al. 2018b
Commercial Buildings - Hospitals	93.82	202.385	310.95	kg CH_4 hospital^{-1} year^{-1}	🟥	🟦	🟦	🟨	Sweeney et al. 2020
Commercial Buildings - Restaurants	0.0381	0.0480	0.0592	MTCH_4 restaurant^{-1} year^{-1}	🟥	🟦	🟦	🟨	Sweeney et al. 2020
Commercial Buildings - Education	-	0.007965	-	MTCH_4 building^{-1} year^{-1}	🟥	🟦	🟦	🟨	ICF 2020

Table 6 Continued

Emissions Source	EF			EF Unit	Geography	Recency	Methodology	Status	Source
	Low	Mid	High						
Commercial Buildings - Lodging	-	0.009035	-	MTCH4 building^{-1} year^{-1}	🟥	🟦	🟦	🟨	ICF 2020
Commercial Buildings - Office	-	0.00645	-	MTCH4 building^{-1} year^{-1}	🟥	🟦	🟦	🟨	ICF 2020
Commercial Buildings - Warehouse	-	0.005605	-	MTCH4 building^{-1} year^{-1}	🟥	🟦	🟦	🟨	ICF 2020
Commercial Buildings - Retail	-	0.0009898	-	MTCH4 building^{1} year^{-1}	🟥	🟦	🟦	🟨	ICF 2020

3.2.4 Activity Data Summary

Presented in Table 7 are activity data descriptions and data sources by emissions source, along with flags for whether activity data were based on assumptions, whether an allocation method was applied to obtain county-level activity, and whether data cleansings were performed to remove suspected outliers.

Table 7. Activity Data Summary for Activity Data Used in the Improved New York State Inventory

Emissions Source	Activity Data Description	Activity Data Based on Assumption	Allocation Method Applied	Data Cleansing Performed	Source
Drill Rigs	Drilling days	X		X	DEC 2022; ESOGIS 2022
Fugitive Drilling Emissions	Count of well completions				DEC 2022; ESOGIS 2022
Oil Well: Mud Degassing	Drilling days for oil wells	X		X	DEC 2022; ESOGIS 2022
Gas Well: Mud Degassing	Drilling days for gas wells	X		X	DEC 2022; ESOGIS 2022
Oil Well: Completions	Count of oil well completions				DEC 2022; ESOGIS 2022
Gas Well: Completions	Count of gas well completions				DEC 2022; ESOGIS 2022
Oil Well: Conventional Production	Mcf of associated gas production				DEC 2022; ESOGIS 2022
Gas Well: Conventional Production	Mcf of gas production				DEC 2022; ESOGIS 2022
Oil Well: Unconventional Production	Mcf of associated gas production	No activity in NYS			
Gas Well: Unconventional Production	Mcf of gas production	No activity in NYS			
Gas: Abandoned Wells	Count of abandoned gas wells				DEC 2022; ESOGIS 2022
Oil: Abandoned Wells	Count of abandoned oil wells	X			DEC 2022; ESOGIS 2022
Oil: Gathering and Processing	Mcf of associated gas production				DEC 2022; ESOGIS 2022
Gas: Gathering and Processing	Mcf of natural gas production				DEC 2022; ESOGIS 2022
Gathering Pipeline	Miles of pipeline	X	X		PHMSA 2022

Table 7 continued

Emissions Source	Activity Data Description	Activity Data Based on Assumption	Allocation Method Applied	Data Cleansing Performed	Source
Oil: Truck Loading	Bbls of crude oil loaded into trucks		X	X	ESOGIS 2022
Gas: Truck Loading	Mcf of gas loaded into trucks	No activity in NYS			
Gas Processing Plant	Count of gas processing plants	No activity in NYS			
Transmission Pipeline	Miles of pipeline		X	X	PHMSA 2022
Gas Transmission Compressor Stations	Count of gas transmission compressor stations	X			PHMSA 2022, NYSDEC permitting database
Gas Storage Compressor Stations	Count of gas storage compressor stations				NYSDEC permitting database
Storage Reservoir Fugitives	TBD—no data available				
LNG Storage Compressor Stations	Count of LNG Storage Compressor Stations				NYSDEC database
LNG Terminal	Count of terminals	No activity in NYS			
Cast Iron Distribution Pipeline: Main	Miles of pipeline		X	X	PHMSA 2022
Cast Iron Distribution Pipeline: Services	Miles of pipeline		X	X	PHMSA 2022
Unprotected Steel Distribution Pipeline: Main	Miles of pipeline		X		PHMSA 2022
Unprotected Steel Distribution Pipeline: Services	Miles of pipeline		X	X	PHMSA 2022
Protected Steel Distribution Pipeline: Main	Miles of pipeline		X	X	PHMSA 2022
Protected Steel Distribution Pipeline: Services	Miles of pipeline		X	X	PHMSA 2022

Table 7 continued

Emissions Source	Activity Data Description	Activity Data Based on Assumption	Allocation Method Applied	Data Cleansing Performed	Source
Plastic Distribution Pipeline: Main	Miles of pipeline		X		PHMSA 2022
Plastic Distribution Pipeline: Services	Miles of pipeline		X		PHMSA 2022
Copper Distribution Pipeline: Main	Miles of pipeline	No activity in NYS			
Copper Distribution Pipeline: Services	Miles of pipeline		X	X	PHMSA 2022
Metering and Regulating Stations	Count of stations	X	X		EPA 2023
Pressure Relief Valves	Miles of pipeline		X	X	PHMSA 2022
Damages	Miles of pipeline		X	X	PHMSA 2022
Blowdowns	Miles of pipeline		X	X	PHMSA 2022
Meters: Residential	Count of services		X		PHMSA 2022
Meters: Commercial	Count of services		X		PHMSA 2022
Meter: Industrial	Count of services		X		PHMSA 2022
Residential Appliances	Count of appliances	X			EIA 2018b; U.S. Census Bureau 2022a
Residential Buildings	Count of buildings				U.S. Census Bureau 2022a
Commercial Buildings	Count of buildings	X			U.S. Census Bureau 2022b

3.2.5 Upstream Stages

3.2.5.1 Drill Rigs

Source Category Description

Drill rigs are machines used to drill holes in the Earth's crust for oil wells and natural gas extraction wells, among other types of wells. They can be massive or small to medium-sized structures. Factors influencing the size and type of rigs are whether or not directional drilling is being performed, the size of the operation, the anticipated length and intensity of the operation, and the depth and range of the well. The small to medium-sized rigs are also called mobile rigs as they are mounted on trucks or trailers and can be easily transferred from one location to another. There are two primary rig types: mechanical and a combination of diesel and electric. Some of the major components of drill rigs are mud tanks, mud pumps, a derrick, a rotary table, a drill string, draw works, and primary and auxiliary power equipment. CH_4 emissions from drill rigs occur from on-site power generation and are correlated to cumulative feet drilled.

Emission Factors

<table>
<tr><th>Drill Rig Engine Power (hp)</th><td colspan="2">300 to 600</td><td colspan="2">600 to 750</td><td colspan="2">750 to 3000</td></tr>
<tr><th>Default EF (g/hp-hr)</th><td colspan="2">0.004</td><td colspan="2">0.003</td><td colspan="2">0.006</td></tr>
<tr><th>EF Source</th><td colspan="6">EPA NONROAD2008 Model</td></tr>
<tr><th>EF Confidence</th><td>Geography Marcellus/ Appalachian Basin</td><td colspan="2">Recency 6-15 Years</td><td colspan="2">Methodology Engineering Estimate</td><td>Status Grey Literature</td></tr>
<tr><th>EF Source Description</th><td colspan="6">This is the default EF from the EPA Oil and Gas Tool, which in turn is based on data from the CenSARA (2012) study. The CenSARA study domain covers basins in Texas, Louisiana, Oklahoma, Arkansas, Nebraska, Kansas, and Missouri. The CenSARA study estimated emissions from drill rigs based on an engineering calculation factoring in hp; EF; load; hours of operation; and the number of draw works, mud pumps, and generator engines. The EF is described as the average EF from the EPA NONROAD2008 model. Drill rig EFs derived from EPA's NONROAD2008 model have been widely applied to state-level emission inventories and represent a comprehensive source of drill rig emission estimates.</td></tr>
</table>

Activity Data

In calculating activity data for drilling rigs, the approach does not distinguish between oil- and gas-directed rigs because once a well is completed it may produce both oil and gas. The activity data, calculated as drilling days, were derived from the Empire State Organized Geologic Information System (ESOGIS). This database contains information on all wells in New York State, including county location, well type, spud date, and completion date. The number of drilling days per well was calculated as the completion date minus the spud date for all well types, including "gas development," "gas wildcat," "gas extension," "dry wildcat," "dry hole," "monitoring storage," "storage," "oil development," "oil extension," "oil wildcat," and "enhanced oil recovery-injection." To correct for outliers, if the calculated drilling days exceeded 50 for a given well, the drilling days for that well were set to 22. The average drilling time of 22 days is based on an assessment of peer-reviewed literature, such as Roy et al. (2014), and engineering judgment based on the specific characteristics of State geological formations. Once well-level drilling days were calculated for each well, the drilling days were summed to the county level.

Since the EFs are based on horsepower hour (hp-hr), information on the average engine size of 402 hp was pulled from EPA's Oil and Gas Tool. The average in the tool is based on the CenSARA study (2012) for diesel-vertical drill rig engines. The hp-hr was calculated by multiplying the number of drilling days by 24 hours per day times the average engine horsepower.

The CH_4 emissions were converted from grams to MTs using a conversion factor of $1e^{-6}$. The MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5, 20}$ factor of 84.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the ESOGIS database contains information at the well level for all analysis years.

Sample Calculations

Equation 4 CH_4 emissions ($MTCO_2e$) = DD x 24 hr/day x hp x EF x CF x $GWP_{AR4, 100}$

where:

- DD = drilling days
- hp = average horsepower of drill rig engine = 402
- EF = CH_4 EF (g/hp-hr) = 0.004
- CF = conversion factor from g to MTs = $1e^{-6}$
- $GWP_{AR5, 20}$ = GWP = 84

For example, there were 3,974 days of drilling in Cattaraugus County in 2010, resulting in 3.83 $MTCO_2e$:

- Drill rig CH_4 ($MTCO_2e$) = 3,974 x 24 hr/day x 402 x 0.004 x $1e^{-6}$ x 25
- Drill rig CH_4 ($MTCO_2e$) = 3.83 $MTCO_2e$

Limitations and Uncertainties

The CenSARA study applies EFs derived for EPA's NONROAD2008 model, which in turn updates the NONROAD2005 model, including no substantive changes for drill rigs. As a result, these EFs are derived from data that are over a decade old. Although the CenSARA study and NONROAD models are not New York State-specific, dill rig engine EFs are unlikely to vary across states. Drill rig engine hp is likely to show the greatest regional variation.

Potential Areas of Improvement

This inventory applies an average drill rig engine power of 402 hp, derived from the EPA Oil and Gas Tool and based on the CenSARA study. This value could be updated to better reflect New York State given better information on the sizes, loads, and primary engine types. In addition, as noted, these EFs, used widely in the EPA Oil and Gas Tool, are over a decade old and may need updating.

3.2.5.2 Fugitive Drilling Emissions

Source Category Description

The first step in completing a well is to case the hole. Casing ensures that the well will not close after removal of drilling fluids and protects the well stream from outside incumbents like water or sand. The next step in well completion involves cementing the well, which includes pumping cement slurry into the well to displace existing drilling fluids and filling in the space between the casing and the actual sides of the drilled well. At the reservoir level, there are two types of completion methods used on wells:

open- or cased-hole completions. An open-hole completion refers to a well that is drilled to the top of the hydrocarbon reservoir. The well is then cased at this level and left open at the bottom. Cased-hole completions require casing to be run in to the reservoir. In order to achieve production, the casing and cement are perforated to allow the hydrocarbons to enter the well stream.

Emission Factors

Source Category	Fugitive drilling emissions			
Default EF (MTCH4 well-1)	0.0521			
Source	EPA 2018b, Annex 3.6-2			
EF Confidence	Geography Rest of the Country	Recency 15+ years	Methodology Engineering Estimate	Status Grey Literature
EF Source Description	This EF is provided by EPA’s 2018 Greenhouse Gas Emission Inventory (EPA 2018a) and is in turn derived from the 1992 Radian/API report, “Global Emissions of Methane from Petroleum Sources.” API Report No. DR140.			

Activity Data

In calculating activity data for drilling rigs, the approach does not distinguish between oil- and gas-directed rigs because once a well is completed it may produce both oil and gas. The activity data, calculated as the count of well completions, were derived from the ESOGIS. This database contains information on all wells in New York State, including county location, well type, and completion date. The number of well completions is based on the reported well completion date for well types including “gas development,” “gas wildcat,” “gas extension,” “dry wildcat,” “dry hole,” “monitoring storage,” “storage,” “oil development,” “oil extension,” “oil wildcat,” and “enhanced oil recovery-injection.” The number of well completions were summed by year of completion to the county level.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the ESOGIS database contains information at the well level for all analysis years.

Sample Calculations

Equation 5 CH_4 **emissions (** $MTCO_2e$ **) = well completions x EF x CF x** $GWP_{AR5, 20}$

where:

- Well completions = count of well completions
- EF = CH_4 EF ($MTCH_4$ $well^{-1}$) = 0.0521
- $GWP_{AR5, 20}$ = GWP = 84

For example, there were 45 well completions in Cattaraugus County in 2020, resulting in 660.8 $MTCO_2e$:

Fugitive drilling CH_4 **(** $MTCO_2e$ **) = 45 x 0.0521 x 84 Fugitive drilling** CH_4 **(** $MTCO_2e$ **) = 660.8** $MTCO_2e$

Limitations and Uncertainties

The EF for fugitive emissions from well drilling is taken from an older study, which may not reflect current best practices for CH_4 capture during drilling. In addition, the study might not reflect likely borehole conditions for New York State, which may be subject to different pressures and porosity than those conditions in the study.

Potential Areas of Improvement

This estimate may be improved by updating the EF based on empirical study of fugitives during drilling operations in the Northeast or Appalachian Basin and would be best tailored to New York State if the drilling observations were taken in the State.

3.2.5.3 Mud Degassing

Source Category Description

Drilling mud is the liquid added to the wellbore to facilitate the drilling process by suspending cuttings, controlling pressure, stabilizing exposed rock, providing buoyancy and cooling, and lubricating the drill bit. Drilling fluids can be water-, oil-, or synthetic-based. Drilling fluids are used as a suspension tool to keep cuttings from refilling the borehole and to control pressure in a well by providing hydrostatic pressure to offset the pressure of the hydrocarbons and the rock formations. Weighing agents are added to the drilling fluids to increase their density and, therefore, their pressure on the well walls. Another important function of drilling fluid is rock stabilization. Special additives are used to ensure that the drilling fluid is not absorbed by the rock formation in the well and that the pores of the rock formation are not clogged. The deeper the well, the more drill pipe is needed to drill the well. This amount of drill pipe gets heavy, and the drilling fluid adds buoyancy, which reduces stress. Additionally, drilling fluid helps to reduce heat by minimizing friction with the rock formation. The lubrication and cooling prolong the life of the drill bit.

Mud degassing refers to the removal of air or gases such as CH_4, hydrogen sulfide (H_2S), and CO_2 in the drilling mud once it is outside of the wellbore. The major source of CH_4 is the release of entrained natural gas from the drilling mud.

Emission Factors

<table>
<tr><td>Source Category</td><td colspan="4">Mud Degassing: Gas and Oil wells</td></tr>
<tr><td>Default EF (MTCH4 drillingday^{-1})</td><td colspan="4">0.2605</td></tr>
<tr><td>Source</td><td colspan="4">EPA Oil and Gas Tool</td></tr>
<tr><td>EF Confidence</td><td>Geography
Rest of the Country</td><td>Recency 15 + Years</td><td>Methodology
Engineering Estimate</td><td>Status Grey Literature</td></tr>
<tr><td>Source Description</td><td colspan="4">This is the default EF from the EPA Oil and Gas Tool, which is in turn based on data from the CenSARA (2012) study. The CenSARA study domain covers basins in Texas, Louisiana, Oklahoma, Arkansas, Nebraska, Kansas, and Missouri. The CenSARA study derives default EFs from the Bureau of Ocean Energy Management's (BOEM's) inventory of emissions in the Gulf of Mexico (Wilson et al., 2007), which is in turn based on the 1977 EPA report, Atmospheric Emissions from Offshore Oil and Gas Development and Production, which states that BOEM were unable to find sources of the data but estimates total gaseous hydrocarbon emissions to be 0.4 Mg.d-1 based on engineering calculations, factoring in bore depth and diameter, porosity, and pressure. This EF, though derived from older engineering estimates, has been widely applied to national and state-level emission inventories, and communication with experts indicates that no more recent estimates are available.</td></tr>
</table>

Activity Data

The activity data, calculated as drilling days, were derived from ESOGIS. This database contains information on all wells in New York State, including county location, well type, spud date, and completion date. The number of drilling days per well was calculated as the completion date minus the spud date. For the estimate of oil well drilling days, the well types included were "oil development," "oil extension," "oil wildcat," and "enhanced oil recovery-injection." For the estimate of natural gas well drilling days, the well types included were "gas development," "gas extension," "gas wildcat," "dry wildcat," "dry hole," "monitoring storage," and "storage." To correct for outliers, if the calculated drilling days exceeded 50 for a given well, the drilling days for that well were set to 22. The average drilling time of 22 days is based on an assessment of peer-reviewed literature, such as Roy et al. (2014), and engineering judgment is based on the observed drilling days in the New York State well data. Once well-level drilling days were calculated for each well, the drilling days were summed to the county level.

CH_4 emissions were calculated as the total drilling days times the EF. The MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5,\,20}$ factor of 84.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the ESOGIS database has information at the well level for all analysis years.

Sample Calculations

Equation 8 CH_4 **emissions** ($MTCO_2e$) **= DD x EF x** $GWP_{AR5,\,20}$

where:

- DD = drilling days
- EF = CH_4 EF ($MTCH_4$ drillingday^{-1}) = 0.2605
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there were 230 days of natural gas well drilling in Cattaraugus County in 2010, resulting in 1,498 $MTCO_2e$:

Equation 9 **Mud degassing** CH_4 ($MTCO_2e$) **= 230 x 0.2605 x 84 = 1,498** $MTCO_2e$

Limitations and Uncertainties

The EF for mud degassing is based on a best guess, specific to offshore oil and gas development, from 1977 data. The limitations and uncertainty of applying this estimate involve appropriateness for application to onshore formations, bore diameters and depths in use in the State, as well as porosity and reservoir pressures. Uncertainty in these calculations is a function of the CH_4 fraction of total hydrocarbon emissions from mud degassing, which is modeled as 65% on the lower bound, 81% for the central estimate, and 95% for the upper bound.

Potential Areas of Improvement

The mud degassing EF may be improved by tailoring the estimate of total gaseous hydrocarbon emissions to New York State-specific bore depths and diameters, as well as reservoir porosity, pressures, and CH$_4$ fraction of total gaseous hydrocarbons.

3.2.5.4 Well Completion

Source Category Description

Well completion is the process of making an oil or natural gas well ready for production. After casing and cementing during well drilling, the completion phase starts with perforation through the production formation, followed by any treatment such as acidizing or fracturing. The last step in completing a well is to install a wellhead at the surface of the well. Often called a production tree or Christmas tree, the wellhead device includes casingheads and a tubing head combined to provide surface control of well subsurface conditions. The main source of CH$_4$ emissions from the completion phase occurs during the flowback period following fracturing.

Emission Factors

Source Category	Well Completions: Gas and Oil Wells			
Default EF (MTCH$_4$ completion^{-1})	1.7			
Source	Allen et al. 2013			
EF Confidence	Geography Marcellus/ Appalachian Basin	Recency 6-15 Years	Methodology Empirical Observation	Status Peer-Reviewed
Source Description	Allen et al. (2013) analyzed well completion flowback events at 190 onshore natural gas sites in the United States. Measured values over the completion event varied from 0.01 Mg CH$_4$ to 17 MgCH$_4$, with a mean of 1.7 MgCH$_4$ emitted per event (95% CI 0.67-3.3 MgCH$_4$ per well completion). Emissions were estimated over 27 events using direct measurements at the flowback tank as well as tracer-ratio measurements to produce site-level EFs. This study is peer reviewed, widely cited, and presents empirical data from observations of Appalachian well completions.			

Activity Data

The activity data, calculated as number of wells, were derived from ESOGIS. This database contains information on all wells in the State, including county location, well type, and completion date.
To estimate the number of wells, the count of wells by county and year was based on type. For oil

wells, the well types included were "oil development," "oil wildcat," "oil extension," and "enhanced oil recovery," and for gas wells, the well types included were "gas development," "gas wildcat," "gas extension," "gas wildcat," "dry hole," "monitoring storage," and "storage."

CH_4 emissions were calculated as the well count times the EF. MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5, 20}$ factor of 84.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the ESOGIS database has information at the well level for all analysis years.

Sample Calculations

Equation 10 $\quad$ CH_4 **emissions** ($MTCO_2e$) **= well count x EF x** $GWP_{AR5, 20}$

where:

- well count = number of wells
- EF = CH_4 EF ($MTCH_4$ completion^{-1}) = 1.7
- $GWP_{AR5, 20}$ = GWP = 84

For example, there were seven natural gas well completions in Cattaraugus County in 2010, resulting in 298 $MTCO_2e$:

Natural gas well completion CH_4 ($MTCO_2e$) = 7 x 1.7 x 84 Natural gas well completion CH_4 ($MTCO_2e$) = 298 $MTCO_2e$

Limitations and Uncertainties

The primary source of uncertainty in this EF results from a limited sample size. The mean value is estimated based on measurements from five completion flowbacks in the Appalachian region, seven in the Gulf region, five in the mid-continent, and 10 in the Rocky Mountain region. Well completion flowback duration was also shown to affect the magnitude of emissions per well completion.

Potential Areas of Improvement

The central estimate for emissions per well completion flowback event is derived from a rigorous peer-reviewed study of well completions around the country. Hourly rates of CH_4 emissions varied widely, indicating the importance of estimating uncertainty using 95% confidence intervals (CI). In addition, this estimate may be improved by estimating emissions at New York State wells during completion, as a large portion of the wells observed were hydraulically fractured.

3.2.5.5 Conventional Production

Source Category Description

The production of conventional oil and gas applies to oil and gas extracted by the natural pressure of the wells after the drilling operations. Unconventional resources require pumping or compression operations to liberate resources from formations where the borehole pressure is too low. After the depletion of maturing fields, the natural pressure of the wells may be too low to produce significant quantities of oil and gas. Different techniques may be used to boost production, mainly water and gas injection or depletion compression, but these oil and gas fields will still be conventional resources. Beyond the use of classical methods of enhanced oil recovery or artificial lift, the oil and gas production is classified as unconventional. There is no unconventional oil and gas production in the State.

Emission Factors

Source Category	Oil Well: Conventional Production	Oil Well: Unconventional Production	Gas Well: Conventional Production	Gas Well: Unconventional Production
Default EF (% of production)	≤ 10 MSCFD: 25.4% > 10 MSCFD: 7.2%	≤ 10,000 MSCFD: 0.15% > 10,000 MSCFD: 0.03%	≤ 10 MSCFD: 25.4% > 10 MSCFD: 7.2%	≤ 10,000 MSCFD: 0.15% > 10,000 MSCFD: 0.03%
Source	Omara, Sullivan, Li, Subramanian, et al. 2016			
EF Confidence	Geography Marcellus/Appalachian Basin	Recency 6-15 Years	Methodology Empirical Observation	Status Peer Reviewed
Source Description	Omara et al., 2016 measured facility-level emissions, comparing conventional and unconventional natural gas sites in West Virginia and Pennsylvania. The range of emissions estimates over the 18 conventional and 13 unconventional sites varied widely, with unconventional sites generally producing much more natural gas but having lower emission rates relative to production. The 25th percentile and 75th percentile represent the upper and lower bounds for uncertainty analysis. The median EFs are presented in this table and used in the New York State inventory.			

Activity Data

The activity data, calculated as volume of associated gas production from oil wells and the natural gas production from natural gas wells, were derived from ESOGIS. This database contains information on all wells in New York State, including county location, well type, and the volume of natural gas produced by year. To estimate the quantity of natural gas produced, the volume produced by county and year was based on well type and well status. For oil wells, the well type included "oil development," "oil extension," and "enhanced oil recovery-injection," and the well status included "active," "drilled deeper," "drilling completed," "plugged back," and "plugged back multilateral." For natural gas wells, the well type included "gas development," "gas extension," and "gas wildcat," and the well status included "active," "drilled deeper," "drilling completed," "plugged back," and "plugged back multilateral." Once wells were identified in the ESOGIS database as producing associate gas or natural gas, the wells were binned into low-producing (≤ 10 MSCFD for gas wells and ≤ 10,000 MSCFD for oil wells) and high-producing wells (>10 MSCFD for gas wells and >10,000 MSCFD for oil wells).

CH_4 emissions were calculated for each category of well production as the volume of natural gas production converted from volume to mass using the ideal gas law times the EFs. MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5, 20}$ factor of 84.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the ESOGIS database has information at the well level for all analysis years.

Sample Calculations

Equation 11 CH_4 emissions ($MTCO_2e$) = production x CF x EF x $GWP_{AR5, 20}$

where:

- production = volume of natural gas produced (Mcf)
- CF = conversion from Mcf to MTs = [(CH_4 molecular weight / ideal gas law conversion factor)/2,000] x 1,000 cf/Mcf x 0.907185 MTs/short ton
- CF = (1000 x 16.043/379.3)/2000 x 0.907185 = 0.019185 MTs/Mcf
- EF = CH_4 EF (fraction of production) = 0.254 for low producing natural gas wells
- $GWP_{AR5, 20}$ = GWP = 84

For example, there were 531,298 Mcf of natural gas produced from low producing natural gas wells in Cattaraugus County in 2020, resulting in 217,476 $MTCO_2e$ as shown:

$$\textbf{Low producing conventional gas well } \mathbf{CH_4\ (MTCO_2e) = 531{,}298 \times 0.019185 \times 0.254 \times 84}$$

$$\textbf{Low producing conventional gas well } \mathbf{CH_4\ (MTCO_2e) = 217{,}476\ MTCO_2e}$$

Limitations and Uncertainties

Omara et al. (2016) show significant differences in emissions between conventional emissions and emissions from high-volume hydraulic fracturing in shale gas formations. Furthermore, these estimates indicate that natural gas production is an important component of emission estimation. The sample size for conventional and unconventional wells is small, and thus uncertainty around the central estimates would be improved by increasing the sample.

Potential Areas of Improvement

These EFs are derived from a broad population but are not New York State-specific. As such, while these estimates may encompass the State EFs, further study of these wells would be necessary to determine State-specific estimates of production emissions.

3.2.5.6 Abandoned Wells

Source Category Description

When a well is finished producing, it is typically abandoned. Abandoned wells may be either plugged or orphaned—and thereby not plugged. Plugging and abandoning the well can take various forms. Each state has specific requirements that govern well abandonment. In New York State, regulations require that certain wells are plugged once operations cease. Plugs are strategically placed to prevent migration of residual oil and gas to other zones, aquifers, or to the surface. Sometimes, when CO_2 has been used for enhanced secondary or tertiary recovery, part of the abandonment procedure involves blowing down the well to release any existing pressure. If this is done, large amounts of gas could be released into the atmosphere. After abandonment, some wells can continue to emit CH_4.

Emission Factors

Source Category	Oil: Abandoned Wells
Default EF (MTCH$_4$ well^{-1} yr^{-1})	0.09855
Source	Kang et al. 2014
EF Confidence	Geography Marcellus/ Appalachian Basin Recency 6-15 Years Methodology Empirical Observation Status Peer Reviewed
Source Description	Kang et al. (2014) measured CH$_4$ emissions from abandoned oil and gas wells in Pennsylvania. Mean emissions were 0.27 kg well^{-1} day^{-1} or 0.09855 MTCH4 well^{-1} yr^{-1}. A static flux chamber methodology was used to measure gaseous emissions from abandoned wellheads and surrounding soil-plant systems, as well as for controls containing no wellhead. This widely cited, peer-reviewed study provides recent EF estimates, derived using empirical observations from abandoned oil and gas wells in two Pennsylvania counties that border New York State.

Source Category	Gas: Abandoned Wells
Default EF (MTCH4 well^{-1} yr^{-1})	0.0878
Source	Townsend-Small et al. 2016
EF Confidence	Geography Rest of the Country Recency 6-15 Years Methodology Empirical Observation Status Peer Reviewed
Source Description	Townsend-Small et al. (2016) measured CH$_4$ emissions from 138 abandoned oil and gas wells in Wyoming, Colorado, Utah, and Ohio. Of the plugged wells, 6.5% had measurable emissions. Mean emissions for all wells (plugged and unplugged) were 10.02 g well^{-1} hr^{-1}, which translates to 0.0878 MTCH$_4$ well^{-1} yr^{-1}. Emissions from pressurized and leaking wellhead components were measured using a high-flow sampler, while emissions from underground and smaller leaks were measured using the static flux chamber method. This study provides recent, peer-reviewed, empirically observed CH$_4$ emission rates from a population of 138 abandoned oil and gas wells.

Activity Data

Activity data, calculated as the number of abandoned wells, were derived from ESOGIS. This database contains information on all wells in the State, including county location, well type, and well status. To estimate the number of abandoned wells, the count of wells by county and year was based on well type and well status. For oil wells, the well type included “oil development,” “oil extension,” “oil wildcat,” and “enhanced oil recovery-injection,” and the well status included “Inactive,” “Not

Reported on AWR," "Shut-In," "Temporarily Abandoned," and "Unknown." For natural gas wells, the well type included "Dry Hole," "Dry Wildcat," "Gas Development," "Gas Extension," "Gas Wildcat," "monitoring storage," and "storage," and the well status included "Inactive," "Not Reported on AWR," "Shut-In," "Temporarily Abandoned," and "Unknown."

To correct for missing data in the ESOGIS database, the number of abandoned oil wells for years 1990 to 1999 were set equal to the number of abandoned oil wells in year 2000.

CH_4 emissions were calculated as the well count times the EFs. The MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5,\,20}$ factor of 84.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the ESOGIS database has information at the well level for all analysis years.

Sample Calculations

Equation 12 CH_4 **emissions** ($MTCO_2e$) **= well count x EF x** $GWP_{AR5,\,20}$

where:

- well count = number of wells
- EF = CH_4 EF ($MTCH_4$ abandoned well^{-1} yr^{-1})
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there were 55 abandoned natural gas wells in Cattaraugus County in 2020, resulting in 405.6 $MTCO_2e$ as shown:

Equation 13 **Abandoned natural gas well** CH_4 ($MTCO_2e$) **= 55 x 0.0878 x 84 Abandoned natural gas well** CH_4 ($MTCO_2e$) **= 405.6** $MTCO_2e$

Limitations and Uncertainties

Both Kang et al. (2014) and Townsend-Small et al. (2016) sampled a relatively small number of oil and gas wells. Given available information, Kang et al. (2014) were unable to distinguish between oil and gas wells, nor did they find a significant difference between plugged and abandoned or orphaned wellheads. Townsend-Small et al. (2016) additionally stress the importance of accounting for regional differences in CH_4 emissions from abandoned and plugged well sites.

Potential Areas of Improvement

Following advice presented in the studies from which these EFs were derived, the EFs should be better tailored to oil or natural gas wells, which were poorly identified in the literature, and in the State are shown to not be distinctive from one another in many instances. In addition, due to differences between New York State and Pennsylvania drilling practices, the EF estimates given here may be improved by employing State-specific sampling and measurements.

In addition, abandoned wells, as defined, should not include shut-in or temporarily abandoned because these status types are applied to idle producing wells. They are included as abandoned wells in this inventory since data on EFs for idle producing wells did not exist in the research literature. The inclusion of the idle wells in the abandoned well source category is relatively insignificant to overall oil and natural gas sector emissions, accounting for less than 0.002% of total emissions.

3.2.6 Midstream Stages

3.2.6.1 Gathering Compressor Stations

Source Category Description

Gathering and processing encompasses all operations between the well site delivery meter and the receipt meter to the transmission segment or local distribution. Systems include gathering pipelines, gathering facilities, and processing plants; equipment includes gathering pipelines, separators, compressors, acid gas removal units, dehydrators, pneumatic devices/pumps, storage vessels, engines, boilers, heaters, and flares. Gathering compressor stations collect oil or natural gas from multiple wells, compress it and discharge it to another location (i.e., another gathering facility, transmission line, or processing plant). Gathering compressor stations often include inlet separators to remove water and/or hydrocarbon condensate, dehydration systems to remove gaseous H_2O, and amine treatment systems. Processing plants often include the same operations but also include systems to remove ethane and/or LNG.

Emission Factors

Source Category	Natural Gas Gathering Compressor Stations			
Default EF (% of production)	0.4			
Source	Marchese et al. 2015			
EF Confidence	Geography Marcellus/ Appalachian Basin	Recency 6-15 Years	Methodology Empirical Observation	Status Peer Reviewed
Source Description	Marchese et al (2015) studied CH_4 emissions at 114 gathering facilities in the United States using downwind tracer flux methodology. Emission rates varied widely from 2 to 600 kg h^{-1}, corresponding to normalized emission rates of 0.4% of throughput, or 42.6 kgCH4 facility-1 hr^{-1}. This peer-reviewed study includes emissions estimates from sites in states adjacent to New York State, providing empirically observed region al emissions estimates from gathering and processing facilities and is validated by results from Mitchell et al. (2015), who found CH_4 emissions of 0.2% of throughput in Pennsylvania gathering facilities.			

Activity Data

Throughput was assumed to be equal to production. As such, activity data, calculated as volume of associated gas production from oil wells and the natural gas production from natural gas wells, were derived from ESOGIS. This database contains information on all wells in New York State, including county location, well type, and the volume of natural gas produced by year. To estimate the quantity of natural gas produced, the volume produced by county and year was based on well type and well status. For oil wells, the well type included “oil development,” “oil extension,” and “enhanced oil recovery-injection,” and the well status included “active,” “drilled deeper,” “drilling completed,” “plugged back,” and “plugged back multilateral.” For natural gas wells, the well type included “ gas development,” “gas extension,” and “gas wildcat,” and the well status included “active,” “drilled deeper,” “drilling completed,” “plugged back,” and “plugged back multilateral.”

CH_4 emissions were calculated as the volume of natural gas production converted from volume to mass using the ideal gas law times the EFs. The MTs of CH_4 were converted to MTCO2e by applying the $GWP_{AR5, 20}$ factor of 84.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the ESOGIS database has information at the well level for all analysis years.

Sample Calculations

Equation 14 $\mathbf{CH_4}$ **emissions** $\mathbf{(MTCO_2e)}$ **= production x CF x EF x** $\mathbf{GWP_{AR5,\,20}}$

where:

- production = volume of natural gas produced (Mcf)
- CF = conversion from Mcf to MTs = [(CH_4 molecular weight / ideal gas law conversion factor)/2,000] x 1,000 cf/Mcf x 0.907185 MTs/short ton
- CF = (1000 x 16.043/379.3)/2000 x 0.907185 = 0.019185 MTs/Mcf
- EF = CH_4 EF (fraction of production) = 0.004
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there were 633,693 Mcf of natural gas produced from gas wells in Cattaraugus County in 2020, resulting in 4,278.3 $MTCO_2e$ as shown:

Equation 15 **Gathering and processing station CH4** $\mathbf{(MTCO_2e)}$ **= 663,693 x 0.019185 x 0.004 x 84**
Gathering and processing station CH4 $\mathbf{(MTCO_2e)}$ **= 4,278.3** $\mathbf{MTCO_2e}$

Limitations and Uncertainties

The results of this study showed a “fat tail” distribution, with a large number of low-emitting sites, and a comparatively small number of high-emitting sites. Furthermore, these estimates are estimated at the site level, corresponding to specific component counts, which may not reflect typical site-level components in the State. As such, it is important to perform sensitivity analysis around this estimate.

Potential Areas of Improvement

These estimates may be improved by better understanding the frequency of high-emitting sites in the State, which complicate the application of a single normalized emissions rate to the general population.

3.2.6.2 Gathering Pipeline

Source Category Description

Gathering pipelines transport gases and liquids from the source of production (well pad) to storage tanks or to the processing facility, refinery, or transmission line. Gathering pipelines are commonly fed by flowlines, each connected to individual wells in the ground. In a gathering pipeline, raw gas is usually carried at pressures from 0–900 pounds per square inch (psi). Compared to other pipelines, lengths in this category are relatively short—approximately 200 meters long.

Emission Factors

<table>
<tr><th>Source Category</th><th colspan="4">Gathering Pipeline</th></tr>
<tr><td>Default EF
(MTCH_4 mile^{-1} yr^{-1})</td><td colspan="4">0.4</td></tr>
<tr><td>Source</td><td colspan="4">EPA SIT Natural Gas and Oil Module</td></tr>
<tr><td>EF Confidence</td><td>Geography Rest of the Country</td><td>Recency 15+ Years</td><td>Methodology Engineering Estimate</td><td>Status Grey Literature</td></tr>
<tr><td>Source Description</td><td colspan="4">This is the default SIT gathering pipeline EF. The SIT documentation indicates that the GRI (1996) study is the source for this EF. EPA/GRI (1996) estimates leak rates from distribution mains from data in the Cooperative Leak Measurement Program and assumes identical leak rates for gathering lines. These EFs are well-aligned with the most recent EPA GHG Inventory (EPA 2018a), which uses a value of 395.5 kg mile^{-1} year^{-1} (Annex Table 3.6-2). In the peer-reviewed literature, Zimmerle et al (2017) find emissions of 402 kg CH_4hr^{-1} from a total of 4,684 km of gathering pipeline in the Fayetteville shale play. This translates to a rate of 402 kg $CH_4.hr^{-1}$ over 2,910.5 miles, or 1.210 $MTCH_4$ mile^{-1} yr^{-1}, indicating that the SIT and EPA estimated EFs applied here are conservatively low.</td></tr>
</table>

Activity Data

The activity data for gathering pipelines is miles of pipeline. State-level data on the gathering pipeline mileage was pulled from the Pipeline and Hazardous Materials Safety Administration (PHMSA) Pipeline Mileage and Facilities database. Based on guidance from DEC, the miles of gathering pipelines from PHMSA were scaled up to account for the fact that only 7.5% of gathering pipeline miles are being reported under PHMSA.

CH_4 emissions were calculated as the miles of pipeline times the EF. The MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5,\,20}$ factor of 84.

Geospatial Data and Allocation Methodology

The adjusted State-level miles of gathering pipeline were allocated to county level using the annual ratio of the volume of natural gas produced in the county to the volume of natural gas produced in New York State. The production data were derived from ESOGIS. This database contains information on all wells in the State, including county location, well type, and the volume of natural gas produced by year. To estimate the quantity of natural gas produced, the volume produced by county and year was based on well type and well status. For associated gas from oil wells, the well type included “oil development,” "oil extension," and "enhanced oil recovery-injection," and the well status included "active," "drilled deeper," "drilling completed," "plugged back," and "plugged back multilateral." For natural gas production from natural gas wells, the well type included "gas development," "gas extension," and "gas wildcat," and the well status included "active," "drilled deeper," "drilling completed," "plugged back," and "plugged back multilateral."

Sample Calculations

Equation 16 CH_4 **emissions (**$MTCO_2e$**) = pipeline miles x SF x AF x EF x** $GWP_{AR5, 20}$

where:

- pipeline miles = state-level miles of gathering pipeline
- SF = scaling factor to account for unreported miles of pipeline = 13.33
- AF = allocation factor based on ratio of county-level natural gas production in 2020 to state-level natural gas production in 2020
- EF = CH_4 EF ($MTCH_4$ $mile^{-1}$ yr^{-1}) = 0.4
- $GWP_{AR5, 20}$ = GWP = 84

For example, according to the PHMSA data, there were 81 miles of gathering pipeline in New York State in 2020. In addition, there was 809,264 Mcf of natural gas production in Cattaraugus County in 2020 and 10,986,744 Mcf of natural gas production in the State. Applying the scaling and allocation factors, there were 79.31 miles of gathering pipeline in Cattaraugus County in 2020 resulting in 2,672.2 $MTCO_2e$ as shown:

Equation 17 **Gathering pipeline** CH_4 **(**$MTCO_2e$**) = 81 x 13.33 x 809,264/10,986,744 x 0.4 x 84**
Gathering pipeline CH_4 **(**$MTCO_2e$**) = 2,672.2** $MTCO_2e$

Limitations and Uncertainties

These per-mile emission rates are based on an older study, with embedded leak frequencies that reflect conditions at the time but may not reflect the current condition of gathering lines in New York State. The value applied here is aligned with the 2018 EPA GHG Inventory EF, but in peer-reviewed literature EFs (Zimmerle et al. 2017) are ~ 3x higher, indicating that this estimate may lead to a lower estimate of gathering pipeline emissions.

Potential Areas of Improvement

PHMSA pipeline statistics may be applicable to derive New York State-specific estimates of emissions. Reported lost and unaccounted for (LAUF) gas, provided in PHMSA data may be used to generate state-level emission estimates, but county-specific gathering line mileage and throughput are necessary for attribution at the county level.

3.2.6.3 Truck Loading

Source Category Description

Gas condensate production, when transferred from storage into tank trucks, can generate significant volumes of CH_4 vapor due to pressure, temperature changes, and evaporation. Historically, this CH_4 was vented to the atmosphere to prevent the internal tank pressure from rising. Since a loading cycle may occur every three to five days or approximately 100 loading transfers per year, emissions can be significant. Many operations are now using closed loop systems where a vapor recovery line is connected to the tank, a vapor recovery unit, or flare stack. These closed loop systems essentially eliminate CH_4 emissions.

Truck loading of crude oil may release CH_4. In addition, it is assumed that natural gas is transported by pipeline, and therefore, there is no truck loading for natural gas in New York State.

Emission Factors

Source Category	Truck Loading			
Default EF ($mgCH_4$ L^{-1} crude oil)	0 or 33.70			
Source	AP-42: Compilation of Air Emission Factors			
EF Confidence	Geography Rest of the Country	Recency 15+ Years	Methodology Engineering Estimate	Status Grey Literature
Source Description	AP-42: Compilation of Air Emission Factors, available at https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors in Chapter 5, Table 5.2-5 indicates between 240 and 580 mg organic emissions lost per L of crude oil transferred into tank trucks. Assuming, as described in the source, ~ 15% of the total organic emissions is CH_4/ethane combined, then using the conservative lower bound gives emissions of 36 mg/L transferred. Data from Mitchell et al. (2015) indicate that CH_4 comprises 93.6% of natural gas produced in New York wells, so we alternatively use 36 x 0.936 = 33.70 mg/L as the CH_4 EF during loading. The available data on emissions from tank loading are sparse, therefore we use AP- 42 air EFs, which are ultimately derived from two industry studies performed in 1977 by Chevron, USA, but are consistent with the EPA recommended methodology.			

Activity Data

The activity data for 2003–2017, calculated as bbl of crude oil production, were derived from ESOGIS. This database contains information on all wells in New York State, including county location, well type, and volume of oil produced. To estimate the quantity of oil produced, the volume produced by county and year was summed for all well types. Since the ESOGIS database contained incomplete oil well production data for 1990–2002, annual oil production values for these years were obtained from EIA's Crude Oil Production report (EIA, 2019a).

Natural gas is transported by pipelines.

Geospatial Data and Allocation Methodology

For 2003–2017, no allocation methodology was necessary since the ESOGIS database has information at the well level for all analysis years. However, information on the location of loading areas would help refine the location of the emissions. For 1990–2002, State-level oil production was allocated to the county level using the ratio of county-level production to State-level production in 2003 from the ESOGIS database.

Sample Calculations

Equation 18 **CH_4 emissions ($MTCO_2e$) = gas condensate loaded x CF1 x EF x CF2 x $GWP_{AR5,\ 20}$**

where:

- gas condensate loaded = volume of gas condensate loaded onto trucks
- CF_1 = conversion factor for barrels to liters = 158.987 liters/bbl
- EF = CH_4 EF (mgCH_4 L^{-1} crude oil) = 0
- CF_1 = conversion from mg to MT = $1e^{-9}$
- $GWP_{AR5,\ 20}$ = GWP = 84

For example, there were 19,875 bbl of oil produced in Allegany County in 2020, resulting in 0 $MTCO_2e$ from truck loading as shown:

Equation 19 **Truck loading of crude oil CH_4 ($MTCO_2e$) = 19,875 x 158.987 x 0 x 1e-9 x 84**
Truck loading of crude oil CH_4 ($MTCO_2e$) = 0 $MTCO_2e$

Limitations and Uncertainties

Based on the boiling points of CH_4 and ethane, it is likely that much of the CH_4/ethane present in crude will be released when the crude is exposed to atmospheric temperature and pressure conditions during storage. Therefore, there are two bounding conditions.

- Assume that any CH_4 present in crude oil stored at oil production sites and transferred via truck will evaporate while stored in atmospheric tanks, and therefore emissions are included/embedded in site-level EFs.
- Assume that none of the CH_4 evaporates prior to truck tank loading, and therefore the 33.7 mg/L EF applies during loading.

A review of some of the oil well sites indicates that many of the wells have tanks associated with them. From the satellite views, it's difficult to assess whether these are oil storage tanks or other tanks such as water or separators. For this inventory, it is assumed that all CH_4 evaporates while stored in atmospheric tanks.

Potential Areas of Improvement

Estimates of emissions from truck loading may be improved by a better understanding of quantities of oil transferred from wellheads to processing sites by truck in New York State as well as confirmation that all CH_4 has evaporated prior to truck loading. At present, the lack of good activity data requires the use of bounding conditions where either all or none of the CH_4 has evaporated prior to loading.

3.2.6.4 Gas Processing Plants

Source Category Description

Raw natural gas comes from three types of wells: oil, gas, and condensate wells. Natural gas that comes from oil wells is known as associated gas. This gas can exist separate from oil in the formation (free gas) or dissolved in the crude oil (dissolved gas). Natural gas from gas and condensate wells, in which there is little or no crude oil, is known as non-associated gas. Gas wells typically produce raw natural gas, while condensate wells produce free natural gas along with a semi-liquid hydrocarbon condensate. Natural gas, once separated from crude oil (if present), commonly exists in mixtures with other hydrocarbons, principally ethane, propane, butane, and pentanes. In addition, raw natural gas contains water vapor, H_2S, CO_2, helium, nitrogen, and other compounds. Natural gas processing plants purify raw natural gas by removing these contaminants using processes such as glycol dehydration to remove water and the amine process to sweeten the natural gas by removing sulfur.

Emission Factors

Source Category	Gas Processing Plant			
Default EF ($MTCH_4$ plant^{-1} yr^{-1})	919.8			
Source	Marchese et al. 2015			
EF Confidence	Geography Marcellus/ Appalachian Basin	Recency 6-15 Years	Methodology Empirical Observation	Status Peer Reviewed
Source Description	This EF is derived from tracer flux measurements of 16 processing plants in 13 U.S. states. The data used in this study are the same as those used in Mitchell et al. (2015). This study combines rigorous sampling methods with robust statistical modeling and finds an estimated facility-level EF of 105 kg plant^{-1} hr^{-1}, or 919.8 $MTCH_4$ plant^{-1} yr^{-1}. This estimate is a downward revision of the EPA SIT default value 1,249.95 $MTCH_4$ plant^{-1} yr^{-1} based on recent, rigorous, empirical observation and statistical modeling.			

Activity Data

According to the EIA and confirmed by DEC, there are no gas processing plants in New York State.

Geospatial Data and Allocation Methodology

N/A

Sample Calculations

Equation 20 **CH_4 emissions ($MTCO_2e$) = gas processing plants x EF x $GWP_{AR5,\ 20}$**

where:

- gas processing plants = number of gas processing plants
- EF = CH_4 EF ($MTCH_4$ plant^{-1} yr^{-1}) = 1,249.95
- $GWP_{AR5,\ 20}$ = GWP = 84

For example, there were no natural gas processing plants in Cattaraugus County in 2020, resulting in 0 $MTCO_2e$ as shown:

Equation 21 **Natural gas processing plant CH_4 ($MTCO_2e$) = 0 x 1,249.95 x 84 Natural gas processing plant CH_4 ($MTCO_2e$) = 0 $MTCO_2e$**

Limitations and Uncertainties

This EF is based on data collected across 13 states and is not specific to New York State. In addition, Marchese et al. (2015) identify uncertainty bounds of +11/-10 kg plant^{-1} hr^{-1} around the central estimate.

Potential Areas of Improvement

Due to the described uncertainty in the EF, it is useful to perform sensitivity analysis around the central estimate.

3.2.6.5 Gas Transmission Pipelines

Source Category Description

Transmission pipelines are used to transport natural gas for long distances across states. They are used to move the product from the production regions to distribution centers. Transmission pipelines operate at high pressures, ranging from 200–1,200 psi, with each transmission line using compressor stations to maintain gas pressure.

Emission Factors

Source Category	Transmission Pipeline			
Default EF ($MTCH_4$ mile^{-1} yr^{-1})	0.62			
Source	EPA SIT Natural Gas and Oil Module			
EF Confidence	Geography Rest of the Country	Recency 15+ Years	Methodology Engineering Estimate	Status Grey Literature
Source Description	This is the default SIT gathering pipeline EF. The SIT documentation indicates that the study is the source for this EF. EPA/GRI (1996) estimates leak rates from distribution mains from data in the Cooperative Leak Measurement Program. The EF used here is approximately half of the value used in the most recent EPA GHG Inventory (EPA 2018a), which uses an EF of 1,122.7 kg mile^{-1} year^{-1} (Annex table 3.6-2), reportedly also derived from the EPA/GRI 1996 study. The updates in the most recent EPA GHG Inventory are not clearly documented, so the EPA/GRI (1996) estimate, which documents the methodology, is used.			

Activity Data

The activity data for transmission pipelines is miles of pipeline. State-level data on the transmission pipeline mileage was pulled from the PHMSA Pipeline Mileage and Facilities database. Due to suspected anomalies in the PHMSA pipeline data, corrections were applied per guidance from DEC. Data reported in the PHMSA database for years 2002–2017 were used to develop a trendline to estimate emissions from 1990–2001. In addition, PHMSA data for year 2002 were applied to years 2003–2005, PHMSA data for year 2008 were applied to years 2009–2012 and PHMSA data for year 2013 were applied to years 2014 to 2017.CH_4 emissions were calculated as the miles of pipeline times the EFs. The MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5,\ 20}$ factor of 84.

Geospatial Data and Allocation Methodology

An estimate of transmission pipeline miles per county were calculated by summing reported line segments from PHMSA's public viewer.[vii] The state-level miles reported in the PHMSA database were allocated to the county level by using the 2017 ratio of the estimated miles of transmission pipeline in the county to estimated miles of transmission pipeline in New York State, calculated by summing transmission line segments from the map.

Sample Calculations

Equation 22 CH_4 emissions ($MTCO_2e$) = pipeline miles x AF x EF x $GWP_{AR5,\ 20}$

where:

- pipeline miles = state-level miles of transmission pipeline
- AF = allocation factor based on ratio of county-level miles of pipeline in 2020 to state-level miles of pipeline in 2020
- EF = CH_4 EF ($MTCH_4$ $mile^{-1}$ yr^{-1}) = 0.62
- $GWP_{AR5,\ 20}$ = GWP = 84

For example, there were 4,536 miles of transmission pipeline in the State in 2017. The data on miles from summing line segments from the PHMSA map indicated there were 124.28 miles of transmission pipeline in Albany County in 2020 and 3,939 miles of transmission pipeline. Applying the allocation factor, there were 143.12 miles of transmission pipeline in Albany County in 2020, resulting in 7,453.5 $MTCO_2e$ as shown:

Equation 23 Transmission pipeline CH_4 ($MTCO_2e$) = 4,536 x 124.28/3,939 x 0.62 x 84
Transmission pipeline CH_4 ($MTCO_2e$) = 7,453.5 $MTCO_2e$

Limitations and Uncertainties

These per-mile emission rates are based on an older study, with embedded leak frequencies that reflect conditions at the time but may not reflect the current condition of gas transmission pipelines in New York State. In addition, the 2018 EPA GHG Inventory (EPA 2018a) indicates that transmission pipeline emissions may be as high as 1,122.7 kg $mile^{-1}$ $year^{-1}$ (Annex table 3.6-2), or 81% higher than the SIT default value.

Potential Areas of Improvement

PHMSA pipeline statistics may be applicable to derive New York State-specific estimates of emissions. Reported LAUF gas, provided in PHMSA data, may be used to generate State-level emissions estimates, but county-specific transmission line mileage and throughput are necessary for attribution at the county level.

3.2.6.6 Gas Transmission Compressor Stations

Source Category Description

Transmission compressor stations are facilities roughly located every 70 miles along a natural gas pipeline to boost the pressure that is lost by the friction of the natural gas moving through the pipeline (Greenblatt 2015). Natural gas enters a compressor station through station yard piping. Scrubbers and filters remove any liquids, solids, or other particulate matter and then gas is directed to individual compressors. Most compressor stations have an aerial cooler system to cool the gas stream before leaving the compressor facility.

Emission Factors

Source Category	Gas Transmission Compressor Stations			
Default EF ($MTCH_4$ station^{-1} yr^{-1})	670			
Source	Zimmerle et al. 2015			
EF Confidence	Geography Marcellus/ Appalachian Basin	Recency 6-15 Years	Methodology Empirical Observation	Status Peer Reviewed
Source Description	Zimmerle et al. (2015) studied 922 transmission and storage compressors, applying probabilistic emissions, activity models, and statistical methods to model emissions, which were then validated using field measurements. The mean emissions rate for transmission stations was 670 MT station^{-1} year^{-1} (+52%/-34%), which is 32% lower than the default SIT value. The estimate applied here is derived from a peer-reviewed study of 823 transmission compressor stations employing empirical observations and statistical modeling techniques.			

Activity Data

The number of natural gas transmission compressors stations were calculated by dividing the number of miles of transmission pipeline by the approximate pipeline distance per compressor station of 70 miles. The resultant number of transmission compressor stations was cross-checked with data provided by the New York State Department of Environmental Conservation (DEC) from their permitting database, which provides compressors stations by county. The type of compressor station was determined by reviewing permits and publicly available information on the compressor stations. While the number of compressor stations in the permitting database is lower than the calculated number, the calculated number likely includes compressor stations with electric compressors that would not require permits (and, therefore, would not be included in the permitting database).

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the DEC database on permits and EIA data set have information at the county level for all analysis years.

Sample Calculations

Equation 24 $$CH_4 \text{ emissions } (MTCO_2e) = \text{compressor stations} \times EF \times GWP_{AR5,\,20}$$

where:

- compressor stations = number of natural gas transmission compressor stations
- EF = CH_4 EF ($MTCH_4$ $station^{-1}$ yr^{-1}) = 670
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there were two natural gas transmission compressor stations in Cattaraugus County in 2020, resulting in 112,560 $MTCO_2e$ as shown:

Equation 25 $$\text{Natural gas transmission compressor station } CH_4 \text{ } (MTCO_2e) = 2 \times 670 \times 84$$ $$\text{Natural gas transmission compressor station } CH_4 \text{ } (MTCO_2e) = 112{,}560 \text{ } MTCO_2e$$

Limitations and Uncertainties

Subramanian et al. (2015) also performed detailed, peer-reviewed, top-down (TD) and bottom-up (BU) analyses of emissions from compressor stations, finding values 30.8% lower than Zimmerle et al. (2015). As identified in many other areas, super-emitting sites comprised a small fraction of the total number of sites, but a large fraction of the total emissions, resulting in wide uncertainty bands. Additionally, this study shows differences between reciprocating and centrifugal compressor stations.

Potential Areas of Improvement

Given the likelihood that differences in compressor engine emissions would not show a large variation, the most pressing need in this area is for the analysis of potentially high-emitting sources.

3.2.6.7 Gas Storage Compressor Stations

Source Category Description

Natural gas can be stored underground in depleted oil or gas reservoirs, salt formation caverns, and mined underground caverns. Whether used to meet typical demand, or as a strategic reserve during a low-priced market or unanticipated supply shortage, gas storage and withdrawal play an important role in maintaining a stable natural gas market. For example, gas can be injected into storage facilities during the summer months and withdrawn during winter months to meet increased customer demand. Storage compressor stations provide the necessary boost to move natural gas between the storage field and the distribution system. The compressor units operate during injection to move natural gas into the storage field as well as during withdrawal from storage to move natural gas to the distribution system.

Emission Factors

<table>
<tr><td>Source Category</td><td colspan="4">Natural Gas Storage Compressor Station</td></tr>
<tr><td>Default EF ($MTCH_4$ station^{-1} yr^{-1})</td><td colspan="4">847</td></tr>
<tr><td>Source</td><td colspan="4">Zimmerle et al. 2015</td></tr>
<tr><td>EF Confidence</td><td>Geography
Marcellus/
Appalachian Basin</td><td>Recency
6-15 Years</td><td>Methodology
Empirical
Observation</td><td>Status Peer
Reviewed</td></tr>
<tr><td>Source Description</td><td colspan="4">Zimmerle et al. (2015) studied 922 transmission and storage compressors, applying probabilistic emissions, activity models, and statistical methods to model emissions, which were then validated using field measurements. The mean emissions rate for transmission stations was 847 MT station^{-1} year^{-1} (+53%/-35%), which is 12.2% lower than the default SIT value. The estimate applied here is derived from a peer-reviewed study of 99 storage compressor stations employing empirical observations and statistical modeling techniques.
This estimate is supported by published data from Subramanian et al (2015), who studied CH_4 emissions at 45 compressor stations across 16 states using 2 methodologies: a BU measurement of individual emission sources showed a strong correlation with a TD measurement using tracer flux techniques to measure CH_4 gas concentrations in downwind plumes. Subramanian et al (2015) found mean emissions of 585.81 $MTCH_4$ station^{-1} yr^{-1}, 30.8% lower than Zimmerle et al. (2015). Sup er-emitting stations were significantly higher emitters than normal stations, with the highest emitting 10% of stations accounting for 50% of emissions. The lowest emitting 50% of stations accounted for 10% of emissions.
Both Zimmerle et al. and Subramanian et al. are peer-reviewed and robust studies. This inventory uses the Zimmerle et al. estimate for storage compressor stations as it has a larger sample size. However, the literature indicates that understanding compressor types, as well as the distribution of emissions, are critical to robustly estimating emissions from compressor stations.</td></tr>
</table>

Activity Data

The number of natural gas storage compressors stations were provided by DEC from their permitting database, which provides compressor stations by county and supplemented with data from EIA collected on the EIA-191 survey (EIA, 2019b). The type of compressor station was determined by reviewing permits and publicly available information on the compressor stations.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the DEC database on permits and EIA data set have information at the county level for all analysis years.

Sample Calculations

Equation 25 **CH_4 emissions ($MTCO_2e$) = compressor stations x EF x $GWP_{AR5,\,20}$**

where:

- compressor stations = number of natural gas storage compressor stations
- EF = CH_4 EF ($MTCH_4$ $station^{-1}$ yr^{-1}) = 847
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there were three natural gas storage compressor stations in Cattaraugus County in 2020, resulting in 213,444 $MTCO_2e$ as shown:

Equation 26 **Natural gas storage compressor station CH_4 ($MTCO_2e$) = 3 x 847 x 84 Natural gas storage compressor station CH_4 ($MTCO_2e$) = 213,444 $MTCO_2e$**

Limitations and Uncertainties

Subramanian et al. (2015) also performed detailed, peer-reviewed, TD and BU analyses of emissions from compressor stations, finding values 30.8% lower than Zimmerle et al. (2015). As identified in many other areas, super-emitting sites comprised a small fraction of the total number of sites but a large fraction of the total emissions, resulting in wide uncertainty bands. Additionally, this study shows differences between reciprocating and centrifugal compressor stations.

Potential Areas of Improvement

As noted, reciprocating and centrifugal compressors show different average emission rates. When normalized by horsepower, however, centrifugal compressors show much lower emissions; therefore, emissions per unit throughput are lower for centrifugal compressors. In addition, the issue of high-emitting sources also applies to compressors, with inconclusive evidence for high-emitting sources being more likely in standby or operational modes. This again highlights the importance of improving the understanding of high-emitting source rates and distributions.

3.2.6.8 Storage Reservoir Fugitives

Source Category Description

Natural gas is stored in underground formations for use at a later date. Underground storage formations are typically depleted oil and gas reservoirs, salt caverns, or mined underground caverns. Fugitive emissions from these storage formations may occur but are not well characterized. This inventory does not include emissions from underground storage facilities due to a lack of available EFs. Inclusion of storage reservoir fugitive emissions is recommended for future study.

3.2.6.9 Liquified Natural Gas Storage Compressor Stations

Source Category Description

LNG storage compressor stations take natural gas from the pipeline system during periods of lower demand, liquefy and store the gas, and then vaporize it during periods of high demand. The process of liquefying natural gas shrinks the gas volume by a factor of approximately 600. The LNG process allows for an economic way to store natural gas for vaporization and distribution at a later date when demand increases. The LNG storage tanks at these stations can be above ground or in ground and could store LNG at very low temperatures in order to maintain the gas in a liquid form. The storage tanks are insulated in order to limit evaporation. A small amount of heat is still able to penetrate the tanks and evaporation can occur, resulting in boil-off gas. This gas is captured and fed back into the LNG flow using compressor and re-condensing systems, preventing the occurrence of venting natural gas. However, during maintenance periods, boil-off gas must be burnt off by the flare stack.

Emission Factors

Source Category	LNG Storage Compressor Station			
Default EF (MTCH$_4$ facility^{-1} yr^{-1})	1,077.48			
Source	2016 GHG Inventory			
EF Confidence	Geography Marcellus/ Appalachian Basin	Recency 6-15 years	Methodology Engineering Estimate	Status Grey Literature
Source Description	The EF is estimated as the annual product of 123 kg facility^{-1} hr^{-1}, which is the rolled- up per-station EF, using assumed inputs from the EPA GHG Inventory, per guidance from Dr. Anthony Marchese, as follows: • 3.85 reciprocating compressors per station (round up to 4). • 0.91 centrifugal compressor per station (round up to 1). Engine hp-hr per station (assuming 4 engines per station) = 8.6 MMhp-hr. Station level fugitive EF = 21,507 standard cubic feet per day (scfd)/station. Reciprocating compressor EF (assuming 4 compressors/station) = 84,464 scfd/station. Centrifugal compressor EF (assuming 1 centrifugal compressor/station) = 30,573 scfd/station. Engine CH$_4$ exhaust per station = 5,640 scfd/station (assuming 4 engines per station). Gas turbine exhaust = 51 scfd/station (assuming 1 gas turbine per station). Station venting = 11,942 scfd/station. This results in an EF of 154,177 scfd/facility, 123 kg hr^{-1} facility^{-1}, or 1,077.48 MTCH$_4$ facility^{-1} yr^{-1}. This estimate is derived from expert review, including EPA guidance and local component count estimates.			

Activity Data

There are currently three large LNG storage facilities in New York State (Astoria, Greenpoint, and Holtsville) and all have been operational since 1990. The location of the facilities was provided by DEC.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the DEC provided the county-level locations of the three facilities.

Sample Calculations

Equation 27 $\mathbf{CH_4}$ **emissions (**$\mathbf{MTCO_2e}$**) = compressor stations x EF x** $\mathbf{GWP_{AR5,\,20}}$

where:

- compressor stations = number of LNG storage compressor stations
- EF = CH_4 EF ($MTCH_4$ station^{-1} yr^{-1}) = 1,077.48
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there was one LNG storage compressor station in Kings County in 2020 resulting, in 2,262,708 $MTCO_2e$ as shown:

Equation 27 **LNG storage compressor station** $\mathbf{CH_4}$ **(**$\mathbf{MTCO_2e}$**) = 1 x 1,077.48 x 84 LNG storage compressor station** $\mathbf{CH_4}$ **(**$\mathbf{MTCO_2e}$**) = 2,262,708** $\mathbf{MTCO_2e}$

Limitations and Uncertainties

This EF is estimated based on rolling up standard assumptions for LNG storage compressor station components. As such, several assumptions were made, including compressor types and counts, engine horsepower and counts, and venting assumptions. These assumptions have not been validated by empirical observations. Uncertainty bounds are estimated by assuming one (plus or minus) reciprocating compressor per station.

Potential Areas of Improvement

Several assumptions were made in estimating the EF for LNG storage compressor stations. This estimate may be improved by validating the assumptions used against LNG storage compressor station components in New York State.

3.2.6.10 LNG Terminal

Source Category Description

An LNG terminal is a facility for re-gasifying the LNG that was transported from production zones. LNG terminals function to berth LNG tankers and unload or reload cargo, store LNG in cryogenic tanks, re-gas LNG, and/or send gas out into the transmission grid. There are no LNG terminals in the State.

3.2.7 Downstream Stages

3.2.7.1 Distribution Pipelines

Source Category Description

Distribution pipelines are a system comprised of mains and service lines that are used by distribution companies to deliver natural gas to homes and businesses. Mains are the step between high-pressure transmission lines and low-pressure service lines. Materials used for these pipes include steel, cast iron, plastic, and copper. Pressures can vary considerably but can be as high as 200 psi. Service pipelines connect to a meter and deliver natural gas to individual customers. Materials used for service pipes include plastic, steel, cast iron, or copper. Pressure of the gas in these pipes is low at around 6 psi.

Emission Factors

The emissions factors for distribution pipeline mains and services have been updated to correct a unit error for the service pipeline emissions factors and discrepancies between reported emissions and estimated emissions for pipeline mains (see appendix A.1).

Source Category		Cast Iron	Unprotected Steel	Protected Steel	Plastic	Copper
Default EF ($MTCH_4$ mile^{-1} yr^{-1})	Main	4.5974	2.1223	0.0588	0.1909	0.4960
	Services	4.5974	2.7115	0.2473	0.0135	0.4960
Source	Lamb et al. 2015; EPA 2018a; EPA 2021					
EF Confidence	Geography NYS		Recency ≤ 5 Years	Methodology Empirical Observation	Status Peer Reviewed	
Source Description	The EFs used for distribution mains and services are derived from utility reported data to the GHGRP. As described elsewhere in the literature, consideration of high-emitting sources leads to a skewed distribution of leak rates, with a few sources accounting for the majority of emissions.					

Note: The EF for cast iron services is assumed to be equal to the EF for cast-iron mains.

Activity Data

Activity data for main and service distribution pipelines are miles of pipeline-by-pipeline material type. Operator-level data on the pipeline mileage by type was pulled from the PHMSA Pipeline Mileage and Facilities database. To correct for potential outliers in the PHMSA data, likely due to incomplete reporting, the following data adjustments were made:

- **Cast-Iron Mains**: 1991 is the average of 1990 and 1992 PHMSA data.
- **Cast-Iron Services**: 1990 to 2003 are based on a trendline from 2004 to 2017 PHMSA data.
- **Unprotected Steel Services**: 1991, 1998 and 2009 are the average of PHMSA data in adjacent years.
- **Protected Steel Mains**: 1994 to 1996 are based on a linear trend using 1993 and 1997 PHMSA data.
- **Protected Steel Services**: 1998 and 2009 are the average of PHMSA data in adjacent years.
- **Copper Services**: 1991 to 1992 are based on a linear trend using 1990 and 1993 PHMSA data; 1998, 2001 and 2010 are the average of PHMSA data in adjacent years.

CH_4 emissions were calculated as the miles of pipeline, by pipeline type, times the EFs. The MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5,0}$ factor of 84.

Geospatial Data and Allocation Methodology

The operator-level miles of distribution pipelines reported in the PHMSA database were allocated to the county-level based on the number of services. The methodology for estimating the number of services is discussed in section 3.2.7.2.

Sample Calculations

Equation 28 CH_4 **emissions (**$MTCO_2e$**) = pipeline miles**$_{type}$ **x AF x EF x** $GWP_{AR5,\ 20}$

where:

- pipeline miles$_{type}$ = state-level miles of distribution pipeline by pipeline material type
- AF = allocation factor based on the ratio of the number of county natural gas services (residential and commercial) to the number of state natural gas services (residential and commercial)
- EF = CH_4 EF ($MTCH_4$ mile^{-1} yr^{-1}) = 2.7115
- $GWP_{AR5,\ 20}$ = GWP = 84

For example, according to the PHMSA data, there were 4,263.04 miles of unprotected steel distribution service pipeline in New York State in 2020. From the allocation method, the total number of natural gas services in Albany County in 2020 was 109,358, and the total number natural gas services in the State in 2020 was 4,559,150. Applying the allocation factor, there were 102.17 miles of unprotected steel distribution service pipeline in Albany County in 2020, resulting in 23,290.1 $MTCO_2e$ as shown:

Equation 29 **Unprotected steel distribution pipeline CH_4 ($MTCO_2e$) = 4,263 x 109,358/4,559, 150 x 2.7115 x 84 Unprotected steel distribution pipeline CH_4 ($MTCO_2e$) = 23,290.1 $MTCO_2e$**

Limitations and Uncertainties

These per-mile emissions rates are based on utility-reported values to GHGRP. The utility-reported values are calculated using emissions factors that may be outdated and are not based on actual emissions.

Potential Areas of Improvement

Performing a survey of actual miles of pipeline-by-pipeline type at the county-level would reduce errors associated with allocating state-level pipeline mileage to the county-level using natural gas services.

3.2.7.2 Pressure Relief Valves

Source Category Description

Pressure relief valves are installed downstream to relieve pressure. The valve opens in relation to the pressure increase of the gas flowing through the pipeline. When the valve opens for routine maintenance, gas may be emitted.

Emission Factors

Source Category	Pressure Relief Valves			
Default EF ($MTCH_4$ $mile^{-1}$ yr^{-1})	0.00096			
Source	EPA 2023, Annex 3.6-2			
EF Confidence	Geography Rest of the Country	Recency 15+ Years	Methodology Engineering Estimate	Status Grey Literature
Source Description	This inventory applies the EFs derived by EPA in the 2021 inventory (EPA 2023), based on data from GRI/EPA 1996.			

Activity Data

The activity data for pressure relief valves is the total miles of distribution pipeline mains, summed across all types of materials. The methodology for deriving the miles of distribution pipeline mains is described in section 3.2.7.1.

Geospatial Data and Allocation Methodology

The operator-level miles of distribution pipelines reported in the PHMSA database were allocated to the county-level based on the number of services. The methodology for estimating the number of services is discussed in section 3.2.7.2.

Sample Calculations

Equation 28 $\mathbf{CH_4}$ **emissions** $\mathbf{(MTCO_2e) = pipeline\ miles \times EF \times GWP_{AR5,\,20}}$

where:

- pipeline miles = state-level miles of distribution pipeline mains
- EF = CH_4 EF ($MTCH_4$ $mile^{-1}$ yr^{-1}) = 0.00096
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there were 1,192.64 miles of pipeline mains in Albany County, resulting in emissions of 96.2 $MTCO_2e$, as shown:

Equation 29 **Pressure Relief Valve** $\mathbf{CH_4\ (MTCO_2e) = 1{,}192.64 \times 0.00096 \times 84}$

Pressure Relief Valve $\mathbf{CH_4\ (MTCO_2e) = 96.2\ MTCO_2e}$

Limitations and Uncertainties

The EFs for this category are based on older studies not local to NYS, so it is possible they do not accurately represent conditions and emissions in the state.

Potential Areas of Improvement

Performing a survey of actual miles of pipeline-by-pipeline type at the county-level would reduce errors associated with allocating state-level pipeline mileage to the county-level using natural gas services.

3.2.7.3 Blowdowns

Source Category Description

A pipeline blowdown is the release of gas to the atmosphere to relieve pressure in the pipeline and allow for pipeline maintenance.

Emission Factors

<table>
<tr><th>Source Category</th><th colspan="4">Blowdowns</th></tr>
<tr><td>Default EF
(MTCH$_4$ mile^{-1} yr^{-1})</td><td colspan="4">0.00196</td></tr>
<tr><td>Source</td><td colspan="4">EPA 2023, Annex 3.6-2</td></tr>
<tr><td>EF Confidence</td><td>Geography
Rest of the Country</td><td>Recency 15+ Years</td><td>Methodology
Engineering Estimate</td><td>Status Grey Literature</td></tr>
<tr><td>Source Description</td><td colspan="4">This inventory applies the EFs derived by EPA in the 2021 inventory (EPA 2023), based on data from GRI/EPA 1996.</td></tr>
</table>

Activity Data

The activity data for blowdown is the total miles of distribution pipeline mains and services, summed across all types of materials. The methodology for deriving the miles of distribution pipeline mains is described in section 3.2.7.1.

Geospatial Data and Allocation Methodology

The operator-level miles of distribution pipelines reported in the PHMSA database were allocated to the county-level based on the number of services. The methodology for estimating the number of services is discussed in section 3.2.7.2.

Sample Calculations

Equation 28 $\mathbf{CH_4 \text{ emissions } (MTCO_2e) = pipeline\ miles \times EF \times GWP_{AR5,\,20}}$

where:

- pipeline miles = state-level miles of distribution pipeline mains and services
- EF = CH_4 EF ($MTCH_4$ mile^{-1} yr^{-1}) = 0.00196
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there were 658 miles of pipeline mains and services in Chemung County, resulting in emissions of 108 $MTCO_2e$, as shown:

Equation 29 $\mathbf{Blowdown\ CH_4\ (MTCO_2e) = 658 \times 0.00196 \times 84}$

$\mathbf{Blowdown\ CH_4\ (MTCO_2e) = 108\ MTCO_2e}$

Limitations and Uncertainties

The EFs for this category are based on older studies not local to NYS, so it is possible they do not accurately represent conditions and emissions in the state.

Potential Areas of Improvement

Performing a survey of actual miles of pipeline-by-pipeline type at the county-level would reduce errors associated with allocating state-level pipeline mileage to the county-level using natural gas services.

3.2.7.4 Damages

Source Category Description

This source category includes mishaps and damages (e.g., dig-ins) to distribution pipelines that result in a release of gas to the atmosphere.

Emission Factors

Source Category	Damages			
Default EF (MTCH$_4$ mile^{-1} yr^{-1})	0.03062			
Source	EPA 2023, Annex 3.6-2			
EF Confidence	Geography Rest of the Country	Recency 15+ Years	Methodology Engineering Estimate	Status Grey Literature
Source Description	This inventory applies the EFs derived by EPA in the 2021 inventory (EPA 2023), based on data from GRI/EPA 1996.			

Activity Data

The activity data for damages is the total miles of distribution pipeline mains and services, summed across all types of materials. The methodology for deriving the miles of distribution pipeline mains is described in section 3.2.7.1.

Geospatial Data and Allocation Methodology

The operator-level miles of distribution pipelines reported in the PHMSA database were allocated to the county-level based on the number of services. The methodology for estimating the number of services is discussed in section 3.2.7.2.

Equation 28 $\mathbf{CH_4}$ **emissions** ($\mathbf{MTCO_2e}$) **= pipeline miles x EF x** $\mathbf{GWP_{AR5,\ 20}}$

where:

- pipeline mile = state-level miles of distribution pipeline mains and services
- EF = CH_4 EF ($MTCH_4$ $mile^{-1}$ yr^{-1}) = 0.03062
- $GWP_{AR5,\ 20}$ = GWP = 84

For example, there were 658 miles of pipeline mains and services in Chemung County, resulting in emissions of 1,692 $MTCO_2e$, as shown:

Equation 29 **Damages** $\mathbf{CH_4}$ ($\mathbf{MTCO_2e}$) **= 658 x 0.03062 x 84**

Damages $\mathbf{CH_4}$ ($\mathbf{MTCO_2e}$) **= 1,692** $\mathbf{MTCO_2e}$

Limitations and Uncertainties

The EFs for this category are based on older studies not local to NYS, so it is possible they do not accurately represent conditions and emissions in the state.

Potential Areas of Improvement

Performing a survey of actual miles of pipeline-by-pipeline type at the county-level would reduce errors associated with allocating state-level pipeline mileage to the county-level using natural gas services.

3.2.7.5 M&R Stations

Source Category Description

Metering and pressure regulating stations (M&R stations) are used in the transmission and distribution of natural gas to measure the flow of gas at custody transfer points and to reduce and regulate pressure and flow. This includes custody transfer from transmission to distribution and downstream pressure reduction stations. Emissions occur from this source from fugitives and from pneumatic devices.

Emission Factors

Source Category	M&R >300	M&R 100-300	M&R <100	Reg >300	R-Vault >300	Reg 100-300	R-Vault 100-300	Reg 40-100	R-Vault 40-100	Reg <40
Default EF (MTCH$_4$ station^{-1} yr^{-1})	2.1427	0.9954	0.7272	0.8689	0.0506	0.143	0.0506	0.1637	0.0506	0.0224
Source	EPA 2023, Annex 3.6-2									
EF Confidence	Geography Rest of the Country			Recency ≤ 5 Years		Methodology Empirical Observation			Status Grey Literature	
Source Description	For M&R<100 and M&R<40, this inventory applies the EFs derived by EPA in the 2021 inventory (EPA 2023), based on data from GRI/EPA 1996. For all other types of stations, the inventory applies the EFs derived in the 2021 inventory, based on data from Lamb et al. 2015 for years 2011-2021, GRI/EPA 1996 for years 1990-1992, and a linear extrapolation for years 1993-2010.									

Activity Data

The activity data for M&R stations are the number of stations; M&R stations are classified by 10 categories based on inlet pressure category (e.g., 100-300, 40-100, etc.), station type (M&R vs. regulator stations), and location (vault vs. above ground).

For M&R stations, national counts are taken from the Greenhouse Gas Inventory. CH_4 emissions were calculated as the number of stations times the EF. The MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5,\,20}$ factor of 84.

Geospatial Data and Allocation Methodology

National counts of M&R stations from the Greenhouse Gas Inventory were used to estimate the number of M&R stations in NYS by applying a ratio of NYS pipeline miles to US pipeline miles and a ratio of M&R stations by type to pipeline miles. State-level M&R stations by type were then distributed to counties using a county to state ratio of gas distribution employees from County Business Patterns (NAICS 2212).

Sample Calculations

Equation 18 $$CH_4 \text{ emissions } (MTCO_2e) = \text{pipeline miles} \times AF_1 \times AF_2 \times \times EF \times GWP_{AR5,\,20}$$

where:

- Pipeline miles = miles of distribution pipeline in NYS
- AF_1 = ratio of national level M&R station by type to total national level pipeline miles
- AF2 = allocation factor based on ratio of county-level number of natural gas distribution employees to the state total number of employees
- EF = CH_4 EF ($MTCH_4$ $meter^{-1}$ yr^{-1})
- $GWP_{AR5,\,20}$ = GWP = 84

For example, there were 4,244 M&R stations with inlet pressure greater than 300 psi in the U.S. In the U.S. in 2021, there were 1,337,012 miles of pipeline mains, resulting in a ratio of 0.0032. Applying this ratio to the pipeline miles in NYS (49,778) results in 158 M&R stations with inlet pressure greater than 300 psi in NYS. The allocation factor for Allegany County based on U.S. Census employment data is 0.061538, resulting in 9.72 M&R stations with inlet pressure greater than 300 psi in Allegany County. This results in emissions of 1,764 $MTCO_2e$ as shown below.

$$\text{M\&R station } CH_4 \text{ emissions } (MTCO_2e) = 49{,}778 \times 0.0032 \times 0.061538 \times 2.1427 \times 84$$

$$\text{M\&R station } CH_4 \text{ emissions } (MTCO_2e) = 1764 \; MTCO_2e$$

To calculate emissions for this source category, repeat the calculation for each M&R station type and sum the emissions from each type.

Limitations and Uncertainties

The EFs for years 1993-2010 are based on an extrapolation, which could be inaccurate. In addition, EFs are based on studies of emissions from the outside of NYS, and it is possible they do not accurately represent conditions and leak rates in the state.

Potential Areas of Improvement

Actual counts for metering and regulating stations are not well established, but it is estimated that there are between 3,000 and 4,000 M&R stations in New York State (6 NYCRR Part 203). The methodology used here estimates more than 5,000 M&R stations in New York State and could be improved with county-level estimates. The methodology also includes many allocation factors and ratios to estimate county-level M&R stations, so direct counts of stations would improve accuracy.

3.2.7.6 Service Meters

Source Category Description

A gas meter is a specialized flow meter that measures the volume of gas transferred from an operator to a consumer. Gas meters can be for residential, commercial, or industrial use. In some cases, such as residential use, when the gas reaches a customer's meter, it passes through another pressure regulator to reduce its pressure to under 0.25 psi.

Emission Factors

Source Category	**Residential Meters**		**Commercial Meters**	**Industrial Meters**
Default EF (MTCH$_4$ meter^{-1} yr^{-1})	0.0015		0.0234	0.105
Source	EPA 2023, Annex 3.6-2			
EF Confidence	Geography Rest of the Country	Recency ≤ 5 Years	Methodology Empirical Observation	Status Grey Literature
Source Description	This inventory applies the residential, commercial, and industrial EFs derived by EPA in the 2021 inventory (EPA 2023), based on data from the Gas Technical Institute (GTI 2009) (for all), GTI (2019) (for commercial and industrial) and Clearstone Engineering (Clearstone 2011) (for residential).			

In the first iteration of the Oil and Gas Methane inventory published in 2019 (NYSERDA 2019), the methodology for service meters used an EF of 0.0097 for commercial/industrial meters derived by EPA in their 2018 Greenhouse Gas Inventory (EPA 2018a). In this version of the inventory, separate EFs were applied for commercial and industrial meters in accordance with updates to the 2021 Greenhouse Gas Inventory (EPA 2023).

Activity Data

The activity data for service meters is the number of service meters. State-level data on the distribution meter counts was pulled from the PHMSA Pipeline Mileage and Facilities database, U.S. Census Bureau reported household utility gas counts and County Business Patterns, and EIA reported residential, commercial, and industrial customer counts.

CH_4 emissions were calculated as the number of distribution meters times the EF. The MTs of CH_4 were converted to $MTCO_2e$ by applying the $GWP_{AR5,\,20}$ factor of 84.

Geospatial Data and Allocation Methodology

Residential meters were allocated to the county level using U.S. Census counts of utility gas as the primary home heating fuel. The meter counts were then geospatially allocated by census tract to the county and gas utility service areas, based on the most recently available geospatial distribution of service areas.[8] Finally, due to an undercounting of homes with utility gas in the one-year census data, census counts were scaled by the total residential meter count reported by EIA.[9] Census data were not readily available for years 1990–2006, so the distribution of meters by census block in 2006 was used as the baseline, and the same methodology was applied to scale the total residential meter count using EIA reported data for those years. The number of homes with utility gas as the primary heat source was reported in the U.S. Census Bureau's American Community Survey.[10]

Commercial meters were allocated based on the count of businesses by zip code, available from the Census County Business Patterns data set[11] geospatially allocated to county and gas service territories. The count of eligible businesses (i.e., those within gas utility service areas) were then scaled by the total count of commercial customers as reported by EIA.[12]

Industrial meters were allocated based on the count of businesses with manufacturing NAICS codes, available from the Census County Business Patterns data set[11] geospatially allocated to county and gas service territories. The count of eligible businesses (i.e., those within gas utility service areas) were then scaled by the total count of industrial customers as reported by EIA.[12]

Sample Calculations

Equation 30 $\textbf{CH}_4\textbf{ emissions (MTCO}_2\textbf{e) = service meters x AF1 x AF2 x EF x GWP}_{\textbf{AR5, 20}}$

where:

- service meters = state-level number of service meters
- AF_1 = ratio of meter type (residential or commercial) to total meters
- AF_2 = allocation factor based on ratio of county-level number of meters (residential or commercial) to the state total number of meters (residential or commercial)
- EF = CH_4 EF ($MTCH_4$ $meter^{-1}$ yr^{-1})
- $GWP_{AR5, 20}$ = GWP = 84

For example, according to the PHMSA data, there were 3,241,702 service meters in New York State in 2020. The ratio of residential to total meters estimated from the allocation methodology is 4,150,738/4,559,150. Based on the allocation methodology, the number of homes in Albany County with utility gas as the primary heat source in 2020 was 101,851 and the total number of homes in the State with utility gas as the primary heat source in 2020 was 4,150,738. Applying the allocation factors to the PHMSA data, there were 72,419 residential service meters in Albany County in 2020, resulting in 2,716 $MTCO_2e$ as shown:

Equation 31 $\textbf{Distribution meter CH}_4\textbf{ (MTCO}_2\textbf{e) = 3,241,702 x 4,150,738/4,559,150 x 101,851/4,150,738 x 0.0015 x 84}$

$\textbf{Distribution meter CH}_4\textbf{ (MTCO}_2\textbf{e) = 9,124.8 MTCO}_2\textbf{e}$

Limitations and Uncertainties

Emissions from services and meters are estimated using values from the EPA 2018 GHG emissions inventory (Annex 3.6, Table 3.6-2), which builds on estimates from the Gas Research Institute (GRI) 1996 study, which in turn is based on a 1992 report from Indaco Air Quality Services titled Methane Emissions from Natural Gas Customer Meters: Screening and Enclosure Studies, which estimates emissions from residential meters, not including service lines, to be 138.5 ± 23.1 scf $meter\text{-}yr^{-1}$.

These estimates are updated using data from GTI (GTI 2009) and Clearstone Engineering (Clearstone 2011) to produce the estimates used in the EPA 2021 GHG Inventory. Given that these meter data are derived from a set of older studies, not local to New York State, it is possible that these estimates do not accurately reflect current conditions and leak rates from meters in the State.

Potential Areas of Improvement

This estimate may be improved by employing more up-to-date estimates of leak rates from residential meters. The EPA/GRI (1996) study indicated that there may be differences in regional leak rates from residential meters, so using New York State or northeast-specific measurements, where available, would be most applicable.

These estimates may also be improved with more accurate counts of meters at the county-level that do not require the application of allocation factors.

3.2.7.7 Residential Appliances

Source Category Description

Natural gas is a common fuel for many residential appliances. This category covers natural gas in appliance exhaust for furnaces, boilers, storage water heaters, tankless water heaters, stoves, and ovens. During ignition and extinguishment, appliance exhaust typically exhibits a brief methane concentration spike compared to the low concentration of methane in exhaust during steady state operation. The methane emissions from residential appliances in this category reflect the appliance exhaust during ignition, extinguishment, and steady-state operation.

Emissions Factors

<table>
<tr><th>Source Category</th><th colspan="4">Residential Appliances</th></tr>
<tr><td rowspan="6">Default EF
(MTCH$_4$ appliance-1 yr^{-1})</td><td>Furnace</td><td>0.00022</td><td colspan="2">(0.00014 – 0.00051)</td></tr>
<tr><td>Boiler</td><td>0.00032</td><td colspan="2">(0.00015 – 0.00075)</td></tr>
<tr><td>Storage Water Heater</td><td>0.000077</td><td colspan="2">(0.00002 – 0.000084)</td></tr>
<tr><td>Tankless Water Heater</td><td>0.0012</td><td colspan="2">(0.00098 – 0.041)</td></tr>
<tr><td>Stove</td><td>0.000056</td><td colspan="2">(0.00004 – 0.000071)</td></tr>
<tr><td>Oven</td><td>0.00013</td><td colspan="2">(0.00011 – 0.00014)</td></tr>
<tr><td>Source</td><td colspan="4">Merrin and Francisco 2019</td></tr>
<tr><td>EF Confidence</td><td>Geography NYS</td><td>Recency
≤ 5 Years</td><td>Methodology
Empirical Observation</td><td>Status
Peer Reviewed</td></tr>
<tr><td>Source Description</td><td colspan="4">Merrin and Francisco (2019) sampled methane concentrations in exhaust from residential natural gas appliances at 72 sites in Boston and Indianapolis and 28 sites in Illinois and New York State. Testing utilized a Picarro G4301 cavity ringdown spectroscopy portable gas concentration analyzer. The authors studied furnaces, boilers, storage water heaters, tankless water heaters, stoves, and ovens. To calculate the annual emissions per appliance-by-appliance type, Merrin and Francisco (2019) used average measured emission factors combined with calculated exhaust flow and appliance usage assumptions based on national usage data from EIA's 2015 Residential Energy Consumption Survey (EIA, 2018). After calculating an absolute emission quantity for ignition and extinguishment spikes and an emission factor during steady state operation, annual per appliance emissions were calculated using the following equation:

$$\begin{aligned} \mathit{appliance\ annual\ emissions}\ (kg) &= \mathit{ignition\ emission}\ (kg/activation) \\ &+ \mathit{extinguishment\ emission}\ (kg/activation) * \frac{activations}{year} \\ &+ \mathit{steady\ state\ emission\ rate}\ \left(\frac{kg}{hr}\right) * \mathit{annual\ runtime}\ \left(\frac{hr}{yr}\right) \end{aligned}$$

The methane emissions factors by appliance type were comparable regardless of location. As the authors note, climate differences will affect usage and total emissions, but appliances are mass-produced and distributed widely so location is unlikely to influence emission factors. Several sources of uncertainty during the data collection include instrument limitations, sample size, exhaust-flow rate assumptions/calculations and limited appliance observation. To account for the uncertainty, Merrin and Francisco report per alliance annual emissions values as well as 97.5% confidence interval ranges.</td></tr>
</table>

Two recent studies reference Merrin and Francisco's work. Lebel et al. (2020) developed emissions factors from natural gas water heaters in northern California and compared the emissions factors to those developed by Merrin and Francisco. While the EFs developed by Lebel et al. are higher than those developed by Merrin and Francisco for water heaters, Lebel et al. (2020) notes that Merrin and Francisco did not measure pilot lights due to their sampling protocol. However, EF values were similar for the components that both studies measured, indicating that EFs are comparable regardless of location/

climate. Saint-Vincent and Pekney (2020) compared the Merrin and Francisco emission factor for furnaces to emission factors used in other countries. They use the EF for furnaces developed by Merrin and Francisco and convert it to units of kg/TJ. Saint-Vincent and Pekney (2020) state that considering steady-state usage and the off state is important when estimating emissions, and the authors note that Merrin and Francisco's EFs consider steady-state usage in addition to ignition.

Activity Data

The activity data are the county-level number of appliances by appliance type. The number of appliances by appliance type in the Middle Atlantic, which consists of New Jersey, New York State, and Pennsylvania,[13] is estimated using information from the 2015 Residential Energy Consumption Survey (RECS; Tables HC3.7, HC6.7, and HC8.7). The RECS reports data on the number of housing units using stoves, ovens, furnaces, boilers, and water heaters, including data on the most used fuel for each appliance type in the Middle Atlantic region. Table 8 shows the estimated number of appliances by appliance type in the Middle Atlantic region in 2015.

Table 8. Number of Natural Gas Appliances in the Mid-Atlantic Region by Appliance Type

Natural Gas Appliance Type	Number of Appliances (million)
Tankless Water Heater	0.17
Storage Water Heater	5.86
Furnace	5.6
Boiler	3.2
Stove	8.44
Oven	7.85

The fraction of housing units with appliance type presented in Table 9 is calculated by dividing the total number of appliances by the total number of housing units in the Middle Atlantic in 2015 from RECS (15.4 million).

Table 9. Fraction of Housing Units with Appliance Type by Appliance

Natural Gas Appliance	Fraction of Housing Units with Appliance Type
Furnace	0.361290323
Boiler	0.206451613
Storage Water Heater	0.378064516
Tankless Water Heater	0.010967742
Stove	0.544516129
Oven	0.506451613

NYSERDA’s Single Family Building Assessment Report[14] and the U.S. Census Bureau[15] are used to develop the fraction of housing units by housing unit type across the three climate zones in the State. These fractions are presented in Table 10.

Table 10. Fraction of Units in Each Climate Zone by Housing Unit Type

Housing Unit Type	Fraction of Units in Climate Zone 4	Fraction of Units in Climate Zone 5	Fraction of Units in Climate Zone 6
Single-family total			
Climate Zone 4	0.181274		
Climate Zone 5		0.146721	
Climate Zone 6			0.066557
Apartments in buildings with 2-4 units	0.285904	0.297971	0.325964
Apartments in buildings with 5 or more units	0.480839	0.501132	0.548213
Mobile homes	0.051983	0.054176	0.059266
Total	1	1	1

The correction factors in Table 11 are then applied to take into account that some counties do not have natural gas service.

Table 11. Correction Factor to Account for Counties without Natural Gas Service

Housing Unit Type	Total Housing Units in 2018	Total Housing Units in Counties with Natural Gas Service in 2018	Total Housing Units in Counties without Natural Gas Service in 2018	Ratio of Total Housing Units to Housing Units with Natural Gas Service
Single-family total	1,316,657	1,292,847	23,810	1.018417022
Other housing types	7,047,277	6,795,613	251,664	1.037033245

The county-level number of appliances by appliance type and housing type is then calculated by multiplying the county-level number of houses from the U.S. Census Bureau by the fraction of housing units with the appliance, the fraction of housing unit type by climate zone, and the correction factor.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary for years 2000–2020 since county-level number of housing units were available from the Census. For years 1990–1999, the ratio of county to state total housing units in 2000 was applied to distribute state-level numbers to county-level.

Sample Calculations

Equation 32

$$\mathbf{CH_4\ emissions\ (MTCO_2\ e) = \sum Housing\ units county \times fraction\ of\ housing\ units appliance \times housing\ unit\ type\ fraction climate\ zone \times CFng\ service \times EFappliance \times GWP_{AR5,\ 20}}$$

where:

- Housing $\text{units}_{\text{county}}$ = total number of housing units in county
- Fraction of housing $\text{units}_{\text{appliance}}$ = fraction of housing units with natural gas appliance
- Housing unit type $\text{fraction}_{\text{climate}}$ = fraction of housing unit type by climate zone
- $CF_{\text{ng service}}$ = correction factor to account for counties without natural gas service
- $EF_{\text{appliance}}$ = CH_4 emissions factor by appliance ($MTCH_4$ appliance^{-1} yr^{-1})
- $GWP_{AR5,\ 20}$ = GWP = 84

For example, there were 7,737 natural gas furnaces in single-family homes in Albany County in 2020, resulting in 143 $MTCO_2e$ as shown below.

Equation 33

$$\mathbf{Gas\ furnace\ CH_4\ (MTCO_2\ e) = 143{,}314 \times 0.36129 \times 0.146721 \times 1.0185 \times 0.00022 \times 84}$$

$$\mathbf{Gas\ furnace\ CH_4\ (MTCO_2\ e) = 143\ MTCO_2\ e}$$

To calculate total emissions for all residential appliances, repeat the calculation and sum the emissions. The total CH_4 emissions from residential appliances in Albany County in 2020 is 3,583.4 $MTCO_2$ e.

Limitations and Uncertainties

There are several limitations to the current draft emission estimates due to unavailable data. The inventory is currently missing emissions from natural gas clothes dryers because data on emissions from residential natural gas clothes dryers are not readily available. The impact of excluding natural gas clothes dryers is likely minimal. A study by Fisher et al. (2018) indicates that pilot lights are a main source of end-use methane emissions and natural gas dryers do not have pilot lights. Furthermore, Merrin and Francisco (2019) note that > 96% of residential natural gas consumption is used for space heating, water heating, and cooking, so end use emissions from other appliances, such as natural gas dryers, should be minimal.

Potential Areas of Improvement

The appliance estimates are based on Mid-Atlantic survey results from RECS. A NYS-specific survey could improve the accuracy of the appliance count estimates. For example, NYSERDA's Single Family Building Assessment Report has some information on the penetration rate of some natural gas appliance types. These rates could be used to adjust the Mid-Atlantic survey results.

3.2.7.8 Residential Buildings

Source Category Description

In addition to emissions from appliances, post-meter fugitive methane emissions in residential buildings occur from plumbing connections and pilot lights. This source category estimates the leakage of methane from residential building pipes, pipe connections and pilot lights from quiescent appliances (e.g., termed quiescent whole-house emissions).

Emissions Factors

Source Category	**Residential Buildings**			
Default EF ($MTCH_4$ housing unit^{-1} yr^{-1})	0.00181 (0.0010596 – 0.0035267)			
Source	Fischer et al. 2018a, Fischer et al. 2018b			
EF Confidence	Geography Rest of Country	Recency ≤ 5 Years	Methodology Empirical Observation	Status Peer Reviewed
Source Description	Fischer et al. measured CH_4 emissions from pipe leaks and pilot lights in 75 single-family California homes when appliances were not operating and quantified emissions using a Bayesian statistical sampling procedure. The emissions factor for this is calculated by dividing the quiescent whole-house emissions (Table 12 in Fisher et al. 2018a) by the number of housing units in California (12.93 million). The estimate for mean whole-house emissions is 23.4 (13.7 – 45.6, 95% confidence) Gg CH_4/yr when using only measurements from houses where the prescribed calibration flow is obtained. Pilot light emissions account for roughly 25% of the quiescent whole-house emissions.			

Activity Data

The activity data for residential buildings is housing units with natural gas service. State-level data on the distribution of meter counts was pulled from the PHMSA Pipeline Mileage and Facilities database,[16] U.S. Census Bureau reported household utility gas counts, and EIA reported residential, commercial, and industrial customer counts.

Geospatial Data and Allocation Methodology

Residential meters were allocated to the county-level using census-reported counts of utility gas as the primary home heating fuel. These data were available from 2006–2020 at the census tract level. These meter counts were then geospatially allocated by census tract to the county and gas utility service areas, based on the most recently available geospatial distribution of service areas.[17] Finally, due to an under-counting of homes with utility gas in the one-year census data, census counts were scaled by the total residential meter count reported by EIA.[18] Census data were not readily available for years 1990–2006, so the distribution of meters by census block in 2006 was used as the baseline, and the same methodology was applied to scale the total residential meter count using EIA reported data for those years. The number of homes with utility gas as the primary heat source was reported in the U.S. Census Bureau's American Community Survey.[19]

Sample Calculations

Equation 34 $\mathbf{CH_4}$ **emissions (**$\mathbf{MTCO_2}$ **e) = housing units**$_{\mathbf{ng}}$ **x EF x GWP**$_{\mathbf{AR5,\ 20}}$

where:

Equation 35 **Housing units**$_{\mathbf{ng}}$ **= number of housing units with natural gas service**

- EF = CH_4 EF ($MTCH_4$ housing unit^{-1} yr^{-1}) = 0.00181
- $GWP_{AR5,\ 20}$ = GWP = 84

For example, there were 13,176 housing units in Cattaraugus County in 2020, resulting in 2,003 $MTCO_2e$ as shown below.

Equation 35 **Residential building** $\mathbf{CH_4}$ **(**$\mathbf{MTCO_2}$ **e) = 13,176 x 0.00181 x 84**
Residential building $\mathbf{CH_4}$ **(**$\mathbf{MTCO_2e}$**) = 2,003** $\mathbf{MTCO_2e}$

Limitations and Uncertainties

Fischer et al. (2018a) assumed methane emissions from multifamily housing can be estimated based on results from single-family homes, because they share many similar characteristics for natural gas plumbing and appliances. The authors did not find a significant ($p < 0.1$) relationship between whole-house leakage and house age.

Potential Areas of Improvement

Data on county-level housing units for NYS from 1990 to 2005 are needed for more accurate estimates of emissions from residential buildings for those years.

3.2.7.9 Commercial Buildings

Source Category Description

Post-meter fugitive methane leaks from commercial buildings are a result of gas appliance and pipeline leaks. Since combustion emissions from gas appliances are covered elsewhere in the NYS GHG inventory, this source category focuses solely on pipeline leaks.

Emissions Factors

<table>
<tr><th>Source Category</th><th colspan="4">Commercial Buildings</th></tr>
<tr><td>Default EF (MTCH4 building^{-1} yr^{-1})</td><td colspan="2">Hospital 0.202385 (0.09382 – 0.31095)
Restaurants 0.0480325 (0.0381091 – 0.0591932)</td><td colspan="2">Education 0.007965
Lodging 0.00645
Office 0.005605
Warehouse 0.0009898
Retail 0.0006273</td></tr>
<tr><td>Source</td><td colspan="2">Sweeney et al. 2020</td><td colspan="2">ICF 2020</td></tr>
<tr><td>EF Confidence</td><td>Geography
Rest of Country</td><td>Recency
≤ 5 Years</td><td>Methodology
Empirical Observation</td><td>Status Grey
Literature</td></tr>
<tr><td>Source Description</td><td colspan="2">Sweeney et al. (2020) developed and validated measurement techniques for fugitive emissions from piping components and combustion equipment in the field for 20 foodservice sites and two inpatient hospitals in California. The project team collected samples from gas-fired appliances and accessible gas piping components at each site and completed an inventory of all gas appliances and visible piping components. The field data was fed into a series of probabilistic and statistical analyses that researchers then input into a Monte Carlo simulation to develop annual emissions by building type. The hospital emissions factors are calculated from data presented on page 138 of the Sweeney et al. report while restaurant emissions factors are derived from scenario 3.</td><td colspan="2">ICF (2020) analyzed field data to characterize methane emissions from commercial buildings in California. Combining estimates of emissions from pipe joints and appliances, the team estimated total fugitive methane emissions from commercial buildings across California to be between 540 and 620 million cubic feet per year as measured or 311 to 392 million cubic feet per year for the alternative estimate designed to reduce the impact of outliers.</td></tr>
</table>

Activity Data

The activity data for commercial buildings are county-level counts of buildings by building type. County-level data on each commercial building type was pulled from the United States Census Bureau's County Business Patterns Datasets. Data on the number of buildings in each county from 1998 to 2011 was pulled for North American Industry Classification System (NAICS) codes; for example, 622 (hospitals), 722110 (full-service restaurants), 722211 (limited-service restaurants), and 722212 (cafeterias, grill buffets, and buffets). From 2012 to 2019, data was pulled for the number of buildings for NAICS codes 622, 722511 (full-service restaurants), 722513 (limited-service restaurants), and 722514 (cafeterias, grill buffets, and buffets). The individual restaurant counts were summed to a total restaurant count per county. County-level data is not available for these NAICS codes before 1998, so the data were held constant from 1990 to 1998.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary since the U.S. Census Bureau reports building counts by type at the county level.

Sample Calculations

Equation 36 $\text{CH}_4 \text{ emissions (MTCO}_2\text{ e)} = \sum \text{commercial buildings}_{\text{type}} \times \text{EF} \times \text{GWP}_{\text{AR5, 20}}$

where:

- commercial $\text{buildings}_{\text{type}}$ = number of commercial buildings by building type.
- EF_{type} = CH_4 EF by building type ($MTCH_4$ building^{-1} yr^{-1}).
- $\text{GWP}_{\text{AR5, 20}}$ = GWP = 84

For example, there were 126 restaurants in Cattaraugus County in 2020, resulting in 508 $MTCO_2e$ as shown below.

Equation 37 $\text{Restaurant CH}_4 \text{ (MTCO}_2\text{ e)} = 126 \times 0.0480325 \times 84$
$\text{Restaurant CH}_4 \text{ (MTCO}_2\text{e)} = 508 \text{ MTCO}_2\text{e}$

To calculate emissions for this source category, repeat the calculation for each commercial building type and sum the emissions from each commercial building type.

Limitations and Uncertainties

This category includes a limited subset of commercial buildings with natural gas service.

Because of factors such as a limited number of buildings and appliances analyzed and outliers in the sample for ICF (2020), the uncertainty associated with this analysis is very high, with a range of emissions spanning approximately 78.6 million to 1.1 billion cubic feet of CH_4 per year. In addition, emissions factors for all buildings are based on studies from California. Therefore, it is possible these do not accurately represent the current conditions and leak rates from commercial buildings in the State.

Potential Areas of Improvement

Since there is not activity data available before 1998 and data is held constant through 1998, more accurate county-level data on commercial buildings prior to 1998 would improve these estimates.

The estimates for this category could be improved with emissions factors and further data on other commercial building types.

4 Results

The following section presents an analysis of the detailed, activity driven, CH_4 emissions inventory for the oil and natural gas sector in New York State, developed through the information provided in section 3.1 and using the methodology in section 3.2. Following best practices described by IPCC guidelines and the EPA, this analysis identifies and describes CH_4 emissions by source category and provides a geospatially resolved breakdown of emissions by county. In addition, the overall trends in CH4 emissions captured by the inventory for 1990–2021 are presented.

4.1 Inventory Updates

The inventory has continuously improved during each iteration of this project; see appendix A for more details on inventory improvements. Table 12 below compares emissions from key inventory years across all three inventories, from the first New York State Greenhouse Gas Inventory, 1990–2015 to the first iteration of the New York State Oil and Gas Sector Methane Emissions Inventory, 1990–2017, the second iteration of the New York State Oil and Gas Sector Methane Emissions Inventory, 1990–2020, and third and current iteration of the New York State Oil and Gas Sector Methane Emissions Inventory, 1990–2021.In the first iteration of the project, CH_4 emissions in 2015 totaled 112,870 metric tons (MT) CH_4 or approximately 2.82 million metric tons (MMT) CO_2e (AR4 GWP_{100}). Results of the first iteration estimated CH_4 emissions to be 27% higher than previous estimates of CH_4 emissions from natural gas systems [2.22 MMT CO_2e, AR4, GWP_{100} in 2015], based on prior inventories developed by the State and using 2015 as the most recent common year. In the first iteration of the NYS Oil and Gas Methane Emissions Inventory 2017 emissions totaled 2.66 $MMTCO_2e$ (AR4 GWP_{100}), or 8.951 $MMTCO_2e$ (AR5 GWP_{20}). The second iteration of the inventory estimates 2017 emissions to total 14.7 $MMTCO_2e$ (AR5 GWP_{20}). Thus, the improvements made to the inventory between the first and second iteration resulted in an emissions increase of 64%. The increase is due to the addition of beyond-the-meter sources and updates to distribution emission factors and conventional production emission factors. The second iteration of the inventory estimates emissions to be approximately 113.5% higher than estimates from the original 2015 inventory when estimates from the 2015 inventory are converted to AR5 GWP_{20} and using 2015 as the most recent common year. The current inventory estimates CH_4 emissions to be 5% higher than the previous iteration of the New York State Oil and Gas Methane Emissions Inventory.

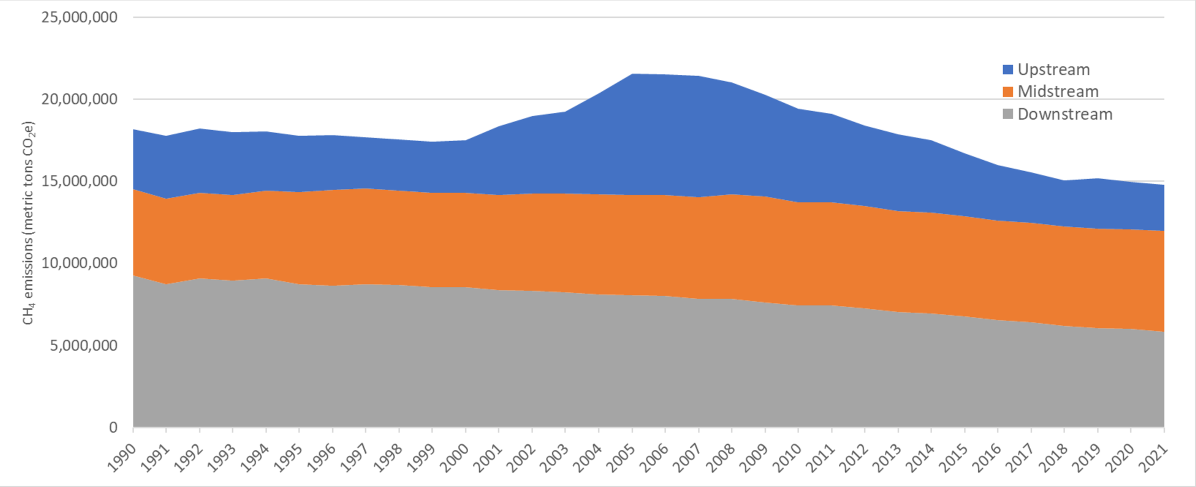
Table 12. Comparison of Emissions Across Key Inventory Years with AR4 and AR5 GWP_{100} and GWP_{20} Values Applied from the Three Inventories

Inventory	AR4 GWP_{100}	AR4 GWP_{20}	AR5 GWP_{100}	AR5 GWP_{20}
1990				
New York State Greenhouse Gas Inventory, 1990–2015	2.8	8.06	3.14	9.41
New York State Oil and Gas Methane Emissions Inventory, 1990–2017	2.74	7.88	3.07	9.21
New York State Oil and Gas Methane Emissions Inventory, 1990–2020	5.17	14.89	5.80	17.40
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	5.42	15.60	6.07	18.20
2005				
New York State Greenhouse Gas Inventory, 1990–2015	3.5	10.07	3.93	11.76
New York State Oil and Gas Methane Emissions Inventory, 1990–2017	3.52	10.12	3.95	11.83
New York State Oil and Gas Methane Emissions Inventory, 1990–2020	6.15	17.72	6.93	20.73
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	6.42	18.48	7.19	21.56
2015				
New York State Greenhouse Gas Inventory, 1990–2015	2.22	6.39	2.49	7.46
New York State Oil and Gas Methane Emissions Inventory, 1990– 2017	2.82	8.12	3.16	9.48
New York State Oil and Gas Methane Emissions Inventory, 1990– 2020	4.74	13.65	5.31	15.92
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	4.98	14.34	5.58	16.73

4.2 Emissions Time Series

Figure 12 shows total CH_4 emissions in New York State from 1990–2021. As noted previously, retrospective emissions are estimated by applying current methodologies and EFs to past activity data. Figure 12 shows that total CH_4 emissions followed a generally increasing trend from 1990 until peaking at 21.564 $MMTCO_2e$ in 2005. Since 2005 CH_4 emissions decreased each year except for a small increase in 2019. Total CH_4 emissions have decreased 31.4% since their peak in 2005, described in more detail in the following section.

Figure 12. Total CH_4 Emissions in New York State from 1990–2021 (AR5 GWP_{20})

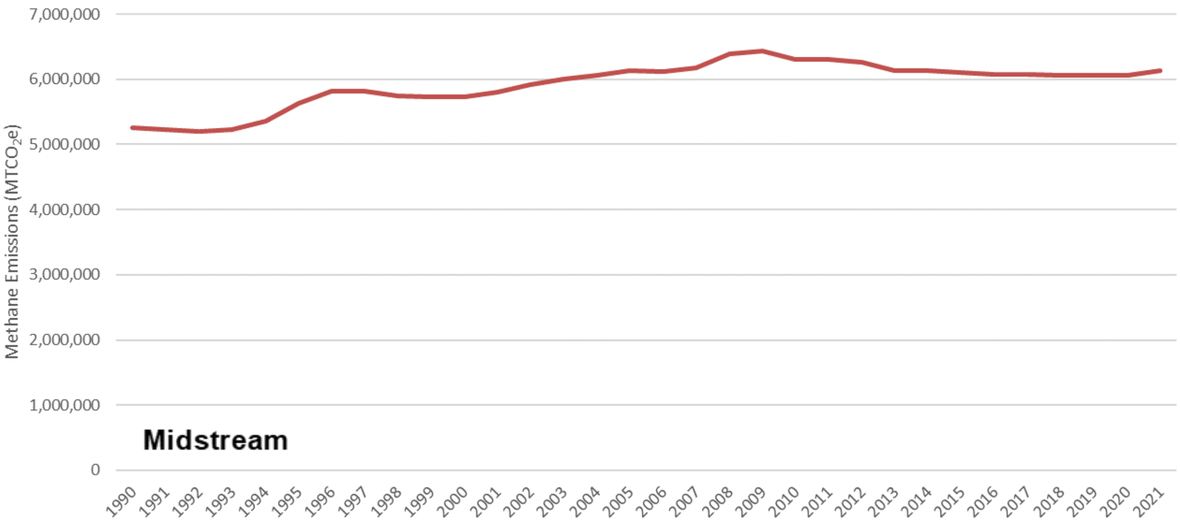


Total emissions are the sum of upstream (Figure 13), midstream (Figure 14), and downstream (Figure 15) emissions. Upstream emissions, though smaller in magnitude than midstream and downstream emissions, have shown greater variation over time, more closely mirroring the cyclical nature of oil and gas exploration and well completions in New York State. Upstream CH_4 emissions peaked at 7.415 $MMTCO_2e$ in 2007, corresponding with the observed peak in natural gas production (shown in Figure 4) and well completions (shown in Figure 2), which both correspond with peak natural gas prices, and which have declined since 2007. Correspondingly, well completions have fallen to zero and natural gas production is around one-fifth of the peak production observed in 2007, resulting in an overall decline in emissions associated with upstream source categories Overall upstream emissions decreased 24% from 1990–2021, and by 62.2% from 2007–2021.

Figure 13. Upstream CH_4 Emissions in New York State from 1990–2021 (AR5 GWP_{20})

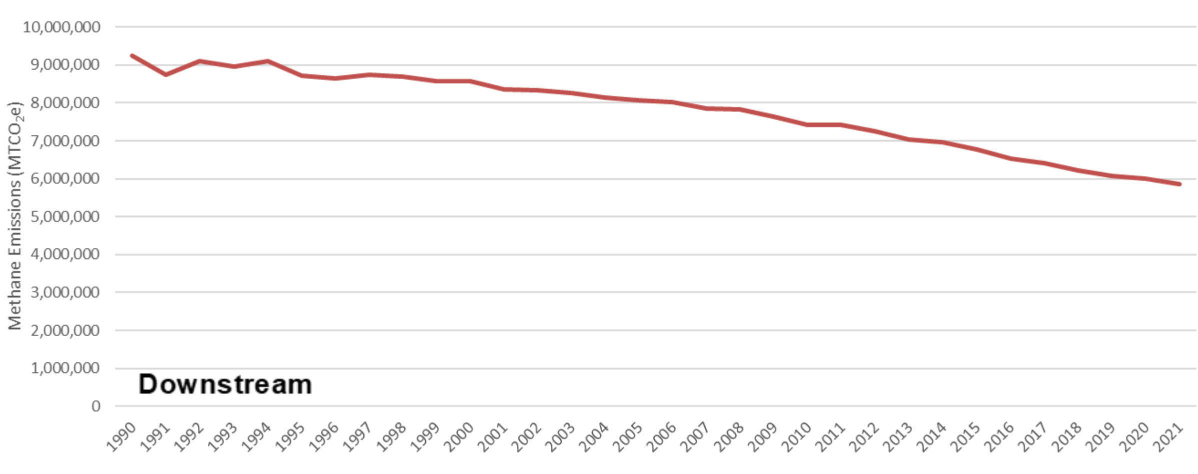
Midstream CH_4 emissions (Figure 14) increased from 1990–2021 by 16.8%. However, since 2009 midstream emissions have declined by 4.6% as a result of declining natural gas production and subsequent natural gas gathering. As shown in Figure 17, midstream CH_4 emissions are largely a function of transmission and storage compressor stations and transmission pipelines. DEC data show increasing compressor counts and transmission pipeline miles in New York State, resulting in generally increasing midstream CH_4 emissions. Although natural gas production in the State has declined since 2006, natural gas consumption has increased, rising by 22% from 1,080,215 million cubic feet (MMcf) in 2005 to 1,317,285 MMcf in 2021 (EIA 2023). Correspondingly, emissions peaked in 2009 due to the addition of new compressor stations required to maintain natural gas pressure along the transmission line in New York State and the addition of transmission pipelines.

Figure 14. Midstream CH_4 Emissions in New York State from 1990–2021 (AR5 GWP_{20})



Downstream CH_4 emissions (Figure 15) decreased by 36.8% from 1990–2021. The two largest source categories in downstream emissions, cast-iron and unprotected steel distribution main pipeline mileage, have both decreased since 1990 and have largely been replaced with plastic distribution mains. Plastic mains have much lower leak rates and therefore a lower EF, resulting in the downward trend observed in Figure 15. Additionally, increasing consumption in New York State has driven increases in the number of residential services and meters, though the growth in the number of meters and services is outweighed by the transition from cast-iron and unprotected steel distribution lines to plastic, resulting in a net decrease of emissions.

Figure 15. Downstream CH_4 Emissions in New York State from 1990–2021 (AR5 GWP_{20})



4.3 Total Emissions

CH_4 emissions from oil and natural gas activity in New York State in 2021 totaled 176,051 $MTCH_4$, equivalent to 14,788,258 $MTCO_2e$ (values given in AR5 GWP_{20} unless otherwise noted). Using 2015 as the most recent common year, this study estimates CH_4 emissions to be 124.3% higher than the previous estimate of CH_4 emissions from the oil and natural gas sector in the 2015 New York State GHG inventory (7.46 $MMTCO_2e$, AR5 GW20). Using 2020 as the most recent common year, this study estimates CH_4 emissions to be 5.1% higher than the previous iteration of the New York State Oil and Gas Methane Emissions Inventory. This inventory estimates emissions to be higher than estimates from previous inventories due to continuous improvements to emissions factors and the addition of more source categories.

4.4 Emissions in Year 2021 by Upstream, Midstream, and Downstream Stages

Figure 16 shows upstream, midstream, and downstream emissions as percentages of total CH_4 emissions, and Figure 17 shows emissions broken out by upstream, midstream, and downstream source categories using AR5 GWP_{20} units. These data over time are also shown in Table 13, Table 14, and Table 15. Downstream emissions totaled 5.850 $MMTCO_2e$ in 2021, accounting for 39.6% of total emissions. Cast iron mains are the largest single-source category, followed by unprotected steel mains, and unprotected steel services. Midstream emissions totaled 6.137 $MMTCO_2e$ in 2021, accounting for

41.5% of emissions, with compressors (storage and transmission) comprising the largest source categories in the inventory and accounting for 39.1% of total emissions. In fact, storage and transmission compressor stations are two of the largest single-source categories identified in New York State. Upstream sources, dominated by conventional gas wells, emitted 2.800 MMTCO$_2$e, accounting for 18.9% of total CH$_4$ emissions. These results reflect the fact that the State is largely a consumer of natural gas. As such, the midstream and downstream source categories are expected to drive the majority of CH$_4$ emissions.

Figure 16. Downstream, Midstream, and Upstream CH$_4$ Emissions in 2021 as Percentages of Total Emissions

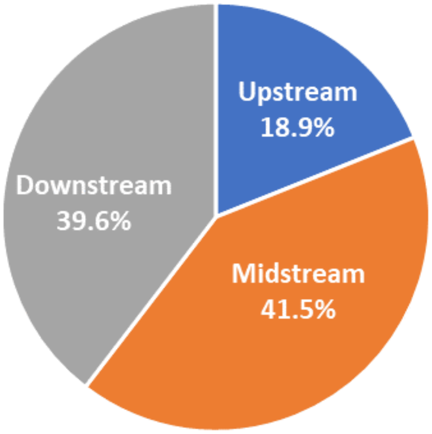
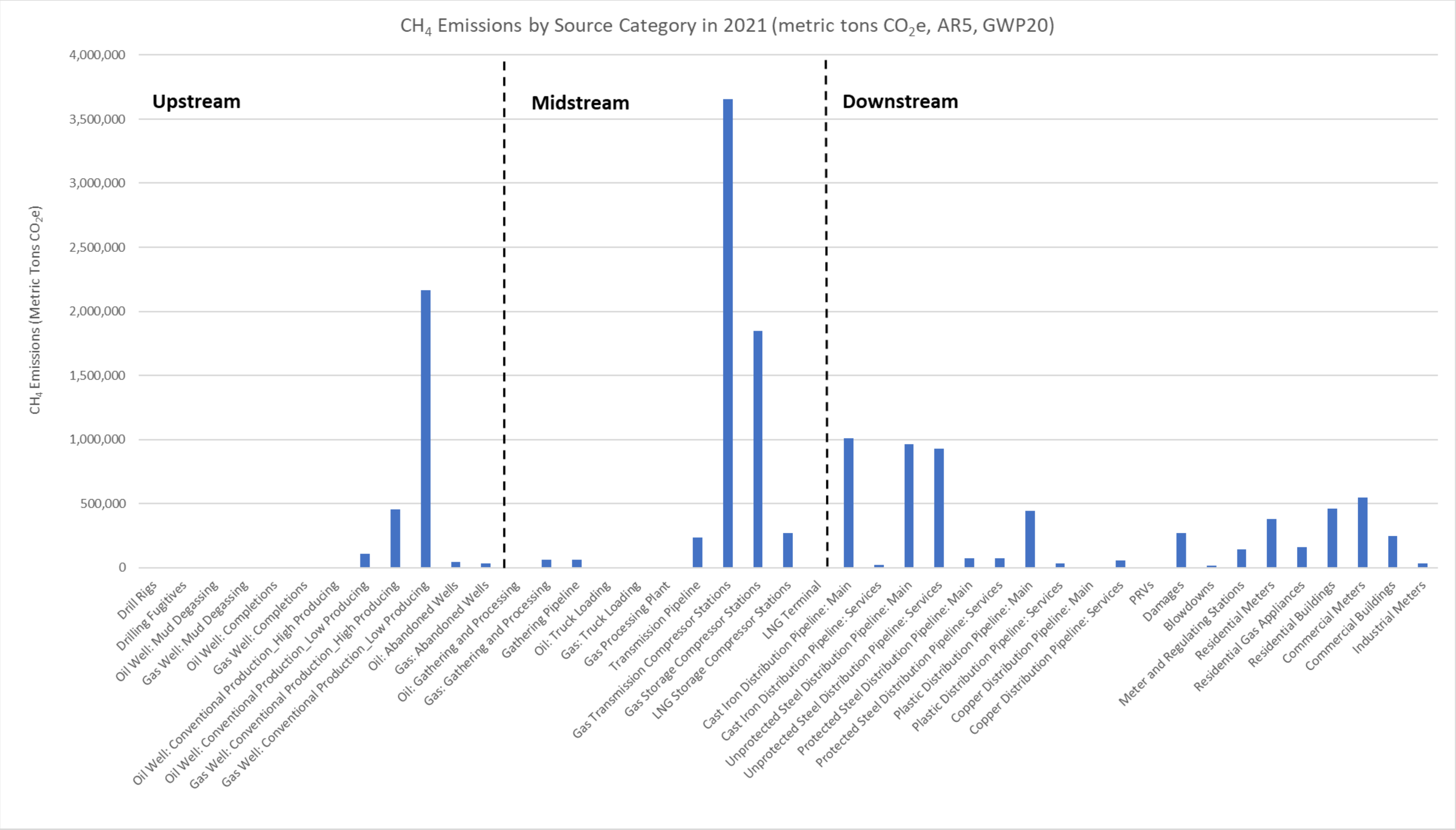


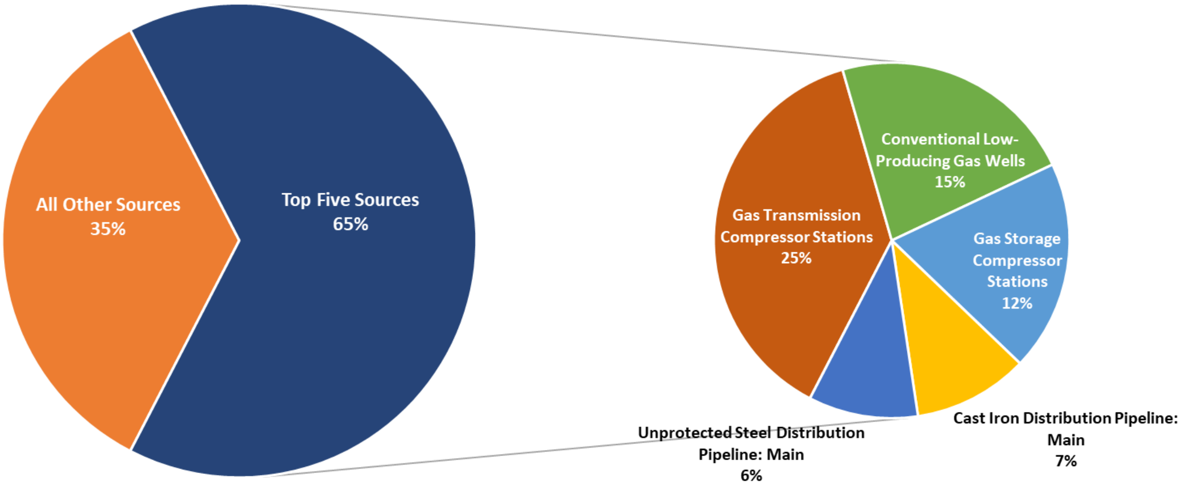
Figure 17. CH_4 Emissions by Source Category and Grouped by Upstream, Midstream, and Downstream Stages in New York State in 2021 (AR5 GWP_{20})



4.5 Emissions by Equipment Source Category in Year 2021

As shown in Figure 17 and Figure 18, the 64 natural gas transmission compressor stations are the largest single source category in New York State, accounting for 3.658 MMTCO$_2$e or 24.7% of total CH$_4$ emissions, followed by low-producing conventional gas wells, accounting for 2.164 MMTCO$_2$e or 14.6% of total CH$_4$ emissions. Taken together, the top five emitting source categories in this inventory [gas transmission compressor stations (24.74%), conventional low-producing gas wells (14.63%), gas storage compressor stations (12.51%), cast iron mains (6.83%), and unprotected steel distribution mains (6.50%)] account for 65.2% of total CH$_4$ emissions, highlighting the importance of compressor stations, gas wells, and cast iron and unprotected steel mains to the New York State CH$_4$ inventory. Considering only gas pipelines, emissions from gathering pipelines account for 0.40% of total emissions, transmission pipelines account for 1.61%, and distribution mains (including cast iron, unprotected steel, protected steel, plastic, and copper pipeline mains) for 16.78%, and distribution service lines for 7.54%. Cast iron distribution mains and unprotected steel mains make up the majority of emissions (79.4%) from distribution pipeline mains and account for 13.32% of total emissions.

Figure 18. Percentage of CH$_4$ Emissions in the Top Five Emitting Source Categories



In addition, the inventory estimates zero CH_4 emissions in 2021 from several source categories. These categories largely relate to oil and gas exploration and well completion activities. Additional source categories identified as having zero emissions include (1) truck loading, which is assumed to be zero as evaporative emissions of CH_4 from oil while stored in atmospheric tanks are incorporated into site-level EFs, (2) gas processing, since there are no processing plants in the State, (3) LNG terminals, since there are also no LNG terminals in the State, and (4) copper distribution mains, since there are none in the State. The 2015 inventory approach, scaling the national inventory to New York State, implicitly and erroneously, included these categories as emitting.

Table 13. CH_4 Emissions by Source Category in New York State from 1990–2000 ($MTCO_2e$; AR5 GWP_{20})

Category	Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Upstream	Drill Rigs	11	13	12	9	7	5	8	5	5	6	7
	Drilling Fugitives	656	792	613	538	394	293	495	284	263	319	372
	Oil Well: Mud Degassing	12,757	22,845	42,232	11,510	19,606	15,799	34,705	21,291	4,595	12,517	8,994
	Gas Well: Mud Degassing	58,731	44,333	35,536	45,340	26,324	14,508	18,600	14,661	26,696	25,339	32,188
	Oil Well: Completions	4,855	7,283	9,710	3,570	4,855	4,712	9,996	4,570	1,142	3,427	2,142
	Gas Well: Completions	16,422	18,136	10,139	13,566	7,426	4,284	5,712	4,712	5,998	4,284	6,997
	Oil Well: Conventional Production—High Producing	9,953	10,360	10,943	6,047	4,385	7,055	5,411	3,479	3,246	3,769	3,688
	Oil Well: Conventional Production—Low Producing	8,761	9,389	7,803	10,479	14,025	12,999	11,533	11,886	11,323	12,088	18,277
	Gas Well: Conventional Production—High Producing	1,722,022	1,589,742	1,594,191	1,450,096	1,193,861	1,054,629	928,337	834,282	798,244	731,520	818,604
	Gas Well: Conventional Production—Low Producing	1,852,908	2,098,568	2,205,519	2,262,407	2,338,361	2,295,476	2,361,037	2,241,400	2,276,735	2,311,491	2,308,732
	Oil Well: Unconventional Production—High Producing	0	0	0	0	0	0	0	0	0	0	0
	Oil Well: Unconventional Production—Low Producing	0	0	0	0	0	0	0	0	0	0	0
	Gas Well: Unconventional Production—High Producing	0	0	0	0	0	0	0	0	0	0	0

Table 13 continued

Category	Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Upstream	Gas Well: Unconventional Production—Low Producing	0	0	0	0	0	0	0	0	0	0	0
	Oil: Abandoned Wells	0	0	0	0	0	0	0	0	0	0	0
	Gas: Abandoned Wells	0	0	0	0	0	0	0	0	15	22	37
Midstream	Oil: Gathering and Processing	691	723	731	501	464	597	482	380	359	400	493
	Gas: Gathering and Processing	124,848	121,367	123,299	116,189	103,150	94,740	88,756	81,647	80,201	77,041	81,836
	Gathering Pipeline	112,896	88,256	62,720	87,808	227,584	231,616	357,056	282,464	207,872	202,048	201,600
	Oil: Truck Loading	187	192	182	151	135	137	139	124	98	93	95
	Gas: Truck Loading	0	0	0	0	0	0	0	0	0	0	0
	Gas Processing Plant	0	0	0	0	0	0	0	0	0	0	0
	Transmission Pipeline	214,861	215,787	216,713	217,640	218,566	219,492	220,418	221,344	222,270	223,196	224,123
	Gas Transmission Compressor Stations	3,320,520	3,320,520	3,320,520	3,320,520	3,320,520	3,320,520	3,320,520	3,320,520	3,320,520	3,320,520	3,320,520
	Gas Storage Compressor Stations	1,209,516	1,209,516	1,209,516	1,209,516	1,209,516	1,494,108	1,565,256	1,636,404	1,636,404	1,636,404	1,636,404
	Storage Reservoir Fugitives	0	0	0	0	0	0	0	0	0	0	0
	LNG Storage Compressor Stations	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525
	LNG Terminal	0	0	0	0	0	0	0	0	0	0	0
Downstream	Cast Iron Distribution Pipeline: Main	2,619,084	2,604,988	2,590,892	2,546,481	2,509,794	2,471,948	2,440,668	2,410,159	2,367,293	2,286,967	2,191,194
	Cast Iron Distribution Pipeline: Services	55,807	55,807	55,247	52,208	52,009	51,552	51,538	56,305	56,575	56,219	56,165
	Unprotected Steel Distribution Pipeline: Main	2,208,983	1,910,910	2,183,668	2,113,072	2,220,214	1,944,069	2,016,626	2,068,860	2,001,117	1,956,548	1,906,454
	Unprotected Steel Distribution Pipeline: Services	2,045,438	1,967,089	1,888,740	1,793,243	1,840,291	1,784,631	1,678,859	1,682,500	1,711,077	1,739,654	1,802,264

Table 13 continued

Category	Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	Protected Steel Distribution Pipeline: Main	67,037	68,040	69,544	70,785	70,628	70,471	70,314	70,157	68,921	69,094	69,623
	Protected Steel Distribution Pipeline: Services	131,417	131,300	137,079	137,968	124,023	127,497	122,451	121,603	120,054	118,506	110,815
	Plastic Distribution Pipeline: Main	109,555	114,077	135,533	148,345	158,303	166,834	175,445	184,554	205,769	213,354	227,882
	Plastic Distribution Pipeline: Services	9,555	9,950	11,821	12,938	13,807	14,551	15,302	16,097	17,947	18,608	19,876
	Copper Distribution Pipeline: Main	0	0	0	0	0	0	0	0	0	0	0
	Copper Distribution Pipeline: Services	87,664	86,825	85,986	85,146	84,509	83,419	83,037	83,125	82,770	82,415	82,116
	Meter and Regulating Stations	177,648	184,582	196,451	199,956	205,387	195,212	203,837	193,647	215,595	212,602	208,728
	Pressure Relief Valves	3,190	3,092	3,344	3,388	3,476	3,384	3,451	3,511	3,558	3,562	3,601
	Damages	182,950	197,968	190,671	192,893	196,768	194,844	196,084	199,812	252,498	207,741	212,035
	Blowdowns	11,711	12,672	12,205	12,347	12,595	12,472	12,551	12,790	16,163	13,298	13,572
	Commercial Meters	394,440	312,376	357,439	406,136	416,661	419,076	420,218	433,148	454,591	457,655	487,855
	Residential Meters	306,829	277,133	320,780	321,822	331,616	327,391	329,499	335,829	338,702	339,824	353,527
	Industrial Meters	133,360	120,778	135,065	130,389	122,478	123,848	84,452	129,019	29,533	34,067	37,743
	Commercial Buildings	177,156	177,156	177,156	177,156	177,156	177,156	177,156	177,156	177,156	176,810	180,482
	Residential Gas Appliances	162,547	161,981	161,328	160,666	160,044	160,656	160,888	159,928	159,515	172,007	184,500
	Residential Buildings	370,188	334,360	387,020	388,277	400,094	394,996	397,539	405,176	408,643	409,996	426,529

Table 14. CH_4 Emissions by Source Category in New York State from 2001–2011 ($MTCO_2e$; AR5 GWP_{20})

Category	Source	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Upstream	Drill Rigs	9	7	6	11	16	32	38	36	17	27	19
	Drilling Fugitives	525	407	315	635	932	1,856	2,214	2,013	1,042	1,466	1,015
	Oil Well: Mud Degassing	12,648	10,306	16,127	30,525	46,390	88,732	95,778	92,845	46,806	113,699	96,784
	Gas Well: Mud Degassing	47,747	29,628	20,482	42,954	61,051	119,038	162,430	151,620	70,548	65,996	32,429
	Oil Well: Completions	3,713	2,570	3,998	7,997	13,566	25,704	27,132	23,419	13,566	29,131	23,848
	Gas Well: Completions	11,852	7,568	4,284	9,568	15,422	33,701	43,840	40,127	19,421	17,564	8,282
	Oil Well: Conventional Production—High Producing	2,128	2,617	1,470	3,148	2,882	8,761	8,162	13,791	5,567	4,715	6,112
	Oil Well: Conventional Production—Low Producing	62,409	59,462	68,608	70,418	123,560	232,818	255,825	232,929	214,897	242,605	235,407
	Gas Well: Conventional Production—High Producing	1,717,477	2,296,308	2,460,493	3,626,681	4,750,000	4,488,906	4,363,603	3,858,593	3,382,830	2,728,391	2,440,594
	Gas Well: Conventional Production—Low Producing	2,347,502	2,348,641	2,399,370	2,389,861	2,357,117	2,390,627	2,454,518	2,424,037	2,433,051	2,480,061	2,521,263
	Oil Well: Unconventional Production—High Producing	0	0	0	0	0	0	0	0	0	0	0
	Oil Well: Unconventional Production—Low Producing	0	0	0	0	0	0	0	0	0	0	0
	Gas Well: Unconventional Production—High Producing	0	0	0	0	0	0	0	0	0	0	0

Table 14 continued

Category	Source	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Upstream	Gas Well: Unconventional Production—Low Producing	0	0	0	0	0	0	0	0	0	0	0
	Oil: Abandoned Wells	0	0	571	555	563	563	596	571	571	596	596
	Gas: Abandoned Wells	37	37	1,438	1,504	1,578	1,585	1,563	1,600	1,600	1,276	1,276
Midstream	Oil: Gathering and Processing	1,101	1,082	1,162	1,284	2,106	4,153	4,482	4,434	3,693	4,082	4,047
	Gas: Gathering and Processing	132,384	164,559	174,479	239,118	301,009	287,031	281,076	252,540	226,251	190,633	175,293
	Gathering Pipeline	146,944	172,480	175,168	171,584	171,136	168,717	229,152	239,053	245,862	155,456	160,205
	Oil: Truck Loading	75	74	73	82	90	140	170	174	150	171	169
	Gas: Truck Loading	0	0	0	0	0	0	0	0	0	0	0
	Gas Processing Plant	0	0	0	0	0	0	0	0	0	0	0
	Transmission Pipeline	225,049	227,746	227,746	227,746	227,746	228,787	228,787	236,912	236,912	236,912	236,912
	Gas Transmission Compressor Stations	3,320,520	3,376,800	3,376,800	3,376,800	3,376,800	3,376,800	3,376,800	3,601,920	3,601,920	3,601,920	3,601,920
	Gas Storage Compressor Stations	1,707,552	1,707,552	1,778,700	1,778,700	1,778,700	1,778,700	1,778,700	1,778,700	1,849,848	1,849,848	1,849,848
	Storage Reservoir Fugitives	0	0	0	0	0	0	0	0	0	0	0
	LNG Storage Compressor Stations	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525
	LNG Terminal	0	0	0	0	0	0	0	0	0	0	0
Downstream	Cast Iron Distribution Pipeline: Main	2,153,349	2,109,710	2,068,002	2,027,840	1,984,973	1,964,892	1,932,067	1,891,131	1,842,086	1,791,883	1,753,651
	Cast Iron Distribution Pipeline: Services	55,745	54,829	54,782	54,782	58,560	58,678	56,912	56,541	52,360	49,652	48,150

Table 14 continued

Category	Source	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Downstream	Unprotected Steel Distribution Pipeline: Main	1,889,161	1,816,247	1,757,061	1,708,570	1,675,964	1,661,738	1,624,158	1,641,985	1,546,270	1,511,882	1,469,453
	Unprotected Steel Distribution Pipeline: Services	1,690,308	1,742,026	1,712,862	1,666,911	1,636,875	1,602,987	1,555,770	1,528,620	1,452,863	1,377,106	1,367,437
	Protected Steel Distribution Pipeline: Main	69,989	70,983	71,616	71,670	71,030	71,756	71,773	71,595	70,655	70,748	70,851
	Protected Steel Distribution Pipeline: Services	108,163	93,457	92,931	88,922	88,287	88,433	85,670	85,809	80,830	75,851	86,046
	Plastic Distribution Pipeline: Main	238,770	249,931	261,893	272,012	281,316	287,799	294,287	304,938	316,461	323,986	330,865
	Plastic Distribution Pipeline: Services	20,825	21,799	22,842	23,725	24,160	24,784	25,267	25,653	26,201	26,464	27,968
	Copper Distribution Pipeline: Main	0	0	0	0	0	0	0	0	0	0	0
	Copper Distribution Pipeline: Services	81,589	81,063	80,404	80,856	79,833	78,818	78,025	76,802	75,509	75,119	76,468
	Meter and Regulating Stations	207,264	209,400	213,841	210,937	214,873	219,174	140,041	146,215	141,198	140,604	145,800
	Pressure Relief Valves	3,646	3,677	3,712	3,733	3,746	3,779	3,788	3,839	3,828	3,841	3,850
	Damages	213,191	215,439	218,281	219,638	220,359	222,188	222,294	224,199	256,407	221,936	226,778
	Blowdowns	13,646	13,790	13,972	14,059	14,105	14,222	14,229	14,351	16,413	14,206	14,516
	Commercial Meters	464,642	475,222	507,769	491,391	500,871	520,828	515,746	501,447	501,306	496,680	515,781
	Residential Meters	341,062	349,855	352,305	356,824	357,201	358,835	360,727	363,274	362,308	359,830	374,433
	Industrial Meters	35,436	17,093	16,901	17,072	21,473	20,537	41,797	40,528	37,828	35,100	38,543
	Commercial Buildings	183,332	189,699	199,277	203,916	206,830	209,245	213,321	216,606	221,111	226,713	230,141
	Residential Gas Appliances	185,833	186,914	188,041	189,051	190,144	191,433	192,517	193,585	194,600	194,757	195,748
	Residential Buildings	411,490	422,099	425,055	430,507	430,962	432,933	435,216	438,289	437,123	434,134	451,753

Table 15. CH_4 Emissions by Source Category in New York State from 2012–2021 ($MTCO_2e$; AR5 GWP_{20})

Category	Source	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Upstream	Drill Rigs	13	11	13	3	2	1	0	11	4	0
	Drilling Fugitives	687	600	705	188	131	83	4	600	214	0
	Oil Well: Mud Degassing	81,138	68,622	86,084	14,070	13,676	13,151	35,799	70,416	23,217	0
	Gas Well: Mud Degassing	8,512	5,777	3,917	481	0	0	0	0	0	0
	Oil Well: Completions	19,992	17,564	21,706	5,998	4,284	2,713	143	18,421	6,712	0
	Gas Well: Completions	1,428	1,714	714	143	0	0	0	0	0	0
	Oil Well: Conventional Production—High Producing	1,385	3,957	2,419	1,573	1,040	1,599	4,616	6,549	1,068	0
	Oil Well: Conventional Production—Low Producing	270,467	265,089	275,317	216,603	198,624	208,045	161,803	178,716	107,634	106,532
	Gas Well: Conventional Production—High Producing	1,931,126	1,632,031	1,361,277	1,135,892	804,919	638,031	528,548	575,603	662,065	452,947
	Gas Well: Conventional Production—Low Producing	2,566,199	2,709,092	2,652,716	2,471,122	2,356,540	2,183,938	2,044,403	2,168,975	2,050,270	2,163,750
	Oil Well: Unconventional Production—High Producing	0	0	0	0	0	0	0	0	0	0
	Oil Well: Unconventional Production—Low Producing	0	0	0	0	0	0	0	0	0	0
	Gas Well: Unconventional Production—High Producing	0	0	0	0	0	0	0	0	0	0
	Gas Well: Unconventional Production—Low Producing	0	0	0	0	0	0	0	0	0	0
	Oil: Abandoned Wells	563	563	563	2,185	3,278	3,957	7,525	26,631	30,472	46,474
	Gas: Abandoned Wells	1,991	3,384	4,372	5,648	6,275	7,653	9,032	20,659	25,504	30,783
Midstream	Oil: Gathering and Processing	4,336	4,394	4,470	3,498	3,186	3,365	2,804	3,178	1,754	1,678
	Gas: Gathering and Processing	147,697	133,331	117,402	102,020	81,829	69,839	61,559	66,135	69,069	59,239
	Gathering Pipeline	143,942	37,139	52,058	37,318	32,928	36,422	32,941	30,231	36,176	59,210
	Oil: Truck Loading	162	165	160	129	101	83	84	84	76	74
	Gas: Truck Loading	0	0	0	0	0	0	0	0	0	0
	Gas Processing Plant	0	0	0	0	0	0	0	0	0	0
	Transmission Pipeline	236,912	238,631	238,631	238,631	238,631	238,631	236,599	236,860	236,235	237,537

Table 15 continued

Category	Source	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Midstream	Gas Transmission Compressor Stations	3,601,920	3,601,920	3,601,920	3,601,920	3,601,920	3,601,920	3,601,920	3,601,920	3,601,920	3,658,200
	Gas Storage Compressor Stations	1,849,848	1,849,848	1,849,848	1,849,848	1,849,848	1,849,848	1,849,848	1,849,848	1,849,848	1,849,848
	Storage Reservoir Fugitives	0	0	0	0	0	0	0	0	0	0
	LNG Storage Compressor Stations	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525	271,525
	LNG Terminal	0	0	0	0	0	0	0	0	0	0
Downstream	Cast Iron Distribution Pipeline: Main	1,705,764	1,642,817	1,577,938	1,529,279	1,396,046	1,320,741	1,225,949	1,137,998	1,070,805	1,009,564
	Cast Iron Distribution Pipeline: Services	45,781	39,072	41,548	34,814	31,887	24,341	21,089	27,577	23,924	21,896
	Unprotected Steel Distribution Pipeline: Main	1,397,787	1,345,695	1,304,229	1,270,428	1,224,184	1,162,627	1,091,930	1,046,020	998,506	960,919
	Unprotected Steel Distribution Pipeline: Services	1,339,788	1,210,824	1,199,886	1,113,670	1,047,384	1,003,169	963,321	957,221	970,999	930,296
	Protected Steel Distribution Pipeline: Main	71,756	71,082	71,751	71,411	71,406	71,698	71,465	70,996	70,761	70,686
	Protected Steel Distribution Pipeline: Services	81,328	85,293	88,119	76,533	74,696	92,929	72,824	74,244	79,262	74,241
	Plastic Distribution Pipeline: Main	338,655	350,521	360,817	371,089	384,186	395,580	407,698	419,415	429,437	440,630
	Plastic Distribution Pipeline: Services	28,332	29,239	30,337	31,040	31,624	31,527	33,136	33,702	38,318	35,117
	Copper Distribution Pipeline: Main	0	0	0	0	0	0	0	0	0	0
	Copper Distribution Pipeline: Services	74,728	72,057	73,305	68,320	63,336	60,551	56,351	54,792	54,792	52,896
	Meter and Regulating Stations	146,136	147,593	143,403	134,639	137,200	138,904	139,582	138,780	140,559	141,060
	Pressure Relief Valves	3,862	3,874	3,904	3,925	3,942	3,960	3,966	3,978	3,989	4,014
	Damages	226,751	227,094	230,786	229,662	229,753	231,346	253,406	254,944	277,849	268,548
	Blowdowns	14,514	14,536	14,773	14,701	14,707	14,809	16,221	16,319	17,785	17,190
	Commercial Meters	507,816	507,020	518,665	525,686	525,925	529,945	533,577	556,427	553,823	547,042
	Residential Meters	368,901	368,219	370,039	370,842	370,449	374,454	375,917	378,722	381,563	379,723
	Industrial Meters	33,875	35,914	35,951	34,162	36,222	37,587	38,698	39,638	37,583	34,068
	Commercial Buildings	235,109	239,678	241,982	244,416	247,234	253,284	253,560	252,344	244,960	244,092
	Residential Gas Appliances	196,319	196,837	197,510	198,073	198,951	199,934	200,932	202,941	204,971	160,347
	Residential Buildings	445,078	444,255	446,451	447,419	446,945	451,778	453,542	456,927	460,354	458,134

4.6 Emissions by County and Economic Region in Year 2021

Figure 19 shows the distribution of emissions by county in New York State. The counties with the largest emissions correspond to the high oil and natural gas exploration and production areas in the west of the State as well as to areas of high population and corresponding gas services around New York City and Long Island. Downstream emissions in counties that correspond to New York City and Long Island (New York, Kings, Bronx, Richmond, Queens, Nassau, and Suffolk) total 4.44 MMTCO$_2$e, which is approximately 75.8% of total downstream emissions. As shown in Figure 20, Erie County had the highest total CH$_4$ emissions, accounting for 10.5% of statewide CH$_4$ emissions from oil and natural gas sector, followed by Chautauqua County (10.1%). Erie County had the second-highest conventional gas production from low producing wells in New York State, as well as the largest miles of transmission pipeline (378 miles) and second-highest number of compressor stations (five gas transmission compressor stations and six gas storage compressor stations), resulting in high-midstream emissions. Chautauqua County ranked highest in gas gathering and processing and in low producing conventional gas production resulting in high upstream and midstream emissions. The top five counties (Erie, Chautauqua, Steuben, Kings, and Queens) accounted for 40.0% of statewide CH$_4$ emissions in 2021. Data for each county are shown in Figure 20 and annual total emissions by county are shown in Table 16 through Table 18.

Figure 19. Map of CH$_4$ Emissions by County in New York State in 2021 (AR5 GWP$_{20}$)

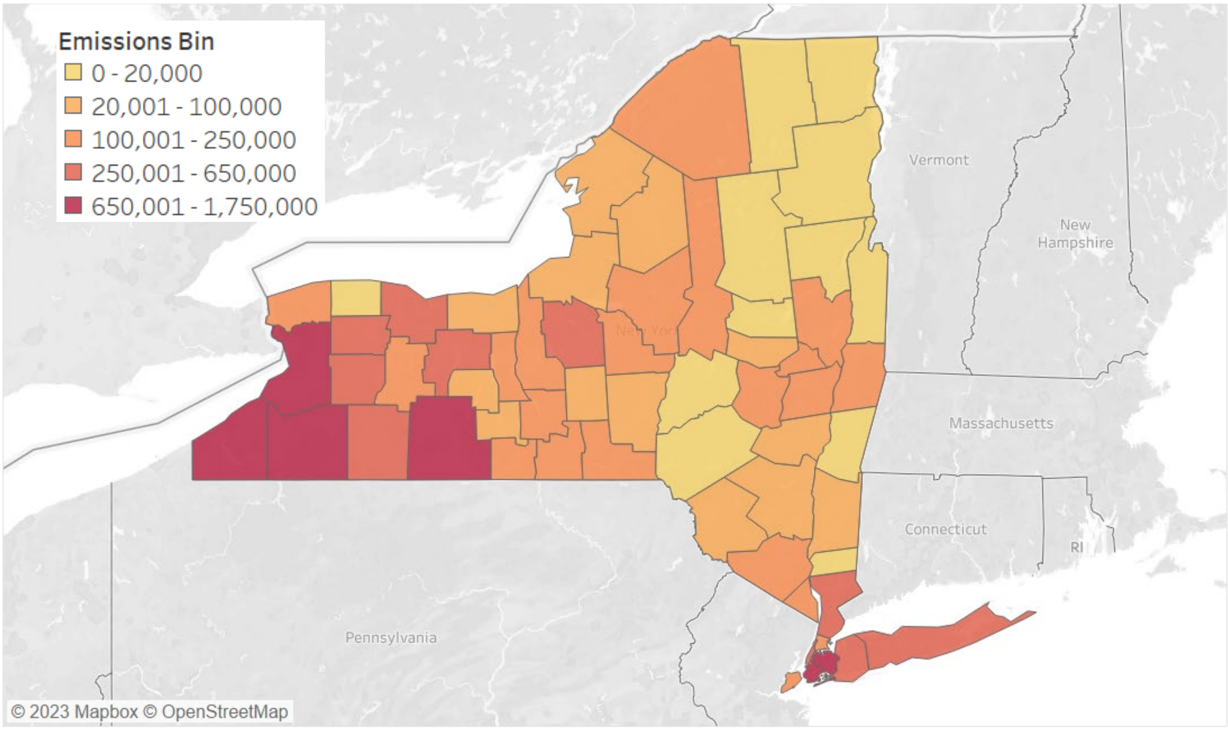


Figure 20. CH$_4$ Emissions by County in New York State in 2021 (AR5 GWP$_{20}$)

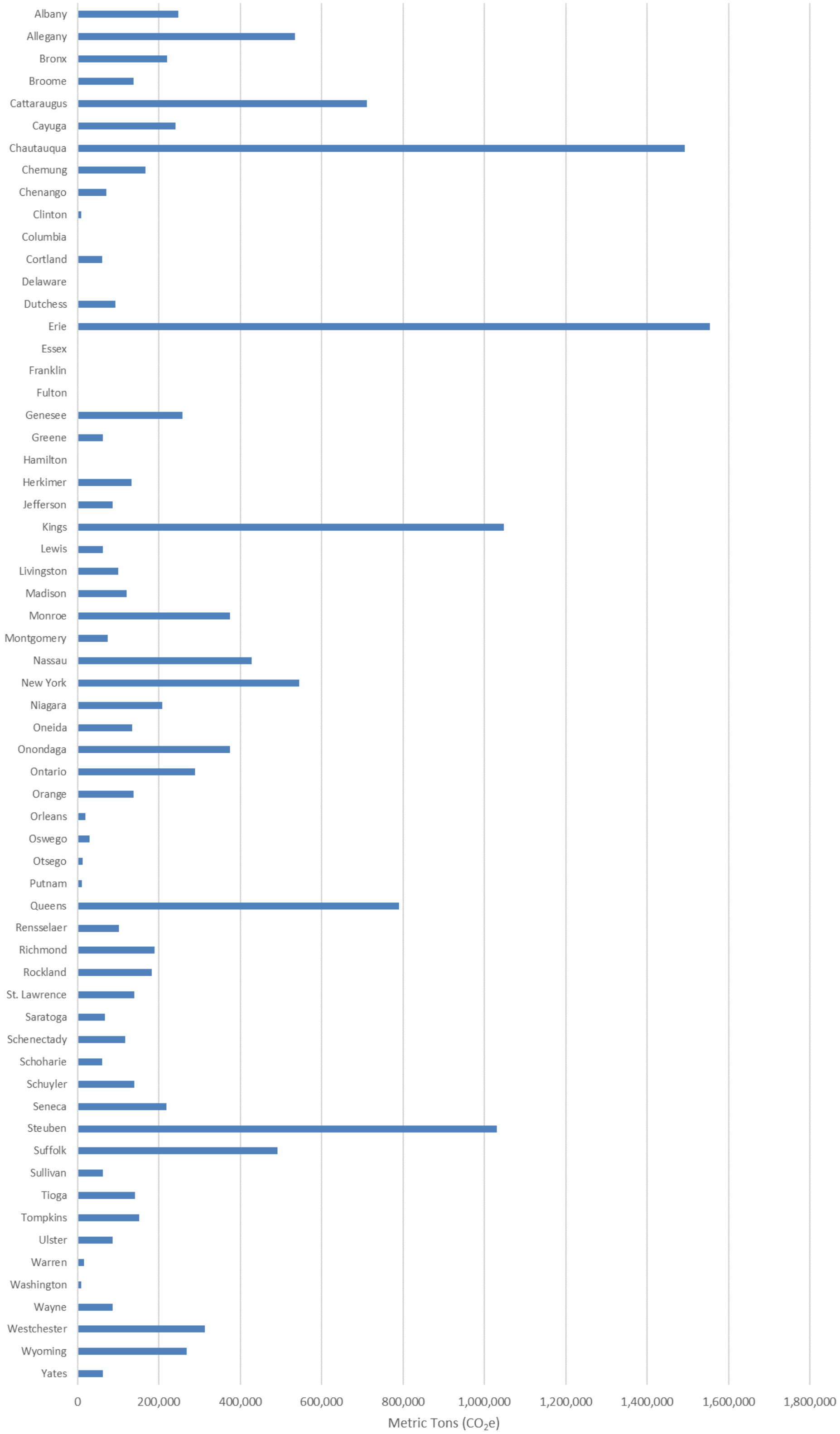


Table 16. CH$_4$ Emissions by County in New York State from 1990–2000 (MTCO$_2$e; AR5 GWP$_{20}$)

County Name	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Albany	335,071	322,506	331,388	327,308	330,810	321,848	319,654	321,762	319,130	317,493	316,983
Allegany	454,784	452,041	474,394	449,679	463,419	453,987	449,638	460,388	449,531	447,129	446,580
Bronx	308,158	290,247	302,604	297,232	302,103	289,353	287,659	290,625	287,945	285,450	285,464
Broome	197,856	190,186	195,791	192,713	194,953	188,841	187,392	188,748	186,720	186,375	185,374
Cattaraugus	571,831	566,965	697,803	684,257	640,911	686,375	651,882	648,601	673,141	673,531	679,994
Cayuga	426,248	405,396	360,486	342,357	344,417	342,884	362,068	359,398	349,962	340,507	331,254
Chautauqua	2,458,639	2,593,031	2,568,881	2,535,050	2,579,895	2,410,288	2,524,717	2,322,646	2,223,240	2,174,066	2,090,254
Chemung	126,639	123,016	125,851	124,283	125,355	123,632	122,749	124,097	122,468	131,701	135,962
Chenango	301	288	277	264	270	262	247	248	252	256	266
Clinton	12,549	11,481	12,009	12,232	12,342	11,941	11,554	11,880	11,260	11,232	11,295
Columbia	1,590	1,592	1,593	1,592	1,602	1,604	1,603	1,610	1,618	1,626	1,636
Cortland	60,058	60,075	60,091	60,107	60,124	60,140	60,156	60,172	60,189	61,509	60,221
Delaware	1,253	1,256	1,261	1,266	1,272	1,277	1,281	1,287	1,292	1,298	1,304
Dutchess	100,131	96,752	98,278	98,744	99,221	98,119	97,326	98,522	97,271	97,301	98,084
Erie	1,863,985	1,825,586	1,888,415	1,919,409	1,844,268	1,875,386	1,843,943	1,828,574	1,824,354	1,778,541	1,778,967
Essex	4,056	3,912	3,978	3,869	3,904	3,797	3,676	3,763	3,584	3,600	3,701
Franklin	4,734	4,390	4,529	4,556	4,611	4,476	4,368	4,422	4,358	4,383	4,438
Fulton	62	54	52	57	59	58	55	56	57	58	61
Genesee	381,643	368,679	354,523	354,509	353,861	354,495	348,101	346,146	341,077	333,399	324,704
Greene	63,668	63,247	63,438	63,544	63,598	63,484	63,371	63,541	63,409	63,465	63,577
Hamilton	549	535	545	537	540	529	523	530	513	515	526
Herkimer	85,270	83,929	84,940	84,493	84,861	83,839	83,506	83,888	83,308	83,168	83,193
Jefferson	102,428	99,972	101,744	100,947	101,624	99,861	99,472	99,982	99,376	99,095	99,052
Kings	1,574,789	1,500,031	1,559,314	1,525,784	1,549,148	1,487,889	1,478,024	1,491,841	1,478,201	1,466,353	1,463,780
Lewis	64,818	64,479	64,617	64,590	64,678	64,487	64,370	64,481	64,417	64,423	64,528
Livingston	158,843	155,898	164,588	156,328	157,948	151,766	151,090	141,030	140,858	136,234	141,342
Madison	94,132	92,616	94,485	89,035	94,440	95,293	93,303	95,843	103,516	116,444	112,755
Monroe	600,426	570,233	592,871	580,875	589,330	566,227	560,319	566,780	557,070	552,950	551,929
Montgomery	84,391	82,953	83,994	83,556	83,939	82,941	82,644	83,041	82,507	82,339	82,265
Nassau	626,417	588,527	613,060	609,293	618,184	596,689	590,828	596,319	591,364	587,557	589,178
New York	778,345	717,746	751,373	755,722	767,402	743,319	736,605	749,710	746,529	741,232	751,033
Niagara	220,257	211,422	218,078	214,571	217,056	210,307	208,361	210,365	207,161	205,709	205,138
Oneida	188,411	181,042	186,343	183,767	185,769	180,372	178,712	180,230	177,802	176,741	176,579
Onondaga	522,206	502,705	517,106	509,879	515,400	500,477	496,839	500,365	495,218	492,435	491,909
Ontario	192,465	189,421	194,306	190,777	190,937	189,918	187,943	190,210	188,558	186,621	188,356

Table 16 continued

County Name	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Orange	175,421	168,066	172,983	171,512	173,160	168,672	167,365	169,422	166,900	166,156	166,711
Orleans	38,323	36,569	36,207	34,808	35,568	34,360	32,887	33,172	33,131	33,362	34,115
Oswego	50,298	67,531	49,684	48,546	49,323	47,210	46,693	47,306	96,123	46,027	45,979
Otsego	1,566	1,573	1,580	1,586	1,593	1,600	1,607	1,613	1,620	1,627	1,634
Putnam	12,907	11,787	12,317	12,602	12,721	12,626	12,488	13,031	12,660	12,762	13,090
Queens	1,181,280	1,122,397	1,167,764	1,144,490	1,162,316	1,116,755	1,109,249	1,118,779	1,109,395	1,100,595	1,099,151
Rensselaer	132,016	127,900	130,954	129,401	130,561	127,454	126,750	127,532	126,379	125,877	125,690
Richmond	304,532	289,230	301,836	294,747	299,949	286,640	285,240	287,033	285,941	283,367	282,810
Rockland	246,743	235,708	243,574	240,043	243,058	235,253	233,483	235,717	233,857	232,352	232,442
St. Lawrence	144,699	141,237	142,387	144,750	145,432	144,691	144,598	145,267	144,929	144,914	145,374
Saratoga	97,836	92,290	96,308	94,390	95,906	92,011	91,209	92,402	91,061	90,447	90,526
Schenectady	158,930	153,492	157,628	155,332	156,949	152,702	151,805	152,605	151,064	150,127	149,775
Schoharie	59,842	59,857	59,873	59,888	59,903	59,919	59,934	59,949	59,965	59,980	59,995
Schuyler	136,308	136,033	136,256	136,205	136,269	136,111	136,639	136,179	136,429	136,721	138,208
Seneca	273,235	258,289	235,952	214,791	220,295	204,948	220,252	222,458	197,291	201,335	205,091
Steuben	447,696	432,414	456,138	451,301	447,898	596,205	696,338	666,680	704,168	753,039	938,886
Suffolk	653,812	621,216	644,384	642,612	649,799	631,585	625,357	635,158	625,537	624,166	627,537
Sullivan	62,698	62,541	62,689	62,615	62,630	62,545	62,395	62,576	62,208	62,280	62,331
Tioga	77,068	75,556	76,240	75,310	75,554	74,952	74,796	75,082	75,676	74,761	75,706
Tompkins	171,997	168,965	171,192	170,217	171,052	168,901	168,253	168,947	168,506	168,627	167,659
Ulster	100,440	97,438	99,266	99,118	99,627	97,877	96,978	98,091	96,762	96,732	96,976
Warren	24,692	23,062	24,103	23,868	24,201	23,252	22,834	23,204	22,589	22,576	22,573
Washington	14,738	13,869	14,516	14,228	14,383	13,806	13,440	13,928	13,065	13,032	13,058
Wayne	101,374	98,978	101,081	99,999	100,570	99,376	98,284	99,472	97,825	97,920	97,953
Westchester	455,506	429,017	445,763	441,894	448,067	432,952	429,062	433,692	430,166	427,813	429,069
Wyoming	343,801	353,442	346,938	331,735	334,495	336,091	316,444	323,215	314,643	310,594	305,489
Yates	62,113	59,892	61,409	61,654	61,217	62,036	61,669	60,949	59,889	63,067	62,148

Table 17. CH_4 Emissions by County in New York State from 2001–2010 ($MTCO_2e$, AR5 GWP_{20})

County Name	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Albany	311,879	311,222	309,236	306,290	304,573	303,919	301,412	300,691	295,178	291,029
Allegany	464,951	524,865	535,409	543,760	559,687	583,561	591,855	607,203	597,698	599,137
Bronx	278,630	279,311	277,128	272,593	270,172	268,832	265,591	264,896	258,550	253,507
Broome	182,673	183,109	212,921	190,430	181,734	176,834	174,978	174,600	170,607	167,757
Cattaraugus	682,510	670,598	636,302	639,280	706,357	883,249	934,047	883,820	833,197	929,750
Cayuga	322,893	330,035	318,697	306,452	254,885	316,439	310,756	309,418	343,586	351,828
Chautauqua	2,111,202	2,038,413	2,022,046	2,008,331	2,034,938	2,097,569	2,205,248	2,244,793	2,182,522	2,038,462
Chemung	805,712	1,483,616	1,441,599	1,362,893	2,314,543	2,192,059	1,972,728	1,483,199	1,134,185	1,009,361
Chenango	249	258	261	1,226	2,158	1,935	16,989	66,085	210,531	232,419
Clinton	11,027	10,925	11,066	10,734	10,733	10,877	10,960	10,883	10,590	10,367
Columbia	1,635	1,656	1,654	1,651	1,649	1,654	1,651	1,704	1,699	1,694
Cortland	60,238	60,285	61,714	61,289	61,075	60,318	60,947	60,461	60,461	60,461
Delaware	1,308	1,324	1,325	1,810	1,324	1,329	1,329	1,375	1,374	1,373
Dutchess	97,128	97,340	98,083	97,572	97,697	97,933	97,974	97,475	96,596	95,742
Erie	1,741,173	1,749,463	1,748,408	1,735,231	1,760,133	1,798,529	1,804,182	1,851,106	1,880,404	1,944,822
Essex	3,582	3,602	3,581	3,589	3,538	3,499	3,515	3,504	3,379	3,355
Franklin	4,288	4,270	4,279	4,169	4,134	4,190	4,122	4,105	3,998	3,895
Fulton	57	60	60	59	59	57	56	57	54	52
Genesee	314,534	321,186	304,014	313,269	298,694	297,061	327,036	315,905	302,482	304,153
Greene	63,463	63,519	63,558	63,494	63,494	63,568	63,605	63,598	63,447	63,381
Hamilton	529	537	538	525	524	526	542	543	521	517
Herkimer	82,691	82,566	82,303	81,973	81,665	81,560	81,401	137,734	137,205	136,780
Jefferson	98,026	97,978	97,538	96,852	96,569	96,422	96,236	96,046	94,971	94,271
Kings	1,433,205	1,428,988	1,414,591	1,397,453	1,384,994	1,377,522	1,355,334	1,354,018	1,322,180	1,298,382
Lewis	64,387	64,432	64,374	64,236	64,243	64,220	64,252	64,245	64,125	64,024
Livingston	134,327	128,862	127,500	134,220	131,454	128,228	134,920	129,843	124,588	119,680
Madison	119,253	121,188	120,199	120,849	118,645	124,379	141,484	173,641	214,254	185,198
Monroe	539,749	536,252	530,330	522,818	517,341	514,486	509,316	507,296	493,401	483,041
Montgomery	81,714	81,622	81,373	81,052	81,347	80,893	80,650	80,608	79,984	79,555
Nassau	576,032	571,331	569,934	561,519	558,759	558,141	545,329	541,029	526,951	516,303
New York	731,737	719,311	722,549	708,914	702,832	706,652	690,472	684,404	667,381	653,502
Niagara	201,571	200,571	198,149	195,914	194,198	193,156	191,818	247,634	243,576	240,605
Oneida	173,499	172,953	171,750	169,867	169,044	167,781	166,491	166,055	162,783	160,344
Onondaga	483,914	482,908	478,362	474,581	470,788	471,024	466,847	463,665	454,517	447,831
Ontario	185,417	185,350	186,232	186,485	183,258	184,356	183,415	244,521	241,532	237,822
Orange	164,303	164,194	163,900	162,497	161,998	162,011	161,511	160,701	157,905	155,661

Table 17 continued

County Name	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Orleans	32,461	32,962	32,476	31,726	31,220	30,762	30,088	29,673	28,422	27,204
Oswego	44,807	44,599	44,113	44,959	42,939	42,669	42,245	42,106	76,294	39,709
Otsego	1,640	1,660	1,660	1,660	1,660	1,668	2,837	1,727	2,355	1,727
Putnam	12,748	12,846	13,173	12,893	13,011	13,141	13,242	13,078	12,704	12,437
Queens	1,076,274	1,074,005	1,064,377	1,050,364	1,041,590	1,036,427	1,018,173	1,015,389	989,735	970,426
Rensselaer	123,856	123,668	123,001	122,173	121,573	121,247	120,638	120,414	118,511	117,113
Richmond	276,227	275,301	272,000	268,291	265,861	264,416	257,290	256,610	248,739	243,207
Rockland	228,284	227,255	225,886	223,375	221,955	221,224	219,301	218,444	213,499	209,894
St. Lawrence	144,681	144,813	145,159	145,005	144,978	144,824	144,691	145,367	144,748	144,330
Saratoga	88,701	88,368	87,735	86,570	85,952	85,840	85,049	84,462	82,094	80,278
Schenectady	147,497	146,961	145,850	144,617	143,822	143,312	142,199	141,957	139,433	137,502
Schoharie	60,011	60,056	60,056	60,056	60,056	60,073	60,073	60,207	60,207	60,207
Schuyler	137,044	138,099	135,815	255,929	462,463	468,250	348,793	251,294	234,927	195,648
Seneca	204,915	210,691	205,097	208,679	205,659	216,297	257,612	339,899	317,763	291,803
Steuben	1,265,167	1,245,006	1,630,008	2,858,403	2,894,367	2,616,743	2,717,795	2,580,999	2,237,253	1,765,629
Suffolk	616,077	615,545	617,026	608,424	608,052	609,140	591,454	588,330	575,319	566,317
Sullivan	62,324	62,351	62,318	62,348	62,388	62,398	62,496	62,577	62,498	62,482
Tioga	147,926	150,623	145,906	146,251	144,942	148,050	147,141	146,000	144,481	145,667
Tompkins	166,781	166,394	166,520	165,656	165,421	164,508	165,012	164,599	162,889	161,965
Ulster	95,989	96,108	96,322	95,761	95,675	95,789	95,572	95,269	94,236	93,478
Warren	22,046	21,828	21,628	21,349	21,131	21,091	21,070	20,876	20,427	19,971
Washington	12,790	12,684	12,502	12,347	12,241	12,214	12,277	12,125	11,803	11,531
Wayne	97,082	96,826	97,652	96,377	97,071	110,723	101,952	98,177	97,906	94,179
Westchester	419,413	417,926	416,888	410,731	407,891	407,397	402,973	399,997	389,912	382,005
Wyoming	303,460	302,015	300,428	305,952	302,873	309,472	311,159	301,839	299,056	295,826
Yates	61,006	59,946	59,830	59,364	59,763	58,827	59,942	64,042	59,873	60,032

Table 18. CH_4 Emissions by County in New York State from 2011–2021 ($MTCO_2e$, AR5 GWP_{20})

County Name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Albany	290,534	286,129	280,557	278,336	274,137	268,457	265,027	259,869	252,940	250,826	246,910
Allegany	602,683	629,102	606,198	611,727	575,620	556,699	561,242	547,401	559,273	518,956	534,699
Bronx	253,146	248,153	240,475	238,368	232,956	225,423	220,654	213,591	223,019	223,360	219,774
Broome	167,382	164,603	160,927	159,353	156,434	152,638	150,353	147,026	140,901	139,811	137,260
Cattaraugus	880,293	840,681	859,824	875,587	739,984	737,328	767,583	743,970	834,622	706,942	710,990
Cayuga	344,843	318,967	302,640	297,722	283,516	274,732	254,646	244,624	241,264	267,356	240,968
Chautauqua	2,035,343	2,024,839	2,037,477	1,942,157	1,805,638	1,665,842	1,472,053	1,385,347	1,569,510	1,417,534	1,491,836
Chemung	933,416	709,618	638,921	506,631	424,584	285,058	229,237	194,551	202,818	184,041	166,964
Chenango	220,700	182,989	154,361	133,002	116,399	101,884	86,169	85,182	81,239	79,560	71,003
Clinton	10,432	10,134	9,898	9,829	9,672	9,402	9,326	9,151	9,148	8,962	8,833
Columbia	1,693	1,691	1,694	1,693	1,688	1,683	1,680	1,664	1,665	1,662	1,659
Cortland	60,461	60,461	60,499	60,499	60,499	60,499	60,499	60,463	60,467	60,456	60,456
Delaware	1,372	1,372	1,380	1,380	1,379	1,378	1,378	1,366	1,375	1,371	1,371
Dutchess	95,883	95,194	94,234	94,054	93,468	92,750	92,362	91,658	94,645	94,197	93,737
Erie	1,934,781	1,882,901	1,809,262	1,767,021	1,710,914	1,664,186	1,629,480	1,514,005	1,564,071	1,611,193	1,554,218
Essex	3,353	3,298	3,203	3,185	3,102	3,032	2,952	2,891	2,638	2,587	2,578
Franklin	3,913	3,796	3,661	3,619	3,543	3,447	3,374	3,306	3,189	3,173	3,078
Fulton	52	52	47	47	43	41	39	38	37	38	36
Genesee	304,114	299,189	287,911	288,264	260,341	252,556	248,031	264,437	225,962	250,155	257,725
Greene	63,396	63,317	63,240	63,176	63,064	62,982	62,991	62,898	62,887	62,876	62,818
Hamilton	510	517	510	501	499	500	493	489	419	393	397
Herkimer	136,683	136,196	135,655	135,399	134,889	134,277	133,945	133,359	132,735	132,464	131,959
Jefferson	94,155	93,378	92,229	91,786	90,891	89,755	89,062	88,046	86,574	86,218	85,585
Kings	1,299,382	1,274,854	1,239,526	1,227,464	1,201,124	1,164,306	1,142,114	1,107,878	1,089,583	1,075,688	1,048,141
Lewis	64,036	63,951	63,799	63,748	63,648	63,538	63,436	63,312	63,340	63,277	63,172
Livingston	117,379	115,064	110,727	113,062	106,722	107,680	107,876	102,854	94,927	150,980	100,948
Madison	211,768	178,601	165,987	156,247	149,414	140,892	129,987	126,437	125,227	125,928	121,023
Monroe	482,003	471,903	457,703	452,192	441,297	426,982	418,267	405,298	390,474	385,027	375,487
Montgomery	79,459	79,033	78,352	78,098	77,575	76,959	76,521	75,922	75,089	74,771	74,309
Nassau	516,240	505,670	492,440	487,878	477,178	463,780	456,370	444,438	441,573	437,271	428,774
New York	655,815	642,291	624,854	620,528	606,105	586,186	576,561	561,231	562,778	557,153	544,498
Niagara	240,291	237,185	232,746	231,255	228,110	223,876	221,370	217,576	213,080	211,770	208,716
Oneida	159,997	157,613	154,083	152,963	150,414	146,907	144,994	141,971	138,274	137,953	134,772
Onondaga	447,005	440,506	431,392	428,045	421,316	411,799	406,212	397,913	384,754	381,436	375,459
Ontario	238,585	237,586	236,450	234,745	234,162	230,728	232,382	230,934	231,650	233,629	288,488
Orange	155,421	153,139	150,307	149,439	147,638	144,944	143,250	140,691	141,425	140,057	138,180

Table 18 continued

County Name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Orleans	27,102	26,483	24,608	24,358	23,056	21,896	21,142	20,361	20,223	20,244	19,404
Oswego	39,713	38,785	37,376	36,980	36,078	34,757	34,337	33,194	31,627	31,363	30,377
Otsego	1,727	1,727	1,739	1,739	1,739	1,739	1,739	1,724	1,726	13,389	12,901
Putnam	12,374	12,055	11,879	11,940	11,822	11,570	11,378	11,182	11,067	10,989	10,801
Queens	970,186	951,670	925,315	916,425	895,689	868,267	851,506	825,660	819,515	808,046	789,814
Rensselaer	117,024	115,576	113,625	112,799	111,406	109,411	108,235	106,473	104,241	103,495	102,408
Richmond	242,928	237,377	229,579	226,517	220,159	212,118	207,275	204,353	198,241	195,178	189,602
Rockland	209,654	205,922	201,198	199,560	196,428	191,648	188,697	191,459	187,458	185,710	182,080
St. Lawrence	144,440	144,532	143,558	143,535	142,738	141,894	141,721	140,829	140,424	140,036	139,440
Saratoga	80,242	78,470	75,884	75,200	73,368	70,842	69,334	70,688	70,253	69,579	67,769
Schenectady	137,178	135,350	132,631	131,594	129,482	126,836	125,134	123,420	119,510	118,929	117,449
Schoharie	60,207	60,207	60,236	60,236	60,236	60,236	60,236	61,182	61,189	61,193	61,151
Schuyler	195,722	185,224	175,792	176,755	172,212	138,812	135,445	140,316	140,164	140,177	139,961
Seneca	264,332	251,678	244,236	241,489	231,812	230,986	223,320	225,482	211,968	214,074	218,470
Steuben	1,593,995	1,473,199	1,381,464	1,359,964	1,283,730	1,189,702	1,143,255	1,107,873	1,092,477	1,084,294	1,031,102
Suffolk	567,687	559,064	548,525	544,495	534,062	523,546	517,769	508,090	502,986	498,887	491,183
Sullivan	62,481	62,370	62,351	62,330	62,303	62,229	62,187	62,127	61,828	61,786	61,774
Tioga	144,181	146,168	143,496	143,346	143,733	142,666	142,423	142,021	141,468	141,323	141,033
Tompkins	161,859	160,901	159,542	159,024	158,079	156,650	156,031	154,746	152,752	152,092	151,411
Ulster	93,515	92,753	91,766	91,624	90,877	90,020	89,519	88,684	87,633	87,196	86,566
Warren	19,898	19,448	18,811	18,541	18,104	17,519	17,169	16,651	16,632	16,374	15,997
Washington	11,526	11,272	10,869	10,673	10,355	10,065	9,861	9,562	8,916	8,839	8,590
Wayne	95,271	93,983	92,508	91,867	91,012	90,576	89,888	89,020	88,074	87,349	86,752
Westchester	381,763	373,787	363,663	360,443	353,016	343,022	337,072	328,192	322,533	319,661	313,719
Wyoming	294,455	291,395	282,468	276,082	270,004	263,557	262,623	264,900	245,052	269,620	268,530
Yates	59,869	58,811	60,746	60,754	59,502	61,188	60,820	62,409	62,025	63,330	63,151

New York State has 10 distinct economic regions, as defined by Empire State Development and shown in Figure 21. The CH_4 emissions for these regions are presented in Table 19. CH_4 emissions in 2021 were greatest in Western New York (30.4% of total emissions) and New York City (18.9%). As discussed in section 2.3, the Western New York region has a large portion of oil and natural gas exploration and development, as well as a high density of pipelines. The New York City region has no oil or natural gas development, but does have a high number of distribution lines, natural gas services, and meters providing end-user populations with commercial and residential gas services.

Figure 21. New York State Economic Regions as Identified by Empire State Development

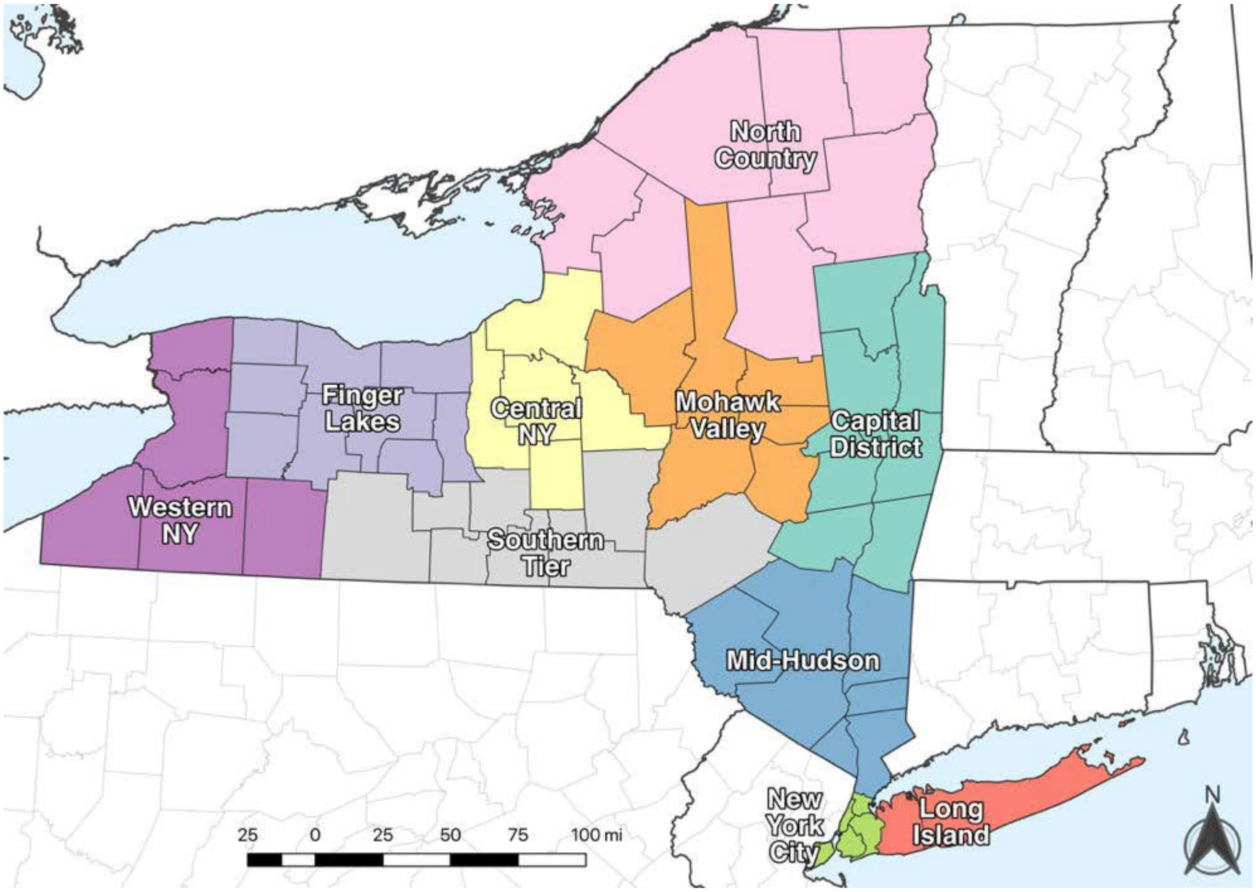


Figure 22. CH_4 Emissions by Economic Region in New York State in 2021 (AR5 GWP_{20})

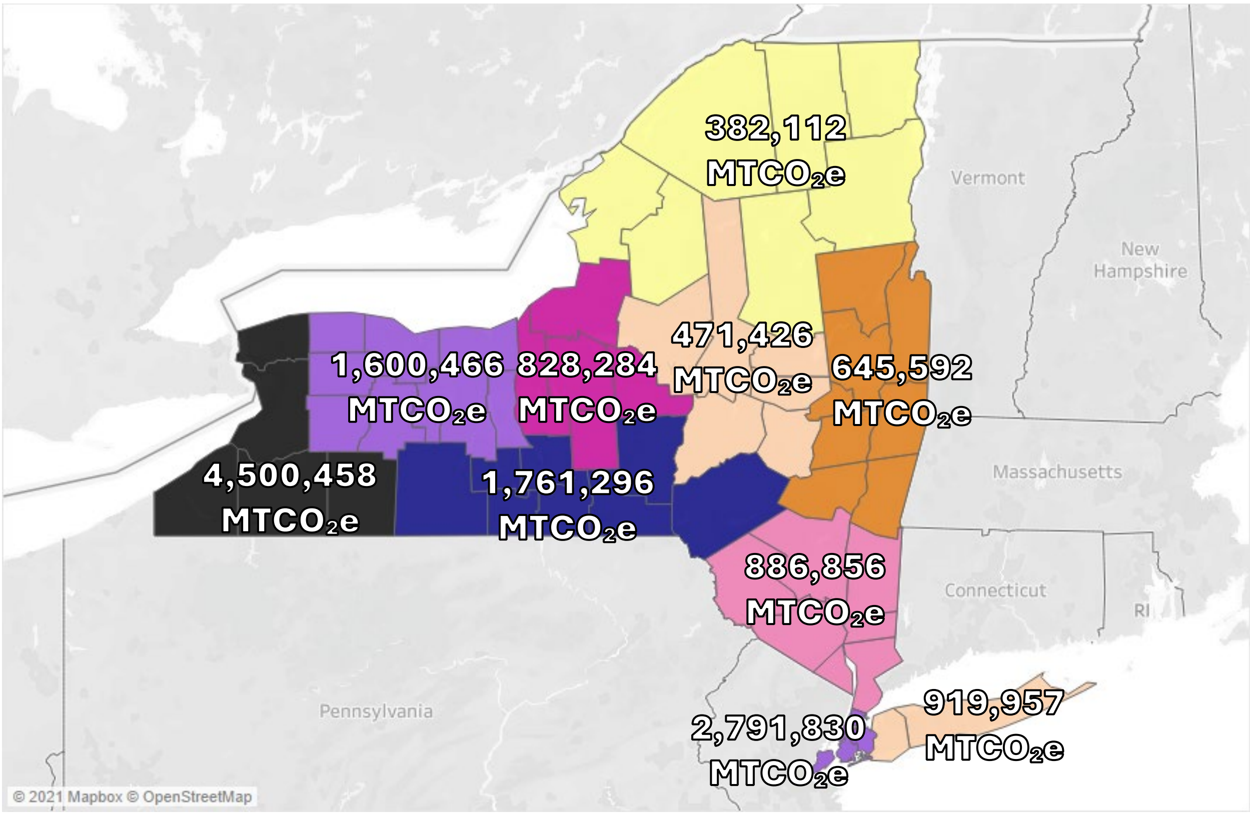


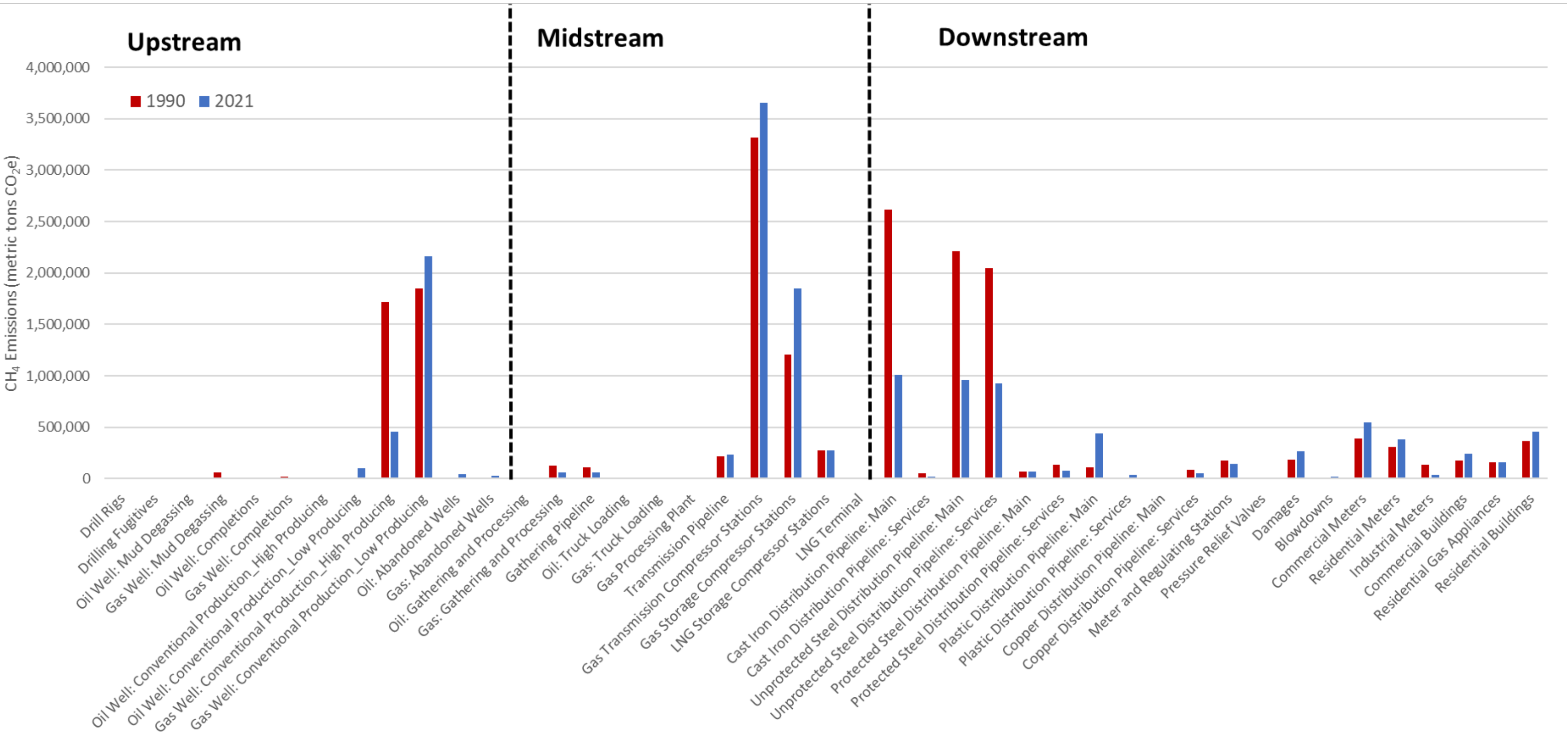
Table 19. CH_4 Emissions by Economic Region in New York State in 2021

Upstate/Downstate	Region	% of CH_4 Emissions
Upstate	Western New York	30.4%
Upstate	Finger Lakes	10.8%
Upstate	Southern Tier	11.9%
Upstate	Central New York	5.6%
Upstate	North Country	2.6%
Upstate	Mohawk Valley	3.2%
Upstate	Capital District	4.4%
Downstate	Hudson Valley	6.0%
Downstate	New York City	18.9%
Downstate	Long Island	6.2%

4.7 Summary of Source Category Comparison: 1990–2021

The largest upstream decrease in emissions was from conventional natural gas production from high-producing wells (-73.7%), which follows the decreasing completion and production patterns shown in Figure 2, Figure 4, and discussed in section 2. The midstream source categories saw increases in emissions from transmission pipelines (+10.6%) due to increases in overall pipeline mileages in New York State over that time period as well as large increases in CH_4 emissions from transmission (+10.2%) and gas storage compressor stations (+52.9%), resulting from increases in the number of compressor stations during that time period in order to accommodate increased pipeline capacity. Increases in pipeline and storage capacity and associated compressors reflect trends toward increasing natural gas consumption, as identified by EIA (2023). In the downstream source categories, there was a large shift away from cast-iron and unprotected steel distribution mains toward lower emitting plastic pipes, resulting in a net decrease in downstream emissions. Cast-iron and unprotected steel distribution mains decreased by 61.5% and 56.5%, respectively, and plastic pipeline mains increased by 302.2%. Although plastic distribution mains and services along with residential and commercial meter emissions have increased, they were offset by larger reductions in emissions from replacing cast-iron and unprotected steel pipelines (Figure 23).

Figure 23. Comparison of Source Category CH₄ Emissions from 1990 and 2021 in New York State, Using AR5 GWP₂₀ Conversion Factors for CH₄

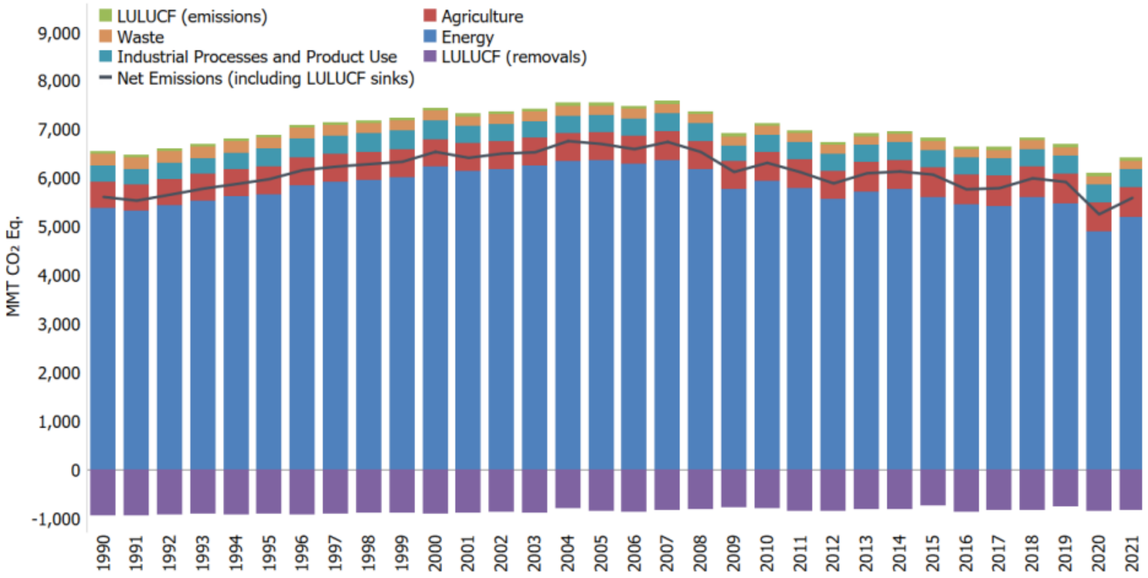


4.8 Emissions Inventory Validation

4.8.1 Comparison to the 2021 EPA GHG Inventory

The 2015 and prior versions of the New York State oil and natural gas sector methane emissions inventory used a scaling approach to scale the national inventory to New York State based on the ratio of national to State natural gas consumption. The current inventory applies a bottom-up, activity-driven methodology to estimate emissions from the oil and natural gas sector. The updated and improved methodology allows for direct comparison with other activity-based, bottom-up inventories, including the 2021 EPA GHG Inventory (EPA 2023). The 2021 EPA GHG Inventory estimated total CH_4 emissions from oil and natural gas systems to be 231.6 $MMTCO_2e$ in 2021. The NYS inventory finds total CH_4 emissions from the oil and natural gas sector to be 14.8 $MMTCO_2e$ in 2021 (AR5 GWP_{20}), equivalent to 6.39% of the total national inventory. Nationwide, EPA estimates a 13.1% decrease in emissions since 1990 and a 8.9% decrease from 2005–2021, and the NYS inventory finds a 18.7% decrease since 1990, which is similar to the nationwide trend, and a 31.49% decrease from 2005–2021. Despite these discrepancies, when viewing nationwide energy emissions trends described in the 2021 EPA GHG Inventory (EPA 2023), the New York State time series CH_4 emissions follows the shape of the energy sector emissions in the national inventory, shown in Figure 24. These data show a similar pattern to that shown in Figure 12, growing to a peak in emissions in 2005 and subsequently declining. As such, patterns in CH_4 emissions in New York State described here follow trends in large-scale nationwide energy shifts.

Figure 24. Reproduction of Figure ES-11 from (EPA 2023), Showing Time Series Trends in Emissions from Energy and Other Sectors



4.8.2 Comparison to Environmental Protection Agency's Greenhouse Gas Reporting Program Values

The EPA FLIGHT database shows Subpart W reported CH_4 emissions in NYS totaled 1.108 $MMTCO_2e$ in 2021, while this inventory estimates a greater amount for the 2021 CH_4 emissions at 14.8 $MMTCO_2e$. One explanation for the discrepancy is that Subpart W reporting is required only for facilities emitting more than 25,000 $MTCO_2e$ annually, whereas New York State has a large number of smaller facilities that emit CH_4, but do not reach the Subpart W reporting threshold. Most notably, Subpart W does not require emissions from meters, pipelines, or buildings to be reported, and more specifically, Subpart W data for 2021 show 1.03 $MMTCO_2e$ emitted by local distribution companies, 0.065 $MMTCO_2e$ from transmission/compression, and 0.012 $MMTCO_2e$ from underground natural gas storage. This inventory estimates emissions from natural gas distribution to be 3.60 $MMTCO_2e$ or 350% of emissions reported under Subpart W—highlighting the importance of identifying proper distribution pipeline leak rates in New York State to update EFs from national averages. The inventory shows that transmission compressor stations are the largest single source category, with estimated emissions of 3.601 $MMTCO_2e$ in 2021, indicating that total transmission compression emissions are underestimated by Subpart W. The inventory estimates emissions from underground natural gas storage to be 1.85 $MMTCO_2e$ in 2021, which is an order of magnitude greater than reported under Subpart W.

If downstream emissions are subtracted from the total inventory, upstream and midstream emissions are estimated to be 8.94 $MMTCO_2e$, which is 160% higher than emissions from these segments reported under Subpart W in NYS. The discrepancy between emissions in Subpart W and the current inventory is higher than the findings of Alvarez et al. (2018), who estimate CH_4 emissions from the oil and natural gas supply chain to be ~ 60% greater than EPA estimates. As mentioned above, these discrepancies are the result of facility reporting thresholds under Subpart W and missing methane emission sources. Again, this discrepancy emphasizes the importance of detailed bottom-up inventories of all sources and the validation of bottom-up inventories with top-down flight or satellite measurements.

4.8.3 Comparison to Other State Inventories

New York State is bordered by Pennsylvania, New Jersey, Connecticut, Massachusetts, and Vermont. The following section provides a breakdown of the most recent inventory year for each of the adjacent states. Pennsylvania primarily uses the default Environmental Protection Agency State Inventory Tool (EPA SIT) tool to estimate emissions from the residential, commercial, industrial, transportation, electricity production, agriculture, waste management, forestry, and land use sectors in Pennsylvania, and uses AR4 GWP_{100} values to report CO_2 equivalents.[20] Pennsylvania estimates total natural gas and oil system emissions to be 12.33 $MMTCO_2e$ in 2019, largely governed by natural gas production (8.11 $MMTCO_2e$), natural gas transmission (2.07 $MMTCO_2e$) and natural gas distribution (2.09 $MMTCO_2e$). As expected, Pennsylvania's estimated emissions from the oil and natural gas sector are much higher than in New York State, when converted to AR5 GWP_{20} estimates. Pennsylvania is the second largest producer of natural gas in the United States, second only to Texas and produced about 7.647 million Mcf of natural gas in 2021, compared with 9,708 Mcf in New York State in 2021.[21] New York State had 49 well completions in 2020, compared to Pennsylvania's 476 unconventional and 51 conventional wells drilled.[22]

New Jersey derives 55% of electricity generation from natural gas and has seen a total of 36 exploration wells drilled, none of which were drilled after 1982, due to a lack of natural gas resources and regulations. As such, New Jersey is primarily a consumer of natural gas, as identified by the 2020 GHG inventory,[23] which estimates emissions of 2.3 $MMTCO_2e$ (AR4, GWP_{20}) from the natural gas transmission and distribution segments. New Jersey employs the EPA SIT to estimate emissions from natural gas transmission and distribution segments.

Connecticut relies heavily on the EPA SIT to calculate GHG emissions by sector. Connecticut is primarily a natural gas consuming state, as they have minimal oil and natural gas resources. Based on review of the 2020 inventory[24] and supporting data, Connecticut does not explicitly estimate emissions from the oil and natural gas sector, instead emissions are reported for the Agriculture, Commercial, Electric Power (consumption), Industrial, Residential, Transportation, and Waste sectors. Total emissions in Connecticut in 2020 were estimated to be 32.71 $MMTCO_2e$ depending on whether emission estimates were based on electric consumption or generation. Given the aggregated nature of the Connecticut GHG inventory, it is challenging to draw direct comparisons to the New York State inventory.

Massachusetts identifies only the transmission and distribution segments of the oil and natural gas sector as relevant to Massachusetts, using the EPA SIT to estimate emissions from leaks in pipelines and services, customer meters, and metering/regulating stations and venting. Estimated emissions from natural gas transmission and distribution systems in 2020,[25] the most recent year of complete data, were 0.7 $MMTCO_2e$.

Vermont's GHG Inventory[26] uses the EPA SIT along with methodologies developed by the Vermont Agency of Natural Resources, Vermont Department of Public Service and the Center for Climate Strategies. Vermont has no upstream production of oil or natural gas, and midstream and downstream emissions estimates are very small, reflecting low consumption of natural gas in the state (13,272 MMcf in 2020) compared with New York State (1,317,285 MMcf in 2021). Vermont estimates total emissions from the midstream and downstream segments of the oil and natural gas sector to be 0.028 $MMTCO_2e$.

A comparison of the New York State inventory with each of the discussed state inventories is shown in Table 20. As shown, the ratio of estimated emissions to consumption is consistent for most states, with the exception of Pennsylvania and Vermont, which both have very different natural gas profiles than the other states. Pennsylvania has much higher upstream production of natural gas, resulting in a much higher ratio of emissions to consumption, as emissions associated with production increase the ratio. Vermont has minimal natural gas infrastructure and very low consumption, resulting in a ratio of emissions to consumption that is an order of magnitude lower than the other states in the region.

Table 20. Comparison of This Inventory to the Most Recent Year of Adjacent State Inventories

	NYS (AR5 GWP20)	**Pennsylvania (AR4 GWP100)**	**New Jersey (AR4 GWP100)**	**Connecticut**	**Massachusetts (AR4 GWP100)**	**Vermont (AR4 GWP100)**
Year	2021	2019	2020	2018	2020	2020
Oil and Gas CH_4 ($MMTCO_2e$)	14.8	12.33	2.3	*	0.7	0.028
Consumption (MMcf)	1,317,285	1,618,008	653,447	277,931	389,013	13,056
Production (MMcf)	9,708	6,896,792	0	0	0	0
Emissions/ consumption	1.12×10^{-05}	7.62×10^{-06}	3.52×10^{-06}	N/A	1.8×10^{-06}	2.14×10^{-06}

* Connecticut data are not broken out for the oil and natural gas sector.

Note: Consumption and production are derived from EIA data for the year of the inventory.

4.8.4 Comparison to Top-Down and Bottom-Up Studies

Validation of an emission inventory using alternate methodologies is an important step in determining the robustness of the inventory. The NYS inventory uses a bottom-up methodology to estimate emissions using site-level activity data and EFs. Recent efforts in the literature have shown discrepancies between bottom-up and top-down methodology (see e.g., Marchese et al. 2015; Mitchell et al. 2015; Omara, Sullivan, Li, Subramanian, et al. 2016; Subramanian et al. 2015; Alvarez et al. 2018). One of the challenges with validating bottom-up emission inventories with top-down studies is the availability of top-down study data. As discussed in section 3.1.2.6, top-down studies require detailed atmospheric measurements and modeling to estimate emission flux. Thorough review of the available literature, and consultation with the Project Advisory Committee (PAC) and other experts during the first iteration, revealed a lack of available top-down data specific to New York State. As identified throughout the discussion of EFs in section 3, it will be beneficial for the State to validate that the EFs applied accurately reflect local conditions. Top-down studies can provide validation of local conditions, but only at the site and regional level, and therefore, New York State should consider top-down validation of the higher emitting segments of the inventory. Such validation could potentially reduce the uncertainty in the inventory.

4.9 Uncertainty

Uncertainty is widely addressed in section 3 in a discussion about uncertainty in relation to the limitations of the EFs used. Although best practices are followed and EFs are employed from a number of EPA tools, several sources have been identified that warrant discussion.

First, emissions from gathering, transmission, and distribution pipelines comprise a large fraction of the total emissions estimated in this inventory. The literature on emission rates from pipelines is not deep, with most studies focusing specifically on certain cities. Therefore, the EFs used are based on guidance from the EPA Oil and Gas Tool and EPA's SIT; however, upon inspection, many of those EFs are derived from older studies that were performed in other states. As such, there is a research need to produce new empirical data on per-mile leak rates that better reflect present conditions in New York State.

Second, transmission and storage compressor stations have been identified as large sources of CH_4 in the State. The emission estimation methodology applies an EF based on peer-reviewed literature, which employs best practices to measure and estimate emissions from compressors. However, those studies, along with others, identify a potentially wide range of emission rates from compressor stations under normal operating conditions, with a non-normal distribution. Therefore, applying a central estimate to estimate emissions inherently introduces uncertainty into the estimate.

Third, this inventory is based on the best available activity data and EFs. However, given data limitations, this inventory is limited to site-level estimates, as component counts are unavailable for New York State facilities. As such, State facilities may have different component compositions to those applied in this inventory, resulting in the possible application of EFs that could be better tailored to New York State.

Fourth, emissions from high-emitting sources are not explicitly estimated. High-emitting sources have been widely observed and described in the literature along all stages of the upstream, midstream, and downstream process, with a small number of sites or facilities contributing a majority of regional emissions in many instances. However, given the unknown distribution of high-emitting sources in the State, it is challenging to apply statistical methods to estimate the likelihood of high-emitting sources.

4.9.1 Emission Inventory Uncertainty

Using the uncertainty bounds identified in Table 6, the following figures present the total time series emissions including upper and lower confidence bounds. Comparing Figure 25 and Figure 27 the lower bound on the uncertainty estimate is driven by midstream emissions. It was determined that selecting the lower-bound value represented the most applicable value to New York State, and so the best estimate and the lower-bound estimate are the same for the upstream and downstream emissions factors.

Upper-bound emissions estimates were determined by selecting the upper bound EF provided by the sources chosen for the best estimate EFs. As such, upper-bound emission estimates may be thought of as representing the upper limit of emissions for the State, based on EFs from other states which employ high-emitting techniques in the oil and natural gas sector. These upper-bound estimates also reflect literature estimates of EFs for many source categories with identified high-emitting sources, as discussed in section 3. As such, these EFs also likely capture the possible range of uncertainty that arises from accounting for high-emitting sources in the State, which is especially notable in the upstream and downstream source categories. In the upstream and downstream source categories, the upper-bound emission estimates are four and two times the best estimate values, respectively, reflecting the wide range of uncertainty that arises from incorporating EFs that are derived with high-emitting sources in the sample population.

Figure 25. Total Emissions Including Best Estimate and Upper and Lower Bounds (AR5 GWP$_{20}$)

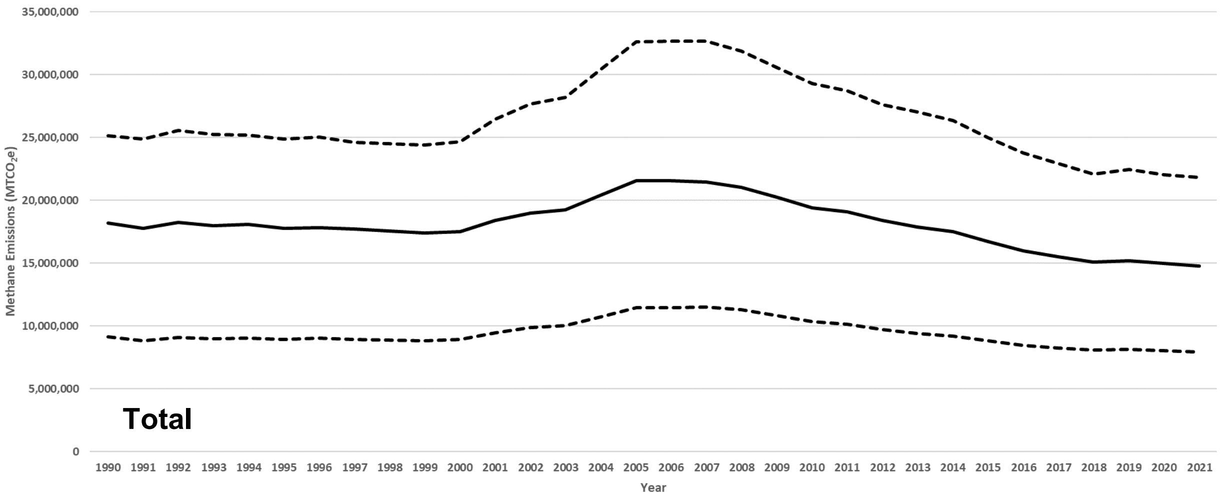


Figure 26. Upstream Emissions Including Upper and Lower Bounds (AR5 GWP$_{20}$)

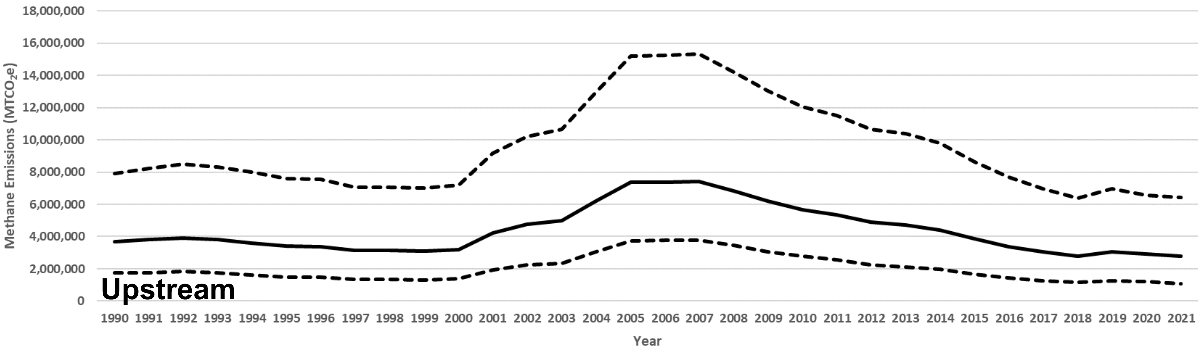


Figure 27. Midstream Emissions Including Upper and Lower Bounds (AR5 GWP$_{20}$)

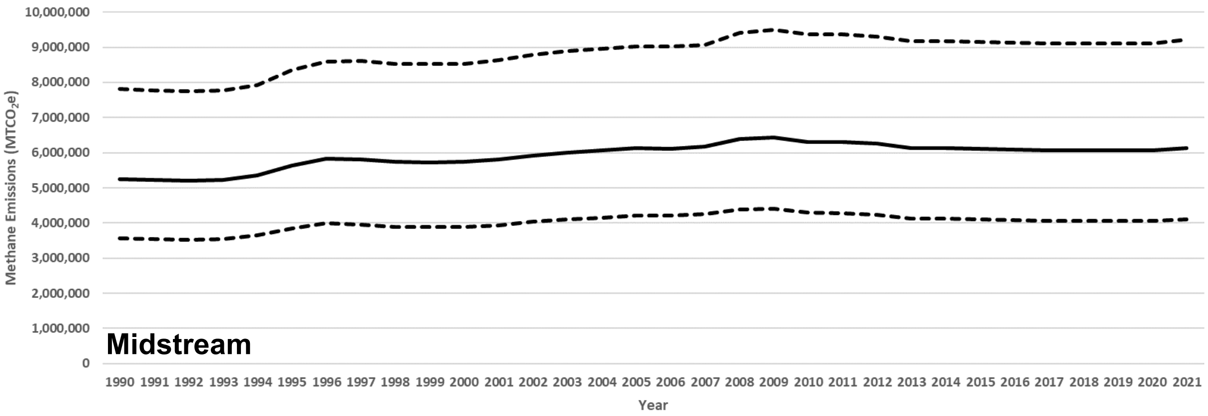
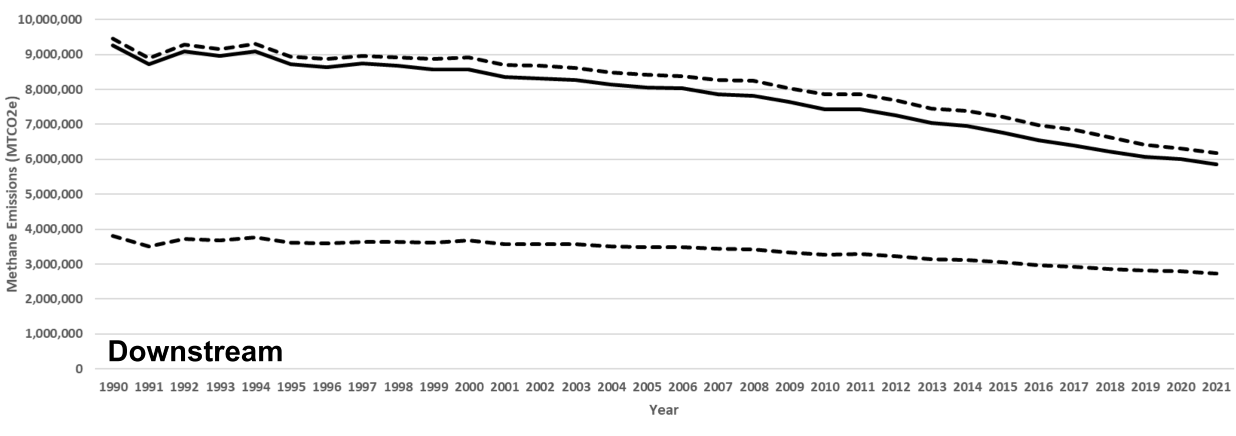


Figure 28. Downstream Emissions Including Upper and Lower Bounds (AR5 GWP$_{20}$)



4.9.1.1 Comparing AR4 and AR5 Emission Estimates

Methane is a short-lived climate pollutant, with a lifetime of approximately 12 years. In order to capture the near-term climate impacts of methane emissions most effectively, results are reported in terms of AR5 GWP$_{20}$. However, these results, along with discussion in appendix A.5, show that reporting emissions using a range of GWPs, including AR4, AR5, and both short-term and long-term climate effects, can provide a more comprehensive illustration of climate impact. Selection of alternate GWPs depending on AR4 or AR5, and short-term or long-term climate effects, can yield markedly different results. Recent literature has indicated that it is important to consider the short-lived effects of CH_4, described by the GWP$_{20}$. The CH_4 emissions estimates presented throughout this report are the AR5

GWP_{20} estimates. Under AR4, GWP_{100} for CH_4 is 25, and GWP_{20} is 72. AR4 estimates from 2007 were updated in 2014 in IPCC's AR5, which increased the GWP_{100} to 28, and GWP_{20} to 84. Under AR6, GWP_{20} was decreased to 82.5 for fossil origin CH_4 and 80.8 for non-fossil origin CH_4 while GWP_{100} was changed to 29.8 for fossil CH_4 and 27.2 for non-fossil CH_4 (IPCC 2021). The following section describes the 2020 emissions estimated in the context of both AR4 and AR5 GWPs and the statewide inventory.

As shown in Table 21, simply changing the GWP from AR4 GWP_{100} to GWP_{20} for the original, 2015 New York State inventory increases CH_4 emissions from 2.22 $MMTCO_2e$ to 6.39 $MMTCO_2e$ for the oil and natural gas sector. Under AR5 GWP_{100}, this inventory finds CO_2e emissions are 11.9% higher than estimates under AR4 GWP_{100}. Under AR5 GWP_{20}, emissions estimates are16.6% higher than estimates under AR4 GWP_{20}.

Table 21. Comparison of AR4 and AR5 GWP_{100} and GWP_{20} Values Applied to the Oil and Gas Systems CH_4 Emissions in New York State ($MMTCO_2e$)

	AR4 GWP_{100}	**AR4 GWP_{20}**	**AR5 GWP_{100}**	**AR5 GWP_{20}**
CH_4 GWP (CO_2e)	25	72	28	84
N_2O GWP (CO_2e)	298	289	265	264
NYSERDA 2015 Inventory				
Oil and Gas CH_4 ($MMTCO_2e$)	2.22	6.39	2.49	7.46
Current Inventory				
2017 Oil and Gas CH_4 ($MMTCO_2e$)	2.66	7.67	2.98	8.95
2020 Oil and Gas CH_4 ($MMTCO_2e$)	4.20	12.09	4.70	14.10
2021 Oil and Gas CH_4 ($MMTCO_2e$)	4.40	12.67	4.93	14.78

5 Future Improvements

Emissions inventory development is a continuous process that requires making improvements as better data on emission factors and emission source activity become available. In addition, measurements of atmospheric methane concentration can be used to assess the completeness/accuracy of the emissions inventory. Below is a list of actions that NYS is currently taking to potentially improve future inventories:

- Continuing to review literature to identify new data on emissions factors and emission source activity.
- Identifying additional sources of methane emissions to include in the NYS oil and natural gas sector methane emissions inventory such as:
  - Residential refrigeration and clothes dryers.
  - Additional commercial buildings, such as grocery stores, religious buildings, service (e.g. vehicle repair, dry cleaning/laundromat, post office, beauty parlor, etc.)
  - Industrial buildings.
- Investigating the impacts of cast iron pipeline reconditioning on emissions estimates from existing cast iron pipeline infrastructure.
- As data become available, comparing top-down measurements of methane emissions to the bottom-up inventory values to verify inventory and identify further areas for potential improvement.

6 Conclusions

With the passage of the Climate Leadership and Community Protection Act in 2019, New York State has committed to reduce economy-wide greenhouse gas emissions 40% by 2030 and no less than 85% by 2050 from 1990 levels. While efforts to date have focused on the reduction of carbon dioxide (CO_2) emissions—the dominant cause of the rise in global average temperature—New York State is turning its attention to methane due to its significant short-term impacts on climate change. The goal of this project is to support CH_4 emission reduction efforts in New York State, and achievement of the Climate Act goals, by improving the State's understanding of CH_4 emissions from the oil and natural gas sector.

Based on the four identified areas of best practices and recommendations developed under the first iteration of the project (described in appendix A and presented in the following table and discussion), this inventory presents a marked improvement compared to prior iterations of the New York State oil and natural gas sector methane emission inventories. Emissions inventory development is a continuous process that requires making improvements as better data on emissions factors and emission source activity become available. In each iteration of this product, the inventory has improved as up-to-date data on activity and emissions factors are identified. NYS is taking additional steps to improve future inventories. Table 22 summarizes the best practice recommendations, implementation of these recommendations when developing the current inventory and areas for future inventory improvement.

Table 22. Summary of Best Practice Recommendations, Implementation of Best Practices and Areas for Future Inventory Improvements

✓	**Recommendation No. 1** New York State should develop a more detailed set of activity data, including site- and component-level data, for its CH_4 inventory in order to create an inventory with the detail needed to capture the impacts of CH_4 mitigation strategies targeted at the site- or component-level. **Implementation in Current Inventory:** Applied the best available activity data, using publicly available inputs as well as data provided by New York State agencies. **Areas for Future Improvement:** • Collect/compile data on the number and location of transmission and storage compressor stations in the State, including stations that only have electric compressors. • Collect/compile data on the county-level miles of distribution pipeline by pipeline material. • Collect/compile data on the county-level number of residential and commercial/industrial gas meters. • Identify additional sources of methane emissions to include in the inventory and collect/compile data on county-level activity.

Table 22 continued

✓	**Recommendation No. 2** New York State should estimate and apply EFs for upstream and downstream oil and gas activities in the State using best available data, validated by both bottom-up and top-down studies, and specific to geographic location. **Implementation in Current Inventory:** Applied the best available EFs from the published literature. **Areas for Future Improvement:** • Develop New York State-specific EFs for well pads during production. • Develop New York State-specific EFs for transmission and storage compressor stations. • Develop an EF for fugitive emissions from storage reservoirs. • Identify EFs for other types of commercial buildings, industrial buildings, and additional residential appliances.
✓	**Recommendation No. 3** New York State should align available geospatial data with inventory data as much as possible to create a geospatial emissions inventory that allows greater consideration of identifying hot spots and air quality concerns as well as verification of emission inventories with empirical data. **Implementation in Current Inventory:** Results are presented geospatially, allocated to the county-level, with the ability to produce sub-county results for many segments. **Areas for Future Improvement:** • Collect air quality data on ambient CH_4 concentrations throughout New York State and use the observed concentrations to verify emission estimates. • As data become available, compare top-down measurements of methane emissions to the inventory to verify inventory and identify areas for potential improvement.
□	**Recommendation No. 4** New York State should conduct uncertainty analysis when calculating and reporting its CH_4 inventory. At a minimum, that uncertainty analysis should account for uncertainties in published EFs, but it could also include an assessment of high-emitting sources across the State. New York State should develop and apply models that help account for the existence of high-emitting sources either in cases where emission releases are known (e.g., reported leakage) or in cases where emission releases are not known (e.g., estimated leakage based on pipeline age or material). **Implementation in Current Inventory:** Assessed uncertainty in the applied EFs to identify the most likely range of CH_4 emission from the oil and natural gas sector. With better information on the statistical distribution of high-emitting sources, this inventory methodology may also be applied to explicitly include high-emitting sources. **Areas for Future Improvement:** Develop a better understanding of the distribution of high-emitting sources and the frequency of operation in the high-emitting state.

In the current inventory, total CH_4 emissions in 2021 were estimated to be 14.788 $MMTCO_2e$ (AR5, GWP_{20}), and estimates for 2020 were equivalent to 6.39% of the total nationwide emissions estimated by EPA. Largely driven by decreases in high-producing well activity—and a transition away from more leak-prone cast-iron and unprotected steel pipelines to plastic—results from this inventory show that, despite an increase in natural gas consumption, total CH_4 emissions have continued to decline since 2005, with an average annual decrease of 1.96% per year. Decreasing emissions agrees with observed large-scale nationwide energy shifts. The largest methane emission source categories identified in the

State inventory developed under this project include transmission compressor stations, low producing conventional gas wells, natural gas storage compressor stations, cast iron distribution pipeline mains, unprotected steel distribution pipeline mains, unprotected steel distribution pipeline services, and high producing conventional gas wells.

The current inventory being presented builds off the methodology developed for the 2017 inventory and incorporates findings from the most current empirical research. By continuing to apply established best practices based on a thorough review of the literature and expert consultation, the inventory improves the methane emissions baseline in New York State.

7 References

Allen, David T. 2014. “Methane Emissions from Natural Gas Production and Use: Reconciling Bottom-up and Top-down Measurements.” *Current Opinion in Chemical Engineering* 5. Elsevier Ltd: 78-83. https://doi.org/10.1016/j.coche.2014.05.004

———. 2016. “Emissions from Oil and Gas Operations in the United States and Their Air Quality Implications.” *Journal of the Air & Waste Management Association* 66 (6). Taylor & Francis: 549-75. https://doi.org/10.1080/10962247.2016.1171263

Allen, David T., Adam P. Pacsi, David W. Sullivan, Daniel Zavala-Araiza, Matthew Harrison, Kindal Keen, Matthew P. Fraser, A. Daniel Hill, Robert F. Sawyer, and John H. Seinfeld. 2015. “Methane Emissions from Process Equipment at Natural Gas Production Sites in the United States: Pneumatic Controllers.” *Environmental Science and Technology* 49 (1): 633-40. https://doi.org/10.1021/es5040156

Allen, David T., David W. Sullivan, Daniel Zavala-Araiza, Adam P. Pacsi, Matthew Harrison, Kindal Keen, Matthew P. Fraser, et al. 2015. “Methane Emissions from Process Equipment at Natural Gas Production Sites in the United States: Liquid Unloadings.” *Environmental Science & Technology* 49(1): 641-48. https://doi.org/10.1021/es504016r

Allen, David T, Vincent M Torres, James Thomas, David W Sullivan, Matthew Harrison, Al Hendler, Scott C Herndon, et al. 2013. “Measurements of Methane Emissions at Natural Gas Production Sites in the United States.” *Proceedings of the National Academy of Sciences of the United States of America* 110 (44). National Academy of Sciences: 17768-73. https://doi.org/10.1073/pnas.1304880110

Alvarez, R.A., David R. Lyon, Anthony J. Marchese, Allen L. Robinson, and Steven P. Hamburg. 2016. “Possible Malfunction in Widely Used Methane Sampler Deserves Attention but Poses Limited Implications for Supply Chain Emission Estimates.” *Elementa: Science of the Anthropocene* 4: 000137. https://doi.org/10.12952/journal.elementa.000137

Alvarez, R.A., S.W. Pacala, J.J. Winebrake, W.L. Chameides, and S.P. Hamburg. 2012. “Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure.” *Proceedings of the National Academy of Sciences of the United States of America* 109 (17). https://doi.org/10.1073/pnas.1202407109

Alvarez, R.A., Daniel Zavala-araiza, David R Lyon, David T Allen, Zachary R Barkley, R Adam, Kenneth J Davis, et al. 2018. “Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain.” *Science* 7204 (June): 1-9. https://doi.org/10.1126/science.aar7204

Balcombe, Paul, Jamie F Speirs, Nigel Brandon, and Adam Hawkes. 2018. “Methane Emissions: Choosing the Right Climate Metric and Time Horizon.” *Environmental Science: Processes & Impacts*. The Royal Society of Chemistry. https://doi.org/10.1039/C8EM00414E

Barkley, Zachary R., Thomas Lauvaux, Kenneth J. Davis, Aijun Deng, Natasha L. Miles, Scott J. Richardson, Yanni Cao, et al. 2017. "Quantifying Methane Emissions from Natural Gas Production in North-Eastern Pennsylvania." *Atmospheric Chemistry and Physics* 17 (22): 13941-66. https://doi.org/10.5194/acp-17-13941-2017

Blackhurst, Michael, H. Scott Matthews, Aurora L. Sharrard, Chris T. Hendrickson, and Ins Lima Azevedo. 2011. "Preparing US Community Greenhouse Gas Inventories for Climate Action Plans." *Environmental Research Letters* 6 (3). https://doi.org/10.1088/1748-9326/6/3/034003

Brandt, A R, G A Heath, E A Kort, F O'Sullivan, G Petron, S M Jordaan, P Tans, et al. 2014. "Energy and Environment. Methane Leaks from North American Natural Gas Systems." *Science (New York, N.Y.)* 343 (6172). United States: 733-35. https://doi.org/10.1126/science.1247045

Brandt, Adam R, Garvin A Heath, and Daniel Cooley. 2016. "Methane Leaks from Natural Gas Systems Follow Extreme Distributions." *Environmental Science & Technology* 50 (22). American Chemical Society: 12512-20. https://doi.org/10.1021/acs.est.6b04303

Brantley, Halley L., Eben D. Thoma, William C. Squier, Birnur B. Guven, and David Lyon. 2014. "Assessment of Methane Emissions from Oil and Gas Production Pads Using Mobile Measurements." *Environmental Science and Technology* 48 (24): 14508-15. https://doi.org/10.1021/es503070q

Burnham, Andrew, Jeongwoo Han, Corrie E Clark, Michael Wang, Jennifer B Dunn, and Ignasi Palou-Rivera. 2012. "Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum." *Environmental Science & Technology* 46 (2). American Chemical Society: 619-27. https://doi.org/10.1021/es201942m

Cathles, Lawrence M., Larry Brown, Milton Taam, and Andrew Hunter. 2012. "A Commentary on 'The Greenhouse-Gas Footprint of Natural Gas in Shale Formations' by R.W. Howarth, R. Santoro, and Anthony Ingraffea." *Climatic Change* 113 (2): 525-35. https://doi.org/10.1007/s10584-011-0333-0

Caulton, D. R., P. B. Shepson, R. L. Santoro, J. P. Sparks, R. W. Howarth, A. R. Ingraffea, M. O. L. Cambaliza, et al. 2014. "Toward a Better Understanding and Quantification of Methane Emissions from Shale Gas Development." *Proceedings of the National Academy of Sciences* 111 (17): 6237-42. https://doi.org/10.1073/pnas.1316546111

CenSARA. 2012. "2011 Oil and Gas Emission Inventory Enhancement Project for CenSARA States." https://www.arb.ca.gov/ei/areasrc/oilandgaseifinalreport.pdf

Clark, Nigel N, David L McKain, Derek R Johnson, W Scott Wayne, Hailin Li, Vyacheslav Akkerman, Cesar Sandoval, et al. 2017. "Pump-to-Wheels Methane Emissions from the Heavy-Duty Transportation Sector." *Environmental Science & Technology* 51 (2). American Chemical Society: 968-76. https://doi.org/10.1021/acs.est.5b06059

Clearstone. 2011. "Clearstone Engineering, Development of Updated Emission Factors for Residential Meters."

Conley, S, G Franco, I Faloona, D R Blake, J Peischl, and T B Ryerson. 2016. "Methane Emissions from the 2015 Aliso Canyon Blowout in Los Angeles, CA." *Science* 351 (6279): 1317 LP-1320. http://science.sciencemag.org/content/351/6279/1317.abstract

EDF. 2018. "Methane Research Series: 16 Studies." 2018. https://www.edf.org/climate/methane-research-series-16-studies

EIA. 2018a. "New York Natural Gas Total Consumption." 2018. https://www.eia.gov/dnav/ng/hist/na1490_sny_2a.htm

EIA. 2018b. Residential Energy Consumption Survey (RECS). 2015 RECS Survey Data. https://www.eia.gov/consumption/residential/data/2015/

EIA. 2019. Natural gas explained - Use of natural gas. https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php

EIA. 2023. "New York Natural Gas Total Consumption." 2023. https://www.eia.gov/dnav/ng/hist/na1490_sny_2a.htm

Empire State Organized Geologic Information System (ESOGIS). 2022. All Wells – ZIP File. https://esogis.nysm.nysed.gov/

Etminan, M., G. Myhre, E. J. Highwood, and K. P. Shine. 2016. "Radiative Forcing of Carbon Dioxide, Methane, and Nitrous Oxide: A Significant Revision of the Methane Radiative Forcing." *Geophysical Research Letters*. https://doi.org/10.1002/2016GL071930

European Environment Agency. 2018. "Annual European Union Greenhouse Gas Inventory 1990-2016 and Inventory Report 2018." https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2018

Fischer, Joseph C. Von, Daniel Cooley, Sam Chamberlain, Adam Gaylord, Claire J. Griebenow, Steven P. Hamburg, Jessica Salo, Russ Schumacher, David Theobald, and Jay Ham. 2017. "Rapid, Vehicle-Based Identification of Location and Magnitude of Urban Natural Gas Pipeline Leaks." *Environmental Science and Technology* 51 (7): 4091-99. https://doi.org/10.1021/acs.est.6b06095

Fischer, M.L., Chan, W.R., Delp, W., Jeong, S. et al. 2018a. An estimate of natural gas methane emissions from California homes. Environmental Science & Technology 52(17): 10205-10213. https://doi.org/10.1021/acs.est.8b03217

Fischer, M.L., Chan, W.R., Delp, W., Jeong, S. et al. 2018b. Supplementary material. An estimate of natural gas methane emissions from California homes. Environmental Science & Technology 52(17): 10205-10213. https://pubs.acs.org/doi/suppl/10.1021/acs.est.8b03217/suppl_file/es8b03217_si_001.pdf

Frankenberg, Christian, Andrew K. Thorpe, David R. Thompson, Glynn Hulley, Eric Adam Kort, Nick Vance, Jakob Borchardt, et al. 2016. "Airborne Methane Remote Measurements Reveal Heavy-Tail Flux Distribution in Four Corners Region." *Proceedings of the National Academy of Sciences* 113(35): 9734-39. https://doi.org/10.1073/pnas.1605617113

GTI. 2009. “Field Measurement Program to Improve Uncertainties for Key Greenhouse Gas Emission Factors for Distribution Sources. GTI Project Number 20497. OTD Project Number 7.7.B”

Harrison, M.R., Tm Shires, Jk Wessels, and Rm Cowgill. 1997a. “Methane Emissions from the Natural Gas Industry.” *Epa and Wma Annual Meeting* 7: 93. http://p2pays.net/ref/07/06348.pdf

———. 1997b. “Methane Emissions from the Natural Gas Industry.” *EPA and WMA Annual*

Meeting 7: 93

Harriss, Robert, Ramón A Alvarez, David Lyon, Daniel Zavala-Araiza, Drew Nelson, and Steven P Hamburg. 2015. “Using Multi-Scale Measurements to Improve Methane Emission Estimates from Oil and Gas Operations in the Barnett Shale Region, Texas.” *Environmental Science & Technology* 49 (13). American Chemical Society: 7524-26. https://doi.org/10.1021/acs.est.5b02305

Hartmann, D. L., a. M. G. K. Tank, and M. Rusticucci. 2013. “IPCC Fifth Assessment Report, Climatie Change 2013: The Physical Science Basis.” *IPCC* AR5 (January 2014): 31-39

Hayhoe, Katharine, Haroon S Kheshgi, Atul K Jain, and Donald J Wuebbles. 2002. “Substitution of Natural Gas for Coal: Climatic Effects of Utility Sector Emissions.” *Climatic Change* 54 (1): 107-39. https://doi.org/10.1023/A:1015737505552

Heath, Garvin, Ethan Warner, Daniel Steinberg, and Adam Brandt. 2015. “Estimating U.S. Methane Emissions from the Natural Gas Supply Chain. Approaches, Uncertainties, Current Estimates, and Future Studies,” no. August. https://doi.org/10.2172/1226158

Hendrick, Margaret F., Robert Ackley, Bahare Sanaie-Movahed, Xiaojing Tang, and Nathan G. Phillips. 2016. “Fugitive Methane Emissions from Leak-Prone Natural Gas Distribution Infrastructure in Urban Environments.” *Environmental Pollution* 213. Elsevier Ltd: 710-16. https://doi.org/10.1016/j.envpol.2016.01.094

Hong, B. & Howarth, R.W. 2016. Greenhouse gas emissions from domestic hot water: heat pumps compared to most commonly used systems. Energy Science & Engineering 4(2): 123-133. https://doi.org/10.1002/ese3.112

Howarth, Robert W. 2014. “A Bridge to Nowhere: Methane Emissions and the Greenhouse Gas Footprint of Natural Gas.” *Energy Science & Engineering* 2 (2): 47-60. https://doi.org/10.1002/ese3.35.

Howarth, Robert W., Renee Santoro, and Anthony Ingraffea. 2011. “Methane and the Greenhouse-Gas Footprint of Natural Gas from Shale Formations.” *Climatic Change* 106 (4): 679-90. https://doi.org/10.1007/s10584-011-0061-5

Hultman, Nathan, Dylan Rebois, Michael Scholten, and Christopher Ramig. 2011. “Erratum: The Greenhouse Impact of Unconventional Gas for Electricity Generation (Environmental Research Letters (2011) 6 (044008)).” *Environmental Research Letters* 6 (4). https://doi.org/10.1088/1748-9326/6/4/049504

ICF. 2020. “Characterization of Fugitive Methane Emissions from Commercial Buildings in California.” California Energy Commission. Publication Number: CEC-500-2020-048.

IPCC. 2006. “2006 IPCC Guidelines for National Greenhouse Gas Inventories.” Vol. 2.

IPCC. 2021. IPCC Sixth Assessment Report, Climate Change 2021: The Physical Science Basis.” https://www.ipcc.ch/report/ar6/wg1/

ITRC. 2018. “Evaluation of Innovative Methane Detection Technologies: Appendix B – Characterization.” Washington, D.C

Jaramillo, Paulina, W Michael Griffin, and H Scott Matthews. 2007. “Comparative Life-Cycle Air Emissions of Coal, Domestic Natural Gas, LNG, and SNG for Electricity Generation.” *Environmental Science & Technology* 41 (17). American Chemical Society: 6290-96. https://doi.org/10.1021/es063031o

Jiang, Mohan, W. Michael Griffin, Chris Hendrickson, Paulina Jaramillo, Jeanne Vanbriesen, and Aranya Venkatesh. 2011. “Life Cycle Greenhouse Gas Emissions of Marcellus Shale Gas.” *Environmental Research Letters* 6 (3). https://doi.org/10.1088/1748-9326/6/3/034014

Johnson, D, A Covington, and N Clark. 2015. “Methane Emissions from Leak and Loss Audits of Natural Gas Compressor Stations and Storage Facilities.” *Environmental Science and Technology* 49 (13): 8132–8138. https://doi.org/10.1021/es506163m

Kang, Mary, Cynthia M. Kanno, Matthew C. Reid, Xin Zhang, Denise L. Mauzerall, Michael A. Celia, Yuheng Chen, and Tullis C. Onstott. 2014. “Direct Measurements of Methane Emissions from Abandoned Oil and Gas Wells in Pennsylvania.” *Proceedings of the National Academy of Sciences* 111 (51): 18173-77. https://doi.org/10.1073/pnas.1408315111

Karion, A., Colm Sweeney, Gabrielle Pétron, Gregory Frost, R. Michael Hardesty, Jonathan Kofler, Ben R. Miller, et al. 2013. “Methane Emissions Estimate from Airborne Measurements over a Western United States Natural Gas Field.” *Geophysical Research Letters* 40 (16): 4393-97. https://doi.org/10.1002/grl.50811

Karion, A, C Sweeney, E A Kort, P B Shepson, A Brewer, M O L Cambaliza, S Conley, K J Davis, A Deng, and M Hardesty. 2015. “Aircraft-Based Estimate of Total Methane Emissions from the Barnett Shale Region.” *Environmental Science and Technology* 49 (13): 8124–8131 https://doi.org/10.1021/acs.est.5b00217

Karion, Anna, Colm Sweeney, Gabrielle Pétron, Gregory Frost, R. Michael Hardesty, Jonathan Kofler, Ben R. Miller, et al. 2013. “Methane Emissions Estimate from Airborne Measurements over a Western United States Natural Gas Field.” *Geophysical Research Letters* 40 (16): 4393-97. https://doi.org/10.1002/grl.50811

Kirchgessner, D. 1997. “Estimate of Methane Emissions from the U.S. Natural Gas Industry.” *Chemosphere* 35: 1365-90. https://doi.org/10.1016/S0045-6535(97)00236-1

Lamb, Brian K., Steven L. Edburg, Thomas W. Ferrara, Touché Howard, Matthew R. Harrison, Charles E. Kolb, Amy Townsend-Small, Wesley Dyck, Antonio Possolo, and James R. Whetstone. 2015. "Direct Measurements Show Decreasing Methane Emissions from Natural Gas Local Distribution Systems in the United States." *Environmental Science and Technology* 49 (8): 5161-69. https://doi.org/10.1021/es505116p

Lavoie, T N, P B Shepson, M O L Cambaliza, B H Stirm, A Karion, C Sweeney, T I Yacovitch, S C Herndon, X Lan, and D Lyon. 2015. "Aircraft-Based Measurements of Point Source Methane Emissions in the Barnett Shale Basin." *Environmental Science and Technology* 49 (13): 7904–7913. https://doi.org/10.1021/acs.est.5b00410

Lebel, E.D., Lu, H.S., Speizer, S.A., Finnegan, C.J. et al. 2020. Quantifying methane emissions from natural gas water heaters. Environmental Science & Technology. https://doi.org/10.1021/acs.est.9b07189

Littlefield, James A., Joe Marriott, Greg A. Schivley, and Timothy J. Skone. 2017. "Synthesis of Recent Ground-Level Methane Emission Measurements from the U.S. Natural Gas Supply Chain." *Journal of Cleaner Production* 148: 118-26. https://doi.org/10.1016/j.jclepro.2017.01.101

Lyon, David R., Ramón A. Alvarez, Daniel Zavala-Araiza, Adam R. Brandt, Robert B. Jackson, and Steven P. Hamburg. 2016. "Aerial Surveys of Elevated Hydrocarbon Emissions from Oil and Gas Production Sites." *Environmental Science and Technology* 50 (9): 4877-86. https://doi.org/10.1021/acs.est.6b00705

Lyon, David R., Daniel Zavala-Araiza, Ramón A. Alvarez, Robert Harriss, Virginia Palacios, Xin Lan, Robert Talbot, et al. 2015. "Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region." *Environmental Science and Technology* 49 (13): 8147-57. https://doi.org/10.1021/es506359c

Marchese, Anthony J., Timothy L. Vaughn, Daniel J. Zimmerle, David M. Martinez, Laurie L. Williams, Allen L. Robinson, Austin L. Mitchell, et al. 2015. "Methane Emissions from United States Natural Gas Gathering and Processing." *Environmental Science and Technology* 49 (17): 10718-27. https://doi.org/10.1021/acs.est.5b02275

McKain, Kathryn, Adrian Down, Steve M. Raciti, John Budney, Lucy R. Hutyra, Cody Floerchinger, Scott C. Herndon, et al. 2015. "Methane Emissions from Natural Gas Infrastructure and Use in the Urban Region of Boston, Massachusetts." *Proceedings of the National Academy of Sciences* 112 (7): 1941-46. https://doi.org/10.1073/pnas.1416261112

Merrin, Z. & Francisco, P.W. 2019. Unburned methane emissions from residential natural gas appliances. Environmental Science & Technology 53: 5473-5482. https://doi.org/10.1021/acs.est.8b05323

Miller, S. M., S. C. Wofsy, A. M. Michalak, E. A. Kort, A. E. Andrews, S. C. Biraud, E. J. Dlugokencky, et al. 2013. "Anthropogenic Emissions of Methane in the United States." *Proceedings of the National Academy of Sciences*. https://doi.org/10.1073/pnas.1314392110

Mitchell, Austin L, Daniel S Tkacik, Joseph R Roscioli, Scott C Herndon, Tara I Yacovitch, David M Martinez, Timothy L Vaughn, et al. 2015. "Measurements of Methane Emissions from Natural Gas Gathering Facilities and Processing Plants: Measurement Results." *Environmental Science & Technology* 49 (5). American Chemical Society: 3219-27. https://doi.org/10.1021/es5052809

Moore C, Stuver S, Kristine W. 2019. Classification of Methane Emissions from Industrial Meters, Vintage versus Modern Plastic Pipe, and Plastic-lined Steel and Cast-Iron Pipe. https://doi.org/10.2172/1556081

Nathan, Brian J, Levi M Golston, Anthony S O'Brien, Kevin Ross, William A Harrison, Lei Tao, David J Lary, et al. 2015. "Near-Field Characterization of Methane Emission Variability from a Compressor Station Using a Model Aircraft." *Environmental Science & Technology* 49 (13). American Chemical Society: 7896-7903. https://doi.org/10.1021/acs.est.5b00705

NYDEC. 2006. "New York's Oil and Natural Gas History - A Long Story, But Not The Final Chapter"

———. 2017. "Methane Reduction Plan." https://www.dec.ny.gov/docs/administration_pdf/mrpfinal.pdf

———. 2022. "Data on Oil, Gas and Other Wells in New York State." 2022.

New York Department of Environmental Conservation (DEC). 2021. Downloadable Oil & Gas Production Data. Yearly Oil and Gas Production Files (zipped format). https://www.dec.ny.gov/energy/36159.html

NYSERDA, and NYDEC. 2018. "New York Greenhouse Gas Inventory: 1990-2015." Albany, NY. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwjo5cKQpcPdAhVq3IMKHecQA2oQFjAAegQIABAC&url=https%3A%2F%2Fwww.nyserda.ny.gov%2F-%2Fmedia%2FFiles%2FEDPPP%2FEnergy-Prices%2FEnergy-Statistics%2Fgreenhouse-gas-inventory.pdf&usg=AOvVa

NYSERDA. 2019. "New York State Oil and Gas Sector Methane Emissions Inventory." NYSERDA Report Number 19-36. Prepared by Abt Associates, Rockville, MD and Energy and Environmental Research Associates, LLC, Pittsford, NY. nyserda.ny.gov/publications

NYSERDA. 2021. "Technical Documentation: Estimating Energy Sector Greenhouse Gas Emissions Under New York State's Climate Leadership and Community Protection Act." https://www.dec.ny.gov/docs/administration_pdf/energyghgerg.pdf

Ocko, Ilissa B., Steven P. Hamburg, Daniel J. Jacob, David W. Keith, Nathaniel O. Keohane, Michael Oppenheimer, Joseph D. Roy-Mayhew, Daniel P. Schrag, and Stephen W. Pacala. 2017. "Unmask Temporal Trade-Offs in Climate Policy Debates." *Science*. https://doi.org/10.1126/science.aaj2350

Omara, Mark, Melissa R. Sullivan, Xiang Li, R. Subramanian, Allen L. Robinson, and Albert A. Presto. 2016. "Methane Emissions from Conventional and Unconventional Natural Gas Production Sites in the Marcellus Shale Basin." *Environmental Science & Technology* 50 (4). American Chemical Society: 2099-2107. https://doi.org/10.1021/acs.est.5b05503

Peischl, J, T B Ryerson, K C Aikin, J A Gouw, J B Gilman, J S Holloway, B M Lerner, et al. 2015. “Quantifying Atmospheric Methane Emissions from the Haynesville, Fayetteville, and Northeastern Marcellus Shale Gas Production Regions.” *Journal of Geophysical Research: Atmospheres* 120 (5). Wiley-Blackwell: 2119-39. https://doi.org/10.1002/2014JD022697

Pétron, Gabrielle, Gregory Frost, Benjamin R. Miller, Adam I. Hirsch, Stephen A. Montzka, Anna Karion, Michael Trainer, et al. 2012. “Hydrocarbon Emissions Characterization in the Colorado Front Range: A Pilot Study.” Journal of Geophysical Research Atmospheres 117 (4): 1-19. https://doi.org/10.1029/2011JD016360

Pétron, Gabrielle, Anna Karion, Colm Sweeney, Benjamin R. Miller, Stephen A. Montzka, Gregory J. Frost, Michael Trainer, et al. 2014. “A New Look at Methane and Nonmethane Hydrocarbon Emissions from Oil and Natural Gas Operations in the Colorado Denver-Julesburg Basin.” *Journal of Geophysical Research*. https://doi.org/10.1002/2013JD021272

Pipeline and Hazardous Materials Safety Administration (PHMSA). 2022. Gas Distribution, Gas Gathering, Gas Transmission, Hazardous Liquids, Liquefied Natural Gas (LNG), and Underground Natural Gas Storage (UNGS) Annual Report Data. https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids

Plant G, Kort, EA, Floerchinger C, Gvakharia A, Vimont I, and Sweeney C. 2019. Large fugitive methane emissions from urban centers along the US east coast. Geophysical Research Letters 46: 8500-8507, doi:10.1029/2019GL082635

Rella, Chris W, Tracy R Tsai, Connor G Botkin, Eric R Crosson, and David Steele. 2015. “Measuring Emissions from Oil and Natural Gas Well Pads Using the Mobile Flux Plane Technique.” *Environmental Science & Technology* 49 (7). American Chemical Society: 4742-48. https://doi.org/10.1021/acs.est.5b00099

Robertson, Anna M, Rachel Edie, Dustin Snare, Jeffrey Soltis, Robert A Field, Matthew D Burkhart, Clay S Bell, Daniel Zimmerle, and Shane M Murphy. 2017. “Variation in Methane Emission Rates from Well Pads in Four Oil and Gas Basins with Contrasting Production Volumes and Compositions.” *Environmental Science & Technology* 51 (15). American Chemical Society: 8832-40. https://doi.org/10.1021/acs.est.7b00571

Roy, Anirban A., Peter J. Adams & Allen L. Robinson. 2014. "Air pollutant emissions from the development, production, and processing of Marcellus Shale natural gas." *Journal of the Air & Waste Management Association* 64(1), 19-37. https://doi.org/10.1080/10962247.2013.826151

Saint-Vincent, P.M.B. & Pekney, N.J. 2020. Beyond the meter: Unaccounted sources of methane emissions in the natural gas distribution sector. Environmental Science & Technology 54: 39-49. https://doi.org/10.1021/acs.est.9b04657

Schade, Gunnar W., and Geoffrey Roest. 2016. “Analysis of Non-Methane Hydrocarbon Data from a Monitoring Station Affected by Oil and Gas Development in the Eagle Ford Shale, Texas.” *Elementa: Science of the Anthropocene* 4: 000096. https://doi.org/10.12952/journal.elementa.000096

Schwietzke, Stefan, Gabrielle Pétron, Stephen Conley, Cody Pickering, Ingrid Mielke-Maday, Edward J. Dlugokencky, Pieter P. Tans, et al. 2017. “Improved Mechanistic Understanding of Natural Gas Methane Emissions from Spatially Resolved Aircraft Measurements.” *Environmental Science & Technology* 51 (12): 7286-94. https://doi.org/10.1021/acs.est.7b01810

Smith, M L, E A Kort, A Karion, C Sweeney, S C Herndon, and T I Yacovitch. 2015. “Airborne Ethane Observations in the Barnett Shale: Quantification of Ethane Flux and Attribution of Methane Emissions.” *Environmental Science & Technology* 49 (13), 8158-8166 https://doi.org/0.1021/acs.est.5b00219

Smith, Mackenzie L, Alexander Gvakharia, Eric A Kort, Colm Sweeney, Stephen A Conley, Ian Faloona, Tim Newberger, Russell Schnell, Stefan Schwietzke, and Sonja Wolter. 2017. “Airborne Quantification of Methane Emissions over the Four Corners Region.” *Environmental Science & Technology* 51 (10). American Chemical Society: 5832-37. https://doi.org/10.1021/acs.est.6b06107

Stephenson, Trevor, Jose Eduardo Valle, and Xavier Riera-Palou. 2011. “Modeling the Relative GHG Emissions of Conventional and Shale Gas Production.” *Environmental Science and Technology* 45 (24): 10757-64. https://doi.org/10.1021/es2024115

Subramanian, R., Laurie L. Williams, Timothy L. Vaughn, Daniel Zimmerle, Joseph R. Roscioli, Scott C. Herndon, Tara I. Yacovitch, et al. 2015. “Methane Emissions from Natural Gas Compressor Stations in the Transmission and Storage Sector: Measurements and Comparisons with the EPA Greenhouse Gas Reporting Program Protocol.” *Environmental Science and Technology* 49 (5): 3252-61. https://doi.org/10.1021/es5060258

Townsend-Small, A, J E Marrero, D Lyon, I Simpson, S Meinardi, and D R Blake. 2015. “Integrating Source Apportionment Tracers into a Bottom-up Inventory of Methane Emissions in the Barnett Shale Hydraulic Fracturing Region.” *Environmental Science and Technology* 49 (13). https://doi.org/10.1021/acs.est.5b00057

Townsend-Small, Amy, Thomas W Ferrara, David R Lyon, Anastasia E Fries, and Brian K Lamb. 2016. “Emissions of Coalbed and Natural Gas Methane from Abandoned Oil and Gas Wells in the United States.” *Geophysical Research Letters* 43 (5). Wiley-Blackwell: 2283-90. https://doi.org/10.1002/2015GL067623

U.S. Census Bureau. 2018. Annual Estimates of County Housing Units for States: 2010 to 2018. https://www.census.gov/data/tables/time-series/demo/popest/2010s-total-housing-units.html

U.S. Census Bureau. 2022a. National, State, and County Housing Unit Totals: 2010-2021. Annual Estimates of Housing Units for the United States, Regions, States, the District of Columbia, and Counties: April 1, 2010 to July 1, 2019; April 1, 2021; and July 1, 2021 (HU-EST2021). https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates/2020-evaluation-estimates/2010s-totals-housing-units.html

U.S. Census Bureau. 2022b. County Business Patterns (CBP). CBP Tables. https://www.census.gov/programs-surveys/cbp/data/tables.html

U.S. EPA. n.d. “GHG Reporting Requirements: Suppart W.” Accessed September 8, 2018. http://www.epa.gov/ghgreporting/index.html

———. 2011. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009.” *EPA 430-R-11- 005*. https://www.epa.gov/sites/production/files/2015-12/documents/us-ghg-inventory-2011-complete_report.pdf

———. 2014. “EPA Oil and Gas Tool - Production Activities Module.”

———. 2017. “Greenhouse Gas Reporting Program - Subpart W.” 2017. https://www.epa.gov/ghgreporting/subpart-w-petroleum-and-natural-gas-systems

———. 2018a. “Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990-2016).” *United States Environmental Protection Agency*. https://doi.org/EPA 430-T-18-003

———. 2018b. “Facility Level Information on GreenHouse Gases Tool.” 2018.

———. 2021. Facility Level Information on GHGs Tool (FLIGHT). https://ghgdata.epa.gov/ghgp/main.do

———. 2023. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021.” *United States Environmental Protection Agency*. EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021

U.S. EPA/GRI. 1996. “Methane Emissions from the Natural Gas Industry. EPA - 600/R-96-080.” https://www.epa.gov/natural-gas-star-program/methane-emissions-natural-gas-industry

Venkatesh, Aranya, Paulina Jaramillo, W Michael Griffin, and H Scott Matthews. 2011. “Uncertainty in Life Cycle Greenhouse Gas Emissions from United States Natural Gas End-Uses and Its Effects on Policy.” *Environmental Science & Technology* 45 (19). American Chemical Society: 8182-89. https://doi.org/10.1021/es200930h

Yacovitch, Tara I., Scott C. Herndon, Gabrielle Pétron, Jonathan Kofler, David Lyon, Mark S. Zahniser, and Charles E. Kolb. 2015. “Mobile Laboratory Observations of Methane Emissions in the Barnett Shale Region.” *Environmental Science and Technology* 49 (13): 7889-95. https://doi.org/10.1021/es506352j

Zavala-Araiza, D, D Lyon, R A Alvarez, V Palacios, R Harriss, X Lan, R Talbot, and S P Hamburg. 2015. “Towards a Functional Definition of Methane Super-Emitters: Application to Natural Gas Production Sites.” *Environ. Sci. Technol.*

Zavala-Araiza, Daniel, David T. Allen, Matthew Harrison, Fiji C. George, and Gilbert R. Jersey. 2015. “Allocating Methane Emissions to Natural Gas and Oil Production from Shale Formations.” *ACS Sustainable Chemistry and Engineering* 3 (3): 492-98. https://doi.org/10.1021/sc500730x

Zavala-Araiza, Daniel, Ramón A. Alvarez, David R. Lyon, David T. Allen, Anthony J. Marchese, Daniel J. Zimmerle, and Steven P. Hamburg. 2017. “Super-Emitters in Natural Gas Infrastructure Are Caused by Abnormal Process Conditions.” *Nature Communications* 8. https://doi.org/10.1038/ncomms14012

Zavala-Araiza, Daniel, David Lyon, Ramón A. Alvarez, Virginia Palacios, Robert Harriss, Xin Lan, Robert Talbot, and Steven P. Hamburg. 2015. "Toward a Functional Definition of Methane Super-Emitters: Application to Natural Gas Production Sites." *Environmental Science and Technology* 49 (13): 8167-74. https://doi.org/10.1021/acs.est.5b00133

Zavala-Araiza, Daniel, David R. Lyon, Ramón A. Alvarez, Kenneth J. Davis, Robert Harriss, Scott C. Herndon, Anna Karion, et al. 2015a. "Reconciling Divergent Estimates of Oil and Gas Methane Emissions." *Proceedings of the National Academy of Sciences* 112 (51): 201522126. https://doi.org/10.1073/pnas.1522126112

Zimmerle, Daniel J., Cody K. Pickering, Clay S. Bell, Garvin A. Heath, Dag Nummedal, Gabrielle Pétron, and Timothy L. Vaughn. 2017. "Gathering Pipeline Methane Emissions in Fayetteville Shale Pipelines and Scoping Guidelines for Future Pipeline Measurement Campaigns." *Elem Sci Anth*. https://doi.org/10.1525/elementa.258

Zimmerle, Daniel J., Laurie L. Williams, Timothy L. Vaughn, Casey Quinn, R. Subramanian, Gerald P. Duggan, Bryan Willson, et al. 2015. "Methane Emissions from the Natural Gas Transmission and Storage System in the United States." *Environmental Science and Technology* 49 (15): 9374-83. https://doi.org/10.1021/acs.est.5b01669

8 Glossary

Abandoned wells

Unplugged wells (primarily oil or gas) that have not been operated and maintained in accordance with prevailing statute and regulation. Many abandoned wells have fallen into advanced states of disrepair.

Associated gas

Gas produced as a byproduct of the production of crude oil.

Conventional reservoir

A reservoir in which buoyant forces keep hydrocarbons in place below a sealing caprock. Reservoir and fluid characteristics of conventional reservoirs typically permit oil or natural gas to flow readily into wellbores. The term is used to make a distinction from shale and other unconventional reservoirs, in which gas might be distributed throughout the reservoir at the basin scale, and in which buoyant forces or the influence of a water column on the location of hydrocarbons within the reservoir are not significant.

Global warming potential

The index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emissions of one kilogram (kg) of a GHG to that from the emissions of 1 kg of CO_2 over a period of time (usually 100 years).

Green completions

Reduced emissions well completions that capture the flowback and collect the natural gas rather than venting the natural gas to the atmosphere.

Orphan wells

A subset of abandoned wells that are abandoned for which no owner can be determined. In most instances, these wells were drilled prior to the existence of a regulatory framework in New York. Due to their advanced age and the lack of comprehensive well information, these wells may present significant public health and environmental hazards.

Plugged well

A well that has been permanently closed, usually after either logs determine there is insufficient hydrocarbon potential to complete the well, or after production operations have drained the reservoir. Different regulatory bodies have their own requirements for plugging operations. Most require that cement plugs be placed and tested across any open hydrocarbon-bearing formations, across all casing shoes, across freshwater aquifers, and perhaps several other areas near the surface, including the top 20 to 50 feet (6 to 15 meters) of the wellbore. The well designer may choose to set bridge plugs in conjunction with cement slurries to ensure that higher density cement does not fall into the wellbore. In that case, the bridge plug would be set and cement pumped on top of the plug through a drillpipe, and then the drillpipe withdrawn before the slurry thickens.

Super-emitters

Super-emitter is a term that has been used in the literature to describe sources with much higher emission rates than the average from that source type. The exact definition of super-emitters varies among the various references [e.g., it may refer to the top 5% highest-emitting sources that are responsible for the majority of that source type's total emissions (Brandt et al. 2016) or sites with the highest proportional loss rates (Zavala-Araiza et al. 2015)]. Depending on the definition, the term super-emitters may include chronic, episodic, routine, and malfunctioning sources. Due to the various uses of this term in the literature and its ambiguity, ITRC and the recent National Academies' report on CH_4 (https://www.nap.edu/catalog/24987/improving-characterization-of-anthropogenic-methane-emissions-in-the-united-states) have chosen to use the term "high-emitting sources" to describe these emission sources.

Unconventional resource

An umbrella term for oil and natural gas that is produced by means that do not meet the criteria for conventional production. What has qualified as unconventional at any particular time is a complex function of resource characteristics; the available exploration and production technologies; the economic environment; and the scale, frequency, and duration of production from the resource. Perceptions of these factors inevitably change over time and often differ among users of the term. At present, the term is used in reference to oil and gas resources whose porosity, permeability, fluid trapping mechanism, or other characteristics differ from conventional sandstone and carbonate reservoirs. Coalbed CH_4, gas hydrates, shale gas, fractured reservoirs, and tight gas sands are considered unconventional resources.

Well completions

A generic term used to describe the assembly of downhole tubulars and equipment required to enable safe and efficient production from an oil or gas well. The point at which the completion process begins may depend on the type and design of well. However, many options applied, or actions performed during the construction phase of a well have significant impact on the productivity of the well.

Appendix A. Inventory Improvement

Appendix A provides detailed description of previous iterations of the inventory and improvements.

A.1 2015 versus 2021 Inventories

The approach for the original 2015 inventory used straightforward calculations and a transparent approach, but the approach had several drawbacks (see appendix A.3.4). By scaling national emissions by consumption, New York State's simplified approach did not account for potentially unique aspects of the State's oil and natural gas sector. Because the approach was highly aggregated and was not resolved by either component-level or geography, the State lost the opportunity to more precisely target its CH_4 reduction policies and programs. The approach also did not account for the uncertainty inherent in EFs and activity data. To develop the 2017 inventory during the first iteration of this project, many improvements were made drawing on the best practices identified in the literature focusing on the (1) use of appropriately scaled activity data, (2) inclusion of state-of-the-science EFs, (3) geospatial resolution of activities and emissions, and (4) application and reporting of uncertainty factors, including high-emitting sources. These best practices were maintained during the current iteration of the project as the inventory was brought up to date with activity data through 2021 for all source categories, emissions factors were improved upon, and new source categories were added to reconcile the inventory with top-down emissions estimates.

A.2. Further Updates for 2021 Inventory

Building on the best practices described above and the previous updates for the 2020 inventory described in Section A.3, further updates were made to the inventory. In addition to updating activity data and calculating emissions through 2021, there are xx main differences in the 2021 inventory:

- Updates to abandoned well counts (appendix A.2.1)
- Addition of downstream sources including industrial meters, metering and regulating stations, pressure relief valves, damages, blowdowns, and several more commercial building types (education, lodging, office buildings, warehouses, retail buildings) (appendix A.2.2)
- Updated commercial meter emissions factor to align with EPA's Greenhouse Gas Inventory (appendix A.2.3)

A.2.1 Abandoned Well Counts

An analysis of the NYS Orphaned Wells Map (Orphaned Wells Map | State of New York (ny.gov)) NYDEC's grant application to plug abandoned wells revealed a discrepancy between the number of abandoned wells estimated by the inventory and the number of wells in the map and DEC's application. To close the gap, the inventory was updated to include additional the types and statuses of wells reported to ESOGIS to expand the definition of "abandoned" used for the inventory. This update resulted in nearly 5,000 additional abandoned wells in New York State, and thus resulted in an increase in abandoned well emissions.

A.2.2 Additional Downstream Sources

A literature review for additional sources and updated emissions factors resulted in several new studies and reports since the New York State Oil and Gas Sector Methane Emissions Inventory, 1990-2020. A review of EPA's GHG Inventory, resulting from the Joint Utilities' Supplemental Proposal for an Annual Greenhouse Gas Emissions Inventory Report, resulted in the addition of several new downstream sources that increased downstream emissions:

- M&R Stations
- Industrial Meters
- Pressure Relief Valves
- Damages
- Blowdowns

In addition, ICF (2020) estimated fugitive emissions from offices, lodging, education, retail, warehouse, and food service buildings in California. This study was used to derive emissions factors for fugitive emissions from these commercial building types to improve the completeness of the NYS Inventory. The addition of these commercial building types resulted in an increase in commercial building emissions.

A.2.3 Updated Commercial Meter Emissions Factor

With the addition of industrial meters in the EPA's GHG Inventory, and thus to this NYS inventory, the commercial meter was also updated. EPA updated the commercial meter EF from 9.7 kg/meter to 23.4 kg/meter. This change is reflected in the New York State Oil and Gas Sector Methane Emissions Inventory, 1990-2021 and resulted in an increase in commercial meter emissions.

A.2.4 Results of 2021 Updates

Table A-6 below compares emissions for 2015, the common year across all four inventories, as well as emissions from 1990 and 2005 from the first New York State Greenhouse Gas Inventory, 1990–2015 to the first iteration of the New York State Oil and Gas Sector Methane Emissions Inventory, 1990–2017, the second iteration of the New York State Oil and Gas Sector Methane Emissions Inventory, 1990–2020, and the third, current iteration of the New York State Oil and Gas Sector Methane Emissions Inventory, 1990–2021.

Table A-6. Comparison of Emissions in Key Inventory Years with AR4 and AR5 GWP_{100} and GWP_{20} Values Applied from the Four Inventories

Inventory	AR4 GWP_{100}	AR4 GWP_{20}	AR5 GWP_{100}	AR5 GWP_{20}
1990				
New York State Greenhouse Gas Inventory, 1990–2015	2.8	8.06	3.14	9.41
New York State Oil and Gas Methane Emissions Inventory, 1990–2017	2.74	7.88	3.07	9.21
New York State Oil and Gas Methane Emissions Inventory, 1990–2020	5.17	14.89	5.80	17.40
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	5.42	15.60	6.07	18.20
2005				
New York State Greenhouse Gas Inventory, 1990–2015	3.5	10.07	3.93	11.76
New York State Oil and Gas Methane Emissions Inventory, 1990–2017	3.52	10.12	3.95	11.83
New York State Oil and Gas Methane Emissions Inventory, 1990–2020	6.15	17.72	6.93	20.73
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	6.42	18.48	7.19	21.56
2015				
New York State Greenhouse Gas Inventory, 1990–2015	2.22	6.39	2.49	7.46
New York State Oil and Gas Methane Emissions Inventory, 1990– 2017	2.82	8.12	3.16	9.48
New York State Oil and Gas Methane Emissions Inventory, 1990– 2020	4.74	13.65	5.31	15.92
New York State Oil and Gas Methane Emissions Inventory, 1990–2021	4.98	14.34	5.58	16.73

In the second iteration of the NYS Oil and Gas Methane Emissions Inventory, 2020 emissions totaled 14,104,891 $MTCO_2e$ (AR5 GWP_{20}). The current iteration of the inventory estimates total emissions of 14,982,220 $MTCO_2e$ in 2020. Thus, the improvements made to the inventory between the second and current iteration resulted in an emissions increase of 6.2%.

A.3 Previous Updates for 2020 Inventory

After an assessment of the 2017 New York State Oil and Gas Sector Methane Emissions Inventory (NYSERDA, 2019) during a second iteration of the project, several updates were made. In addition to updating the 2017 inventory with activity data and emissions for 2018–2020, there are four main differences between the 2017 inventory and the 2018–2020 inventories discussed in the following section:

- Updates to distribution emissions factors based on utility reported data (appendix A.2.1).
- Addition of beyond the meter sources including residential appliances, residential buildings, and commercial buildings from 1990 to 2020 (appendix A.2.2).
- Expressing methane emissions in terms of CO_2e using the Fifth Assessment Report of the IPCC (AR5) Global warming potential (20 year) GWP_{20} (appendix A.2.3).
- Updates to conventional production emissions factors from Omara et al. (2016) (appendix A.2.4).

Table A-1. Summary of Updates to the Inventory

Update	2017 Version	2020 Version
Activity data	1990 – 2017	1990 – 2020
Distribution Emissions Factors	Uses distribution EFs based on the 2018 EPA GHG Inventory	Uses distribution EFs based on utility reported data
GWP	AR4 GWP_{100}	AR5 GWP_{20}
Conventional Production Emissions Factors	Low emissions factors from Omara et al. (2016)	Mid emissions factors from Omara et al. (2016)

A.3.1 Updates to Distribution Emissions Factors

A comparison of utility reported distribution pipeline emissions under the Environmental Protection Agency's (EPA) GHG Reporting Program (FLIGHT database) and the estimated distribution pipeline emissions in NYS's 2017 oil and natural gas sector inventory revealed discrepancies between utility reported emissions and the NYS estimated emissions for pipeline mains and services. To ensure that the NYS methane emissions inventory aligns with utility reported data, the pipeline emissions factors for mains and services were updated to match the emissions factors used by utilities. In addition, all emissions factor units were updated to kg/mile for consistency. Table A-2 below shows a comparison of the emissions factors used in the 2017 NYS inventory (yellow shading) to the updated emissions factors used in the 2020 inventory (green shading). These updates resulted in a 330% increase in distribution pipeline emissions (868,826 to 3,736,804 $MMTCO_2e$ AR5 GWP_{20} in 2020) and a 26% increase in overall emissions from the oil and natural gas sector (11,236,913 to 14,104,891 $MMTCO_2e$ AR5 GWP_{20} in 2020).

Table A-2. Comparison of Distribution Pipeline Methane EFs Based on Utility Reported Emissions versus EFs Used in the NYS 2017 Oil and Natural Gas Sector Inventory

	2017 EF Units	Calculated from Utility Reported Data to GHGRP	2017 NYS Inventory EF		Updated EF Units	Calculated from Utility Reported Data to GHGRP	Updated NYS Inventory EF	
		2017	2017 Low	2017 High		2017	2017 Low	2017 High
Mains								
Cast Iron	kg/mile	4,583.2	1,157.3	4,597.4			1,157.3	4,597.4
Unprotected Steel	kg/mile	2,115.8	861.3	2,122.3			861.3	2,122.3
Protected Steel	kg/mile	58.8	96.7	96.7			58.8	96.7
Plastic	kg/mile	190.0	28.8	190.9			28.8	190.9
Copper	kg/service		4.9	4.9	kg/mile		496.0	496.0
Services								
Cast Iron	kg/mile		1,157.3	4,597.4			1,157.3	4,597.4
Unprotected Steel	kg/service	31.9	14.5	32.8	kg/mile	2,711.5	1,198.7	2,711.5
Protected Steel	kg/service	3.3	1.3	3.4	kg/mile	247.3	94.5	247.3
Plastic	kg/service	0.2	0.3	0.3	kg/mile	13.5	13.5	13.5
Copper	kg/service	5.0	4.9	4.9	kg/mile	496.0	496.0	496.0

A.3.2 Addition of Beyond the Meter Sources

New York State’s 2017 methane emissions inventory estimated methane emissions from the oil and natural gas sector up to and including emissions from the meter but lacked end-use emission estimates beyond the meter. Since completing the 2017 inventory, more research has been published on end-use emissions beyond the meter which allowed inclusion of these emissions estimates. Including methane emissions from beyond the meter end-use processes may help to further reconcile discrepancies in emission estimates from top-down versus bottom-up approaches, as discussed in section 3.1.2.6.

For example, a recent top-down measurement study by Plant et al. (2019) indicates that downstream emissions in the northeastern United States are around 0.8% of consumption. For comparison, the 2019 bottom-up downstream emissions estimated for the 2019 NYS inventory are around 0.2% of consumption, which agrees well with the data on delivery and losses reported by natural gas utilities to EPA’s FLIGHT database. Thus, in addition to the inherent methodological differences, the discrepancy between top-down studies such as Plant et al. and the NYS inventory could be partially due to missing end-use sources.

The following section provides the results of a literature search on beyond the meter end-use methane emissions. The purpose of the literature review was to determine the universe of appliances and buildings that might be contributing to end-use methane emissions and the leak rates from those appliances and building plumbing.

To conduct the literature review, the Energy Information Administration (EIA) was searched to identify the end uses of natural gas in the residential and commercial sectors,[27] and the following key terms were identified and used to guide the literature review:

1. residential methane emissions end use
2. commercial methane emissions end use
3. residential methane leaks end use
4. commercial methane leaks end use
5. methane emissions from
    - cooking
    - furnaces
    - water heaters
    - refrigeration
    - drying clothes

The results of the literature review are presented in Table A-3 and Table A-4 and were used to develop the beyond-the-meter methane emission estimation methods for residential appliances (section 3.2.7.3), residential buildings (section 3.2.7.4), and commercial buildings (hospitals and restaurants; section 3.2.7.5). Due to a lack of available data, emissions were not estimated for residential refrigeration or clothes driers or for many commercial building types. The addition of these appliances and building types has been identified as an area for future improvement. The addition of these beyond the meter sources increased the overall emissions in the oil and natural gas sector inventory by 9% over the 2017 inventory estimate (5% from residential buildings, 2.2% from residential appliances, and 1.8% from commercial buildings).

Table A-3. Literature Review of Beyond-the-Meter Emissions: Results Containing Emissions Factors

Author	Year	Title	Summary	Appliance(s) Covered	Emissions	Geography
Hong & Howarth	2016	Greenhouse gas emissions from domestic hot water: heat pumps compared to most commonly used systems	EF for residential NG tankless and storage water heaters estimated to be 0.82 to 4.02 kg/GJ water heated. The EF is a lifecycle emissions factor and includes emissions before the meter.	tankless water heaters storage water heaters	0.82 to 4.02 kg/GJ of water heated	U.S.
Fischer et al.	2018	An estimate of natural gas methane emissions from California homes	Post meter methane emissions from residential natural gas are estimated using measurements from a sample of homes (75 single family homes) and appliances. Whole house emissions are typically less than 1 g CH_4/day. The authors estimate that methane emissions from residential natural gas are 35.7 Gg/yr.	post-meter	<1 g CH_4/day/housing unit	California
Merrin & Francisco	2019	Unburned methane emissions from residential natural gas appliances	EF = 0.38 g/kg of NG consumed for US residential appliances. Calculates total methane emissions and methane emissions per year for each appliance (furnace, boiler, water heater, tankless water heater, stove, oven).	furnace boiler storage water heater tankless water heater stove oven	furnace = 0.22 kg/appliance boiler = 0.32 kg/appliance storage water heater = 0.077 kg/appliance tankless water heater = 1.2 kg/appliance stove = 0.066 kg/appliance oven = 0.13 kg/appliance	72 sites in Boston and Indianapolis and 28 sites in IL and NY
Lebel	2020	Quantifying methane emissions from natural gas water heaters	Examined water heaters from 64 northern California homes. Tankless water heaters emitted 2.39 kg CH_4/yr and storage water heaters emitted 1.40 kg CH_4/yr. U.S. emissions from water heaters are estimated to be 82.3 Gg CH_4/yr.	storage water heaters tankless water heaters	storage water heaters = 1.40 kg/unit/yr tankless water heaters = 2.39 kg/unit/yr	California
Saint-Vincent & Pekney	2020	Beyond the meter: Unaccounted sources of methane emissions in the natural gas distribution sector	Estimates that residential homes and appliances could release 9.1 Gg CH_4/year, with furnaces being the most leak-prone appliance. Reports an EF of 4.1 kg/TJ for the furnaces in the US based on the Merrin & Francisco paper. EFs from other countries: 4.3 kg CH_4/TJ consumed (UK heating units or furnaces), 2.3 kg CH_4/TJ consumed (Germany furnaces), 4.5 kg CH_4/TJ consumed (Japan furnaces), 1 kg CH_4/TJ consumed (Switzerland). Type of furnace, efficiency, furnace technology, and age may affect EFs. Mentions that Hong and Howarth (summarized above) calculated an EF for residential NG tankless and storage water heaters to be between 0.60 and 4.02 kg/GJ.	furnaces	4.1 kg/TJ NG consumed	U.S.

Table A-4. Literature Review Results Containing Activity Data

Author	Year	Title	Summary	Activity Data	Geography
EIA	2018	2015 Residential Energy Consumption Survey (RECS) Survey Data	Survey data provides information on the appliances used by households, including stoves, ovens, water heaters, furnaces, and boilers. Data are also included on end-use consumption by fuel in the U.S. and in the Northeast for space heating, water heating, air conditioning, refrigerators, and other. More detailed consumption data provides the site energy consumption of natural gas space heating, water heating, clothes dryers, cooking, pool heaters, and hot tub heaters in the Northeast. There are also housing characteristics tables.	Counts and consumption of appliances by fuel type in the Northeast	Northeast, Mid-Atlantic
EIA	2016	2012 Commercial Building Energy Consumption Survey (CBECS) Survey Data	Survey data provides information on building characteristics and consumption and expenditures in the United States.	Natural gas consumption by census region and number of building end-use appliances	U.S., some data tables by census region
EIA	2019	Use of natural gas	Identifies specific end uses (i.e., using natural gas for heating buildings and water, for drying clothes, to operate refrigeration and cooling equipment, for outdoor lighting).	N/A	U.S.
NYSERDA	2019	Single-Family Building Assessment–Residential Building Stock Assessment	Provides a profile of new and existing homes in NYS based on data from a representative sample of homes and reports changes in building and equipment stock since the 2015 RSBS, including changes in the saturation of energy- consuming equipment (electric, natural gas, and other fuels), building characteristics, and energy management practices. The RBSA also collected customer household and demographic information.	Counts of single-family homes by climate zone	New York State
U.S. Census Bureau	2018	Annual estimates of county housing units for States: 2010–2018	Provides total number of housing units by county.	Counts of housing units by county	New York State

A.3.3 Global Warming Potential

The current inventory calculates emissions using AR5 GWP_{20}, as required by the Climate Act, while the previous iteration used AR4 GWP_{100}.

A.3.4 Updates to Conventional Production Emissions Factors

The 2017 New York State Oil and Gas Sector Methane Emissions Inventory (NYSERDA, 2019) used the 25th percentile emissions factors from Omara et al. (2016). These were updated to the median emissions factors for the 2020 New York State Oil and Gas Sector Methane Emissions Inventory to be consistent with the out-of-state Oil and Gas methane inventory (NYSERDA 2021). Table A-5 summarizes these emissions factor changes. These updates resulted in a 13% increase in overall emissions from the oil and gas sector (from 12,482,204 to 14,104,891 $MMTCO_2e$).

Table A-5. Comparison of Emissions Factors Used in the 2017 Inventory and in the Updated 2020 Inventory

Source	Original EF	Updated EF	Units	Source
Oil Well: Conventional Production	9.4	25.4	% of throughput	≤ 10 MSCFD (top) > 10 MSCFD (bottom) Omara et al (2016)
	4.1	7.2		
Gas Well: Conventional Production	9.4	25.4	% of throughput	≤ 10 MSCFD (top) > 10 MSCFD (bottom) Omara et al (2016)
	4.1	7.2		
Oil Well: Unconventional Production	0.1	0.15	% of throughput	≤ 10,000 MSCFD (top) > 10,000 MSCFD (bottom) Omara et al (2016)
	0.018	0.03		
Gas Well: Unconventional Production	0.1	0.15	% of throughput	≤ 10,000 MSCFD (top) > 10,000 MSCFD (bottom) Omara et al (2016)
	0.018	0.03		

A.3.5 Results of 2020 Updates

Table A-6 below compares emissions for 2015, the common year across all three inventories, from the first New York State Greenhouse Gas Inventory, 1990–2015 to the first iteration of the New York State Oil and Gas Sector Methane Emissions Inventory, 1990-2017 and the second iteration of the New York State Oil and Gas Sector Methane Emissions Inventory, 1990-2020.

Table A-6. Comparison of Emissions in Key Inventory Years with AR4 and AR5 GWP_{100} and GWP_{20} Values Applied from the Three Inventories

Inventory	AR4 GWP_{100}	AR4 GWP_{20}	AR5 GWP_{100}	AR5 GWP_{20}
1990				
New York State Greenhouse Gas Inventory, 1990–2015	2.8	8.06	3.14	9.41
New York State Oil and Gas Methane Emissions Inventory, 1990-2017	2.74	7.88	3.07	9.21
New York State Oil and Gas Methane Emissions Inventory, 1990-2020	5.17	14.89	5.80	17.40
2005				
New York State Greenhouse Gas Inventory, 1990–2015	3.5	10.07	3.93	11.76
New York State Oil and Gas Methane Emissions Inventory, 1990-2017	3.52	10.12	3.95	11.83
New York State Oil and Gas Methane Emissions Inventory, 1990-2020	6.15	17.72	6.93	20.73
2015				
New York State Greenhouse Gas Inventory, 1990–2015	2.22	6.39	2.49	7.46
New York State Oil and Gas Methane Emissions Inventory, 1990-2017	2.82	8.12	3.16	9.48
New York State Oil and Gas Methane Emissions Inventory, 1990-2020	4.74	13.65	5.31	15.92

In the first iteration of the NYS Oil and Gas Methane Emissions Inventory, 2017 emissions totaled 2,664,182 $MTCO_2e$ (AR4 GWP_{100}), or 8,951,651 $MTCO_2e$ (AR5 GWP_{20}). The second iteration of the inventory estimates total emissions of 14,701,916 $MTCO_2e$ in 2017. Thus, the improvements made to the inventory between the first and second iteration resulted in an emissions increase of 64%.

A.4 2015 Methane Emissions Inventory Assessment

A.4.1 Summary

The 2015 New York State Greenhouse Gas (GHG) Inventory (NYSERDA and DEC 2018) provides estimates of CH_4 emissions across various sectors and activities in the State, including emissions from the oil and natural gas sector. This section of the report provides an assessment of the CH_4 estimate from New York State's 2015 GHG Inventory on oil and gas systems, drawing on recent literature to identify areas in which the inventory can be improved to more accurately account for CH_4 emissions using the latest science and activity data. The opportunities for the greatest improvement center around four key areas as follows:

- Applying a more detailed BU activity-based analysis, with validation from top-down (TD) studies.
- Using emission factors (EFs) for activities within the oil and natural gas sector, informed by the peer-reviewed literature and studies most applicable to the equipment in place in wells and geographic regions of New York State.
- Including uncertainty analysis to provide a range of possible emissions, with special consideration of high-emitting sources, sometimes referred to as super-emitters.
- Presenting the inventory using at least two different global warming potential (GWP) calculations (GWP100 and GWP_{20}, i.e., global warming potential for 100 years and 20 years, respectively).

These improvements are discussed below in more detail. Appendix A.3.4 provides information on the State's original CH_4 inventory approach and the weaknesses inherent in that approach. Appendix A.3.5 provides information on alternative approaches and tools used by the federal government or other states to enhance CH_4 inventory development.

The assessment of the original 2015 inventory included an analysis of key research and data gaps as well as cataloging emission source types applicable to New York State. To the extent possible, the assessment documents information on the potential relative contribution of emission source types to overall fugitive CH_4 emissions. The assessment is informed by the following questions:

- What types of sources are not taken into account?
- Are some missing sources insignificant and therefore reasonable to exclude?
- Which sources create the biggest environmental impacts?
- What data quality issues exist for each data source?
- Are there ways to improve the resolution of the analysis to demonstrate the effects that State policies (such as changes to flaring or well plugging) might have on actual CH_4 emissions?

The literature review linked with the assessment and included an evaluation of how existing annual emission accounting methodologies could incorporate the results of new scientific studies of fugitive CH_4 emissions. For example, one question informing the literature review was how standardized inventories best account for the non-normal distribution of emissions resulting from high-emitting sources (i.e., "super-emitters"). The CH_4 emission accounting methodology and associated emission inventory for oil and natural gas activities in New York State developed during the first iteration of this project for the 2017 New York State Oil and Gas Sector Methane Emissions Inventory were derived using bottom-up (BU) best practices and best available data identified from the assessment and literature review.

A.4.2 Relevant Inventory Products

Repeated reference is made throughout the report to a few select inventory products. As a convenience to the reader, Table A-7 provides an overview of and reference to these products.

Table A-7. Glossary of Relevant Inventory Products

EPA Greenhouse Gas Reporting Program (GHGRP): This program collects GHG data from self-reporting facilities with emissions of 25,000 tons of carbon dioxide equivalent (CO_2e) each year. Subpart W of the GHGRP specifically covers CH_4 emissions from 10 segments in the petroleum and natural gas industry (EPA 2017).
New York State Greenhouse Gas Inventory, 1990–2015: The 2018 iteration of the New York State Greenhouse Gas Inventory contains estimated emissions up to 2015 (NYSERDA and DEC 2018).
U.S. Greenhouse Gas Emissions and Sinks, 1990–2016: This document provides an overview of U.S. GHG emissions, including CH4 emissions from oil and natural gas systems (EPA 2018a).
United States Environmental Protection Agency (EPA) Nonpoint Oil and Gas Emission Estimation Tool: The EPA Nonpoint Oil and Gas Emission Estimation Tool (Oil and Gas Tool) contains information used to develop a nonpoint (i.e., originating from many diffuse sources) source emissions inventory for upstream oil and natural gas activities across the 54 source categories (EPA 2014).
EPA State Inventory and Projection Tool (SIT): The Natural Gas and Oil Module of the EPA tool, SIT, contains data updated to include 2016, which allows states to independently develop state-level emission inventories, and covers CH_4 and carbon dioxide (CO_2) emissions from natural gas and petroleum systems.

A.4.3 Project Advisory Committee

To ensure project success, a Project Advisory Committee (PAC) was established to provide technical oversight and peer review throughout the duration of the project. The PAC consisted of six voluntary members with knowledge on air pollutant emissions from the oil and natural gas sector. Each member's name, affiliation, and title are presented in Table 1.

Committee Member	Affiliation	Title
Cynthia McCarran	New York State Department of Public Service	Deputy Director, Office of Electric, Gas, and Water
Catherine Dickert	New York State Department of Environmental Conservation	Director of Mineral Resources
Kevin Speicher	New York State Department of Public Service	Chief, Natural Gas and Hazardous Liquid Pipeline Safety
Ona Papageorgiou	New York State Department of Environmental Conservation	Environmental Engineer
David Lyon	Environmental Defense Fund	Scientist
Jennifer Snyder	U.S. Environmental Protection Agency	Environmental Engineer

The PAC served as advisors to the research team, its members actively contributing their expertise and knowledge in the oil and natural gas sector. The research team relied on the PAC's input to help ensure that the project remained scientifically rigorous and accurate and that deliverables fulfilled the project objectives. During the course of this project, three meetings were held with the PAC to solicit feedback on the draft inventory and this report. In addition, the research team routinely reached out to PAC members for guidance on CH4 emission inventory development. New York State Energy Research and Development Authority (NYSERDA) would like to thank the PAC members for their valuable contributions throughout this project.

The project also received support and guidance from Dr. Anthony Marchese, Professor of Mechanical Engineering at Colorado State University and an expert in CH4 emissions derived from the oil and natural gas sector.

A.4.4 New York State's 2015 Methane Inventory: Approach and Weaknesses

The State's approach to quantifying CH_4 emissions from the oil and natural gas sector represents a simplified throughput-based, aggregated approach (Allen 2014, 2016) that relies on national CH_4 inventory estimates combined with State and national-level natural gas consumption data (NYSERDA and DEC 2018). As reflected in the inventory calculation spreadsheet (provided by NYSERDA), New York State takes the ratio of State-to-national natural gas use and multiplies that by total U.S. CH_4 emissions from the natural gas sector [as reported by the EPA in its national GHG Inventory report (EPA 2018b)] to quantify State emissions. The formula used is described in Equation 1.

Equation 1 $\boldsymbol{E_{NY} = E_{US} \cdot \frac{NG_{NY}}{NG_{US}}}$

where:

- ENY represents the CH_4 emissions from the State's natural gas systems in million metric
- tons of CO_2 equivalents (MMTCO_2e).
- EUS represents the CH_4 emissions from the national natural gas system as estimated by
- the EPA in its national GHG Inventory in MMTCO_2e.
- NGNY represents the amount of gas consumption in New York State in Bcf.
- NGUS represents the amount of gas consumption in the nation in Bcf, as reported by
- the U.S. Department of Energy's EIA.

The above methodology was applied in the State inventory to natural gas consumption. EIA statistics[28] and data from the State Energy Data System (SEDS)[29] show that total nationwide natural gas consumption in 2015 was 27,244 Bcf. SEDS reports New York State natural gas consumption in 2015 was 1,353 Bcf.

Therefore, the NG_{NY}/NG_{US} consumption ratio used to scale national emissions was 4.97% (i.e., 1,353 Bcf/27,244 Bcf). EPA (2018a) estimates that 2015 emissions from the entire natural gas supply chain to be 46.1 $MMTCO_2e$. Using the NG_{NY}/NG_{US} consumption ratio yields an estimate of 2.29 $MMTCO_2e$ for the State in 2015. (Note that this estimate differs from the published estimate of 2.22 $MMTCO_2e$ due to EPA revisions to transmission, storage, and distribution emissions.)

Discrepancies between data reported by EPA's national inventory, using data from the GHGRP and other sources, and the New York State inventory are explained by differences in the methodologies underlying the two inventories. The EPA inventory applies BU, activity-based methods, to estimate nationwide emissions; while the State inventory uses a scaling factor, based on consumption comparisons, to adjust the national inventory to the State. As such, any underlying differences in ratios of upstream, midstream, and downstream emissions are unaccounted for, as the methodology assumes New York State.

State is essentially a scaled-down version of the whole country. In comparison, CH_4 emissions from EPA's GHGRP (reported in Envirofacts) estimate total New York State petroleum and natural gas system emissions accounted for 1.334 $MMTCO_2e$. The EPA GHGRP reporting requirements include GHG emissions from sources emitting 25,000 $MTCO_2e$ each year in 41 categories.[30] GHGRP Subpart W outlines petroleum and natural gas system reporting requirements and methodology but does not include a number of sectors in the petroleum and natural gas system, including transmission and distribution pipelines, and customer meters. As such, the GHGRP covers many of the largest sources of emissions but does not address emissions from smaller emission sources and does not cover all segments in the petroleum and natural gas system.

The approach used by New York State had its benefits. The calculations were straightforward, and the approach was transparent. However, there were at least three drawbacks to the original approach used for the 2015 inventory:

- New York State's simplified approach does not account for potentially unique aspects of the State's oil and natural gas sector; instead, it scales national emissions by consumption, an approach that may overestimate or underestimate the actual emissions. For example, unlike other states, New York State does not currently allow HVHF. This will distort EFs as HVHF has been shown to have higher per-well CH_4 emissions than other methods. As another example, data from EPA's GHGRP Subpart W indicate that 93.6% of CH4 emissions in New York State originate from local natural gas distribution companies, with 4.0% from transmission and compression and 2.3% from underground natural gas storage. These differ from EPA's reported national averages that show 16% of emissions originating from distribution, 27% from transmission and storage, 11% from processing, and 46% from production.

- Because the approach is highly aggregated and is not resolved by either component-level or geography, the State loses the opportunity to more precisely target its CH_4 reduction policies and programs.
- The approach does not account for the uncertainty inherent in EFs and activity data.

Without addressing these and other concerns, New York State would be challenged to accurately assess CH4 emissions, emission changes in the State, and the impacts of reduction measures under such programs as the Methane Reduction Plan (DEC 2017) and the Climate Act. For these reasons, New York State moved to a BU, activity-driven, component-level CH4 emissions inventory using State-specific data.

A.4.5 Best Practices for State Methane Inventory Development

The following section identifies a number of widely applied inventory tools developed by the EPA that can provide guidance on best practices for estimating emissions. These tools include EPA's SIT, GHGRP, and Oil and Gas Tool. The tools were referenced to improve first New York State Greenhouse Gas Inventory (1990–2015) and develop the New York State Oil and Gas Sector Methane Emissions Inventory (1990–2017) and the second iteration of the New York State Oil and Gas Sector Methane Emissions Inventory (1990 –2020).

A.4.6 EPA's State Inventory Tool

There is no single best approach for conducting statewide CH_4 inventories for the oil and natural gas sector; however, some guidance does exist (Blackhurst et al. 2011). That guidance includes the use of consistent reporting categories, disaggregating segments, incorporating uncertainty and variability, and establishing benchmarks against which future inventories and emission reduction plans may be judged.

The EPA has provided some state-level tools that capture important elements of this sector through its SIT[31], which includes a Natural Gas and Oil Module. The SIT is used by a number of states to generate state-level GHG inventories, including all states that border New York State (Connecticut, New Jersey, Massachusetts, Pennsylvania, Rhode Island, and Vermont).

The Natural Gas and Oil Module of the SIT collects information on EFs for natural gas production and distribution sources as shown in Table 3. The EPA SIT focuses on five primary areas related to the natural gas supply chain: (1) production, (2) transmission and storage, (3) distribution pipeline, (4) distribution services, and (5) venting and flaring. See Figure 13 for an image of the natural gas supply chain.

With respect to uncertainty analysis, the SIT specifies the following:

> The main sources of uncertainty…relate to the emission factors… Statistical uncertainties arise from natural variation in measurements, equipment types, operational variability and survey and statistical methodologies. The main emission factor…is determined by bundling together the factors of several individual components and sources. In the process of aggregation, the uncertainties of each individual component get pooled to generate a larger uncertainty for the simplified emission factor.

The SIT goes on to suggest that the approach taken to estimate EFs is "relatively accurate" at the national level but may be different at the state level. Thus, one of the primary recommendations from the assessment is for New York State to invest in collecting better EF data at the State level.

Table A-9. Source Categories and Default EFs from the EPA SIT for Oil and Natural Gas Systems in New York State

Source: https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-mileage-and-facilities and EPA SIT Oil and Natural Gas Systems Module

Source Category	Source Type	Default EF	EF Units (2015)
Petroleum Systems	Oil production	453.5	kg CH_4 1,000 bbl^{-1} yr^{-1}
	Oil refining	4.33	kg CH_4 1,000 bbl^{-1} yr^{-1}
	Oil transportation	3.88	kg CH_4 1,000 bbl^{-1} yr^{-1}
Natural Gas Production	Onshore wells	4.10	$MTCH_4$ $well^{-1}$ yr^{-1}
Gathering and Processing	Gathering pipeline	0.4	$MTCH_4$ $mile^{-1}$ yr^{-1}
Natural Gas Processing	Gas processing plant	1,249.95	$MTCH_4$ $plant^{-1}$ yr^{-1}
LNG Storage	Liquefied natural gas (LNG) storage compressor stations	1,184.99	$MTCH_4$ $plant^{-1}$ yr^{-1}
Natural Gas Transmission	Transmission pipeline	0.62	$MTCH_4$ $mile^{-1}$ yr^{-1}
	Gas transmission compressor stations	983.66	$MTCH_4$ $station^{-1}$ yr^{-1}
Natural Gas Storage	Gas storage compressor stations	964.15	$MTCH_4$ $station^{-1}$ yr^{-1}
Natural Gas Distribution Pipeline	Cast-iron distribution pipeline	5.80	$MTCH_4$ $mile^{-1}$ yr^{-1}
	Unprotected steel distribution pipeline	2.12	$MTCH_4$ $mile^{-1}$ yr^{-1}
	Protected steel distribution pipeline	0.06	$MTCH_4$ $mile^{-1}$ yr^{-1}
	Plastic distribution pipeline	0.37	$MTCH_4$ $mile^{-1}$ yr^{-1}
	Total miles of distribution pipeline (alternative)	0.54	$MTCH_4$ $mile^{-1}$ yr^{-1}
Natural Gas Distribution Services	Total number of services	0.02	$MTCH_4$ $service^{-1}$ yr^{-1}
	Number of unprotected steel services	0.03	$MTCH_4$ $service^{-1}$ yr^{-1}
	Number of protected steel services	0.003	$MTCH_4$ $service^{-1}$ yr^{-1}
Natural Gas Venting and Flaring	Amount of natural gas vented	0	$MTCH_4$ $BBTU^{-1}$ yr^{-1}
	Percent of vented natural gas flared	80	Percent

A.4.7 Greenhouse Gas Reporting Program: Subpart W Calculation Tool

EPA’s GHGRP, Subpart W for Petroleum and Natural Gas Systems, collects data from owners or operators of petroleum and natural gas systems that emit greater than 25,000 $MTCO_2e$ of GHGs per year. Owners and operators collect GHG data and estimate emissions using the Subpart W Calculation Tool, which are then reported to EPA’s GHGRP and made available through EPA’s Facility Level Information on Greenhouse Gases Tool (FLIGHT; EPA 2018b) and Envirofacts.

Subpart W provides a more detailed framework for emissions estimation compared to the SIT, including estimated emissions from equipment components such as valves, flanges, and connectors. Subpart W uses two methodologies for determining EFs: (1) Non-Method 21 factors and (2) Method 21 factors. Method 21 is an EPA protocol for monitoring specific volatile organic compounds (VOCs), including CH_4, from process equipment using portable instrumentation. It should be noted that many of Subpart W EFs are derived from older studies.

By evaluating the activity data and EFs associated with Subpart W reporting, one can begin to understand the advantages that a more detailed inventory can provide. Using Subpart W-type reporting, states can identify those specific areas of the oil and natural gas production, processing, transmission, storage, and distribution systems that have the greatest impact on the emissions inventory. This allows states to target policies and programs specifically to those areas. A more detailed description of the Subpart W methodology is provided in appendix A, along with a breakdown of Subpart W EFs for natural gas systems in the eastern United States. The Subpart W oil and natural gas sector reporting facilities for New York State for 2016 are shown in Figure 10 and Table 4. Emissions reported by facilities emitting greater than 25,000 $MTCO_2e$ per year in the State show that local distribution companies account for 93.6% of CH_4 emissions reported, transmission compressor stations account for 4%, and natural gas storage 2.3%.

Figure A-2. Oil and Natural Gas Facilities Reporting to Subpart W in 2017

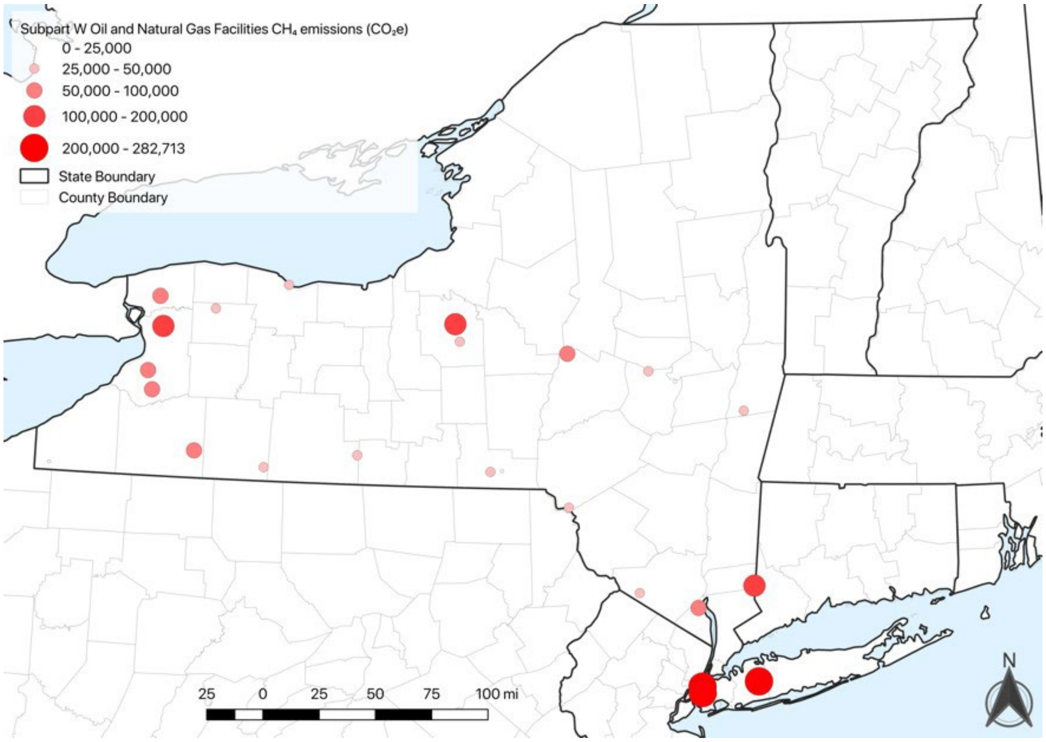


Table A-10. List of All Facilities Reporting for 2016 under Subpart W

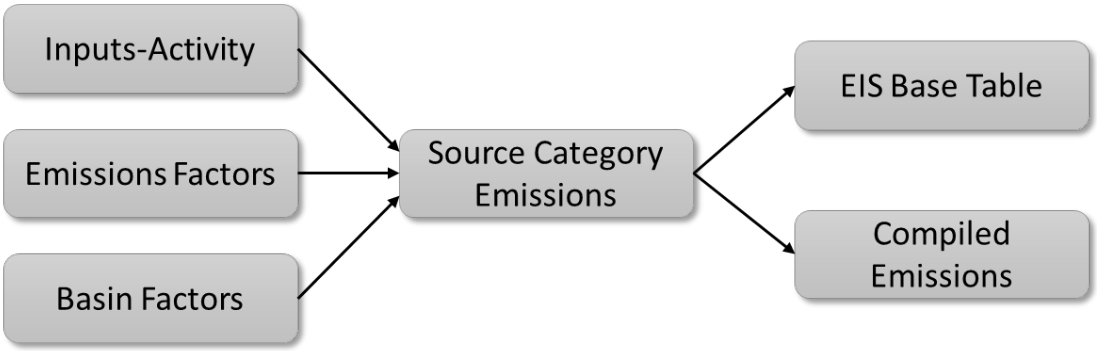
Table Shows Name, City, and County Location and Total CH_4 Emissions [metric ton (MT) CO_2e]

Year	Facility Name	City Name	County Name	CH_4 Emissions ($MTCO_2e$)
2016	Con Edison Natural Gas Delivery System	New York	New York	244,810
2016	Central Hudson Gas and Electric Corp.	Poughkeepsie	Dutchess	26,002
2016	Empire Oakfield Station	Oakfield	Genesee	1,732
2016	Hancock Compressor Station	Hancock	Delaware	2,063
2016	Iroquois Gas Wright Compressor Station	Delanson	Schoharie	2,971
2016	Keyspan Gas East Corporation	Hicksville	Nassau	286,080
2016	Minisink Compressor Station	Westtown	Orange	1,931
2016	Millennium Pipeline Company Compressor	Corning	Steuben	729
2016	NFGSC Concord Station	Springville	Erie	21,141
2016	NFGSC Hinsdale Station	Hinsdale	Cattaraugus	3,186
2016	NFGSC Independence Station	Andover	Allegany	26,512
2016	Niagara Mohawk Power Corporation	Syracuse	Onondaga	201,123
2016	National Fuel Gas Distribution Corporation	Williamsville	Erie	183,614
2016	New York State Electric and Gas	Binghamton	Broome	41,813
2016	Rochester Gas & Electric Corp.	Rochester	Monroe	36,520
2016	Southeast	Brewster	Putnam	4,943
2016	Stony Point	Stony Point	Rockland	3,949
2016	TGP Station 229 Hamburg	Eden	Erie	4,515
2016	TGP Station 230, Lockport Compressor	Lockport	Niagara	1,643
2016	TGP Station 241 Lafayette	Lafayette	Onondaga	2,791
2016	TGP Station 245 West Winfield	West Winfield	Herkimer	2,673
2016	TGP Station 249 Carlisle	Carlisle	Schoharie	2,507
2016	TGP Station 254 Nassau	Nassau	Rensselaer	1,600
2016	The Brooklyn Union Gas Company	Brooklyn	Kings	229,246
			Total	**1,334,094**

A.4.8 EPA Oil and Gas Tool

The EPA's Oil and Gas Tool (EPA 2014) contains information used to develop a nonpoint source (i.e., originating from many diffuse sources) emissions inventory for upstream oil and natural gas activities across the 54 source categories listed in Table 5. The basic concept of the tool is to calculate the source category emissions using activity data, EFs, and basin factors (i.e., basin-level EFs). A conceptual flow is presented in Figure A-3.

Figure A-3. Conceptual Flowchart of EPA's Oil and Gas Tool



The Oil and Gas Tool is a Microsoft Access®-based tool used to generate county-level emission estimates of criteria and hazardous air pollutants (HAP). The Oil and Gas Tool was developed for state, local, and tribal agencies to help estimate criteria air pollutants (CAP) and HAP for submission to the EPA for use in the National Emissions Inventory (NEI). Though the Oil and Gas Tool was not specifically developed for GHGs, it does include EFs for CH_4 and other GHG sources. States are able to adjust EFs and data submitted to the NEI, which can also be reflected in GHG EFs. At present the EFs included for CH_4 in the Oil and Gas Tool reflect default factors developed by Environ for the Central States Air Resource Agencies (CenSARA) in 2012 (CenSARA 2012), and thus are not New York State-specific. The user is able to use pre-populated values or manually specify the geographic region, source categories, basin-level gas factors, EFs, and activity adjustments.

Like Subpart W, the Oil and Gas Tool provides a more detailed framework for BU, activity-based estimation of CH_4 emissions from oil and gas sources in the State. Using EFs from the Oil and Gas Tool and Subpart W, New York State can develop a detailed activity-based BU inventory of CH_4 emissions from oil and natural gas activities.

Default Oil and Gas Tool CH_4 EFs from natural gas operations in the State are shown in Table 6. The Oil and Gas Tool identifies EFs for every basin, county, and state in the U.S. For New York State, the CH_4 EFs for oil and natural gas are constant across basins, and in fact reflect default EFs for the tool derived from the CenSARA 2012 study. The Oil and Gas Tool lists EFs by activity, source category, and component, including emissions using different control devices/methods.

Table A-11. List of Sources Included in EPA's Oil and Gas Tool

Activity	Source Category	Source Classification Code (SCC)	SCC Description
Exploration	Drill Rigs	2310000220	Oil and Gas Exploration Drill Rigs
Exploration	Hydraulic Fracturing	2310000660	Oil & Gas Expl & Prod/All Processes/Hydraulic Fracturing Engines
Exploration	Mud Degassing	2310023606	On-Shore Coal Bed Methane (CBM) Exploration/Mud Degassing
Exploration	Mud Degassing	2310111100	On-Shore Oil Exploration/Mud Degassing
Exploration	Mud Degassing	2310121100	On-Shore Gas Exploration/Mud Degassing
Exploration	Well Completions	2310023600	On-Shore CBM Exploration: CBM Well Completion: All Processes
Exploration	Well Completions	2310111700	On-Shore Oil Exploration: Oil Well Completion: All Processes
Exploration	Well Completions	2310121700	On-Shore Gas Exploration: Gas Well Completion: All Processes
Production	Artificial Lifts	2310000330	Oil & Gas Expl & Prod/All Processes/Artificial Lift
Production	Associated Gas	2310011000	On Shore Crude Oil Production All Processes
Production	Condensate Tanks	2310021010	On-Shore Gas Production/Storage Tanks: Condensate
Production	Condensate Tanks	2310023010	On-Shore CBM Production/Storage Tanks: Condensate
Production	Crude Oil Tanks	2310010200	Oil & Gas Expl & Prod/Crude Petroleum/Oil Well Tanks Flashing & Standing/Working/Breathing
Production	Dehydrators	2310021400	On-Shore Gas Production Dehydrators
Production	Dehydrators	2310023400	Coal Bed Methane NG Dehydrators
Production	Fugitives	2310011501	On-Shore Oil Production/Fugitives: Connectors
Production	Fugitives	2310011502	On-Shore Oil Production/Fugitives: Flanges
Production	Fugitives	2310011503	On-Shore Oil Production/Fugitives: Open Ended Lines
Production	Fugitives	2310011505	On-Shore Oil Production/Fugitives: Valves
Production	Fugitives	2310021501	On-Shore Gas Production/Fugitives: Connectors
Production	Fugitives	2310021502	On-Shore Gas Production/Fugitives: Flanges
Production	Fugitives	2310021503	On-Shore Gas Production/Fugitives: Open Ended Lines
Production	Fugitives	2310021505	On-Shore Gas Production/Fugitives: Valves
Production	Fugitives	2310021506	On-Shore Gas Production/Fugitives: Other

Table A-11 continued

Activity	Source Category	Source Classification Code (SCC)	SCC Description
Production	Fugitives	2310023511	On-Shore CBM Production/Fugitives: Connectors
Production	Fugitives	2310023512	On-Shore CBM Production/Fugitives: Flanges
Production	Fugitives	2310023513	On-Shore CBM Production/Fugitives: Open Ended Lines
Production	Fugitives	2310023515	On-Shore CBM Production/Fugitives: Valves
Production	Fugitives	2310023516	On-Shore CBM Production/Fugitives: Other
Production	Gas-Actuated Pumps	2310023310	Coal Bed Methane NG Pneumatic Pumps
Production	Gas-Actuated Pumps	2310111401	On-Shore Oil Exploration/Oil Well Pneumatic Pumps
Production	Gas-Actuated Pumps	2310121401	On-Shore Gas Exploration: Gas Well Pneumatic Pumps
Production	Heaters	2310010100	On-Shore Oil Production/Heater Treater
Production	Heaters	2310021100	On-Shore Gas Production/Gas Well Heaters
Production	Heaters	2310023100	On-Shore CBM Production/CBM Well Heaters
Production	Lateral/Gathering Compressor Engines	2310021251	On-Shore Gas Production/Lateral Compressors 4 Cycle Lean Burn
Production	Lateral/Gathering Compressor Engines	2310021351	On-Shore Gas Production/Lateral Compressors 4 Cycle Rich Burn
Production	Lateral/Gathering Compressor Engines	2310023251	On-Shore CBM Production/Lateral Compressors 4 Cycle Lean Burn
Production	Lateral/Gathering Compressor Engines	2310023351	On-Shore CBM Production/Lateral Compressors 4 Cycle Rich Burn
Production	Liquids Unloading	2310021603	On-Shore Gas Production Gas Well Venting Blowdowns
Production	Liquids Unloading	2310023603	Coal Bed Methane NG Venting Blowdowns
Production	Loading Emissions	2310011201	On-Shore Oil Production/Tank Truck/Railcar Loading: Crude Oil
Production	Loading Emissions	2310021030	On-Shore Gas Production/Tank Truck/Railcar Loading: Condensate
Production	Loading Emissions	2310023030	On-Shore CBM Production/Tank Truck/Railcar Loading: Condensate
Production	Pneumatic Devices	2310010300	Oil Production Pneumatic Devices

Table A-11 continued

Activity	Source Category	Source Classification Code (SCC)	SCC Description
Production	Pneumatic Devices	2310021300	On-Shore Gas Production Pneumatic Devices
Production	Pneumatic Devices	2310023300	On-Shore CBM Production Pneumatic Devices
Production	Produced Water	2310000550	Produced Water
Production	Wellhead Compressor Engines	2310021102	On-Shore Gas Production/Natural Gas Fired 2Cycle Lean Burn Compressor Engines 50 to 499 HP
Production	Wellhead Compressor Engines	2310021202	On-Shore Gas Production/Natural Gas Fired 4Cycle Lean Burn Compressor Engines 50 to 499 HP
Production	Wellhead Compressor Engines	2310021302	On-Shore Gas Production/Natural Gas Fired 4Cycle Rich Burn Compressor Engines 50 to 499 HP
Production	Wellhead Compressor Engines	2310023102	On-Shore CBM Production/CBM Fired 2Cycle Lean Burn Compressor Engines 50 to 499 HP
Production	Wellhead Compressor Engines	2310023202	On-Shore CBM Production/CBM Fired 4Cycle Lean Burn Compressor Engines 50 to 499 HP
Production	Wellhead Compressor Engines	2310023302	On-Shore CBM Production/CBM Fired 4 Cycle Rich Burn Compressor Engines 50 to 499 HP

Table A-12. New York State CH_4 EFs from EPA Oil and Gas Tool

Source: CenSARA (2012)

Activity	Source Category	Component/Activity	EF	Unit	Control Status	Control Device
Oil and Gas Exploration and Production	Artificial Lifts	Artificial Lift	0.834624	g/hp-hr	0	Uncontrolled
	Crude Oil Tanks	Oil Well Tanks—Flashing & Standing/Working/Breathing	0.04	Pound (Lb)/million British thermal unit (MMBTU)	1	Flare
On-Shore Gas and CBM Production	Condensate Tanks	Storage Tanks: Condensate	0.04	Lb/MMBTU	1	Flare
	Dehydrators	Dehydrators	0.04	Lb/MMBTU	1	Flare
			2.3	Lb/Mcf-s	0	Flare
	Fugitives[a]	Connectors	-	kilogram (kg)/component	0	Uncontrolled
		Flanges	-	kg/component	0	Uncontrolled
		Open Ended Lines	-	kg/component	0	Uncontrolled
		Valves	-	kg/component	0	Uncontrolled
		Other	-	kg/component	0	Uncontrolled
	Heaters	Heater Treater	2.3	Lb/Mcf-s	0	Uncontrolled
	Lateral/Gathering Compressor Engines	Lateral Compressors 4 Cycle Lean Burn	4.536	gram (g)/horsepower hour (hp-hr)	0	Catalytic Oxidizer
		Lateral Compressors 4 Cycle Rich Burn	0.834624	g/hp-hr	0	Selective non-catalytic reduction (SNCR)
	Liquids Unloading	Gas Well Venting—Blowdowns	0.04	Lb/MMBTU	0	Uncontrolled
	Wellhead Compressor Engines	Natural Gas Fired 2 Cycle Lean Burn Compressor Engines 50 to 499 hp	5.261644	g/hp-hr	0	Catalytic Oxidizer
		Natural Gas Fired 4 Cycle Lean Burn Compressor Engines 50 to 499 hp	4.536	g/hp-hr	0	Catalytic Oxidizer
		Natural Gas Fired 4 Cycle Rich Burn Compressor Engines 50 to 499 hp	0.834624	g/hp-hr	0	SNCR

[a] No EFs are provided for fugitive emissions since the Oil and Gas Tool calculates fugitive emissions using pollutant ratios.

A.5 Integrating Best Practices into the New York State Methane Inventory

This section builds on appendix A.3 to propose a new model for New York State that includes more precise activity data, EFs, geospatial issues, and uncertainty analysis (including the issue of high-emitting sources).

A.5.1 Best Practices

The original New York State approach for constructing the statewide CH_4 inventory had its limitations. Although the nature of the highly aggregated, sectoral, analysis is consistent with the U.S. national GHG Inventory and in some sense captures all source activities, in another sense it did not provide detailed information about those source activities in a meaningful and actionable way. An alternative approach, which was applied to develop the first iteration of the New York State Oil and Gas Sector Methane Emissions Inventory (1990–2017) and the second iteration of the New York State Oil and Gas Sector Methane Emissions Inventory (1990 –2020), would include a level of data refinement and spatial and temporal resolution that more accurately reflects State conditions, accounts for uncertainty, and has results that allow New York State to focus programs and policies on particular parts of the system where the greatest emission reductions may be realized.

The following section presents the recommendations related to four best practices for inventory development that were applied to the New York State case to develop the New York State Oil and Gas Sector Methane Emissions Inventory. These best practices are (1) use of appropriately scaled activity data, (2) inclusion of state-of-the-science EFs, (3) geospatial resolution of activities and emissions, and (4) application and reporting of uncertainty factors, including high-emitting sources.

A.5.2 Activity Data

The original 2015 New York State CH_4 inventory applied a highly aggregated, throughput-based approach. Section 3 outlines an activity-based approach aligned with EPA’s SIT, GHGRP tool, and Oil and Gas Inventory Tool. Section 3 also demonstrates that activity data are available that would allow the State to conduct an activity-based inventory aligned with best practices.

Recommendation #1: New York State should develop a more detailed set of activity data, including site-level and component-level data, for its CH_4 inventory in order to create an inventory with the detail needed to capture the impacts of CH_4 mitigation strategies targeted at the site- or component-level.

A.5.3 Emission Factors

Based on the approach to constructing the CH_4 inventory in the original inventory, the State applied a de facto high-level, aggregate EF for the entire sector which represented a national average and may not be appropriate for conditions in New York State. In reality, emission characteristics and average loss rates can vary significantly by regions and across the country (Alvarez et al. 2018) and also depend on well geography, age of the infrastructure, and statewide approaches to operations like venting and flaring.

Recommendation #2: New York State should estimate and apply EFs for upstream, midstream, and downstream oil and gas activities using best available data, validated by both BU and TD studies, and specific to geographic location in the State.

TD emission inventories employ remote-sensing techniques, including mobile vehicle, and aircraft-and satellite-mounted sensors to monitor atmospheric conditions. These atmospheric conditions, when coupled with atmospheric transport models, can be used to identify magnitudes and sources of emissions. TD emission inventories have the benefit of being decoupled from the activity, as a measure of the level of atmospheric concentration, and thus can be useful to validate BU, activity-driven inventories. One limitation of TD inventories is that they require sophisticated monitoring and atmospheric modeling systems, and thus are often limited to smaller study areas.

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One approach common to TD inventories is aerial mass balance, which estimates the flow rate of a gas through a given parcel of air based on the dimensions of the parcel; atmospheric conditions, including wind; and the gas-mixing ratio. Once the flow rate is known and the air parcels in the region have been analyzed, it is possible to back-calculate the source of emissions and the mass of gas emitted. An example set of studies that used TD emission estimates is shown in Table A-13.

Table A-13. CH_4 Emission Rates (as a percent of production throughput) for Nine Survey Areas Derived from Aircraft-Based TD Studies

Calculated and reported in Alvarez et al. (2018).

TD Survey Area (Shale Basin)	Natural Gas Production ($Bcf \cdot day^{-1}$)	Estimated CH_4 Emissions from Oil and Natural Gas Production [megagram (Mg)$\cdot hr^{-1}$]	Estimated Emissions Rate (% of production)	Reference
Haynesville	7.7	73 ± 54	1.3	Peischl et al. 2015
Barnett	5.9	60 ± 11	1.4	Karion et al. 2015
Marcellus	5.8	18 ± 14	0.4	Barkley et al. 2017
San Juan	2.8	57 ± 54	3.0	Smith et al. 2017
Fayetteville	2.5	27 ± 8	1.4	Schwietzke et al. 2017
Bakken	1.9	27 ± 13	3.7	Peischl et al. 2015
Uinta	1.2	55 ± 31	6.6	Karion et al. 2013
Weld	1.0	19 ± 14	3.1	Pétron et al. 2014
West Arkoma	0.4	26 ± 30	9.1	Peischl et al. 2015
9-Basin Total	**29.0**	**360 ± 92**	**1.8% ± 0.5%**	

A.5.4 Geospatial Location

Geospatial data are publicly available for many of the inputs necessary for compiling activity-based oil and natural gas CH_4 inventories for New York State. Well locations and annual production data are available from DEC and processing and storage plant locations are available from EIA. Pipeline locations are not publicly available due to U.S. Homeland Security concerns, but small-scale (low geographic precision) pipeline locations are available from EIA or upon request from gis.ny.gov. Aggregate data on pipeline construction type are available, but do not include geospatial information. A map of available geospatial data is shown in Figure 7.

Geospatially resolved emission inventories are important for a number of reasons. First, estimating emissions geospatially allows policymakers and regulators to identify emission hotspots and address emissions in those hotspot areas. Geospatially resolved emission inventories also have important implications for air quality studies. While CH_4 is a global GHG, whose impacts are global regardless of emissions location, co-pollutants (not studied here) such as VOCs and other criteria pollutants have local impacts on human and environmental health. Geospatial inventories of these pollutants are a critical input to air quality modeling efforts to assess human and environmental health impacts, which leads us to our third recommendation:

Recommendation #3: New York State should align available geospatial data with inventory data as much as possible to create a geospatial emissions inventory that allows greater consideration for identifying hot spots and air quality concerns as well as verification of emission inventories with empirical data.

A.5.4 Uncertainty Analysis and High-Emitting Sources

The issue of uncertainty is an important one for CH_4 inventories. As previously mentioned, EFs can vary significantly, and best practice suggests that inventories should account for some range of uncertainty in reporting. In addition, the issue of high-emitting sources, sometimes referred to as super-emitters, has received significant attention in the inventory literature (Zimmerle et al. 2015; Zavala-Araiza et al. 2015, 2017; Yacovitch et al. 2015; Lavoie et al. 2015; Lyon et al. 2016) and is discussed further in section 3.1.4. Depending on the definition used, high-emitting sources represent a small group of emission sources that contribute a disproportionately high amount of emissions across the supply chain due to abnormal process conditions, as opposed to emissions associated with non-functioning equipment (Allen 2016; Allen, Sullivan, et al. 2015). As such, emissions across a population may follow a skewed fat-tailed distribution, and therefore EFs based on mean emission rates may not capture the total volume of CH_4 emitted (ITRC 2018). An alternative and more technical term, “high-emitting sources,” has been developed by the Interstate Technology and Regulatory Council (ITRC; ITRC 2018). There is very little research on how significant this problem is in New York State, thus leading to our fourth recommendation:

Recommendation #4: New York State should conduct uncertainty analysis when calculating and reporting its CH_4 inventory. At a minimum, that uncertainty analysis should account for uncertainties in published EFs, but it could also include an assessment of high-emitting sources across the State. New York State should develop and apply models that help account for the existence of high-emitting sources either in cases where emission releases are known (e.g., reported leakage) or in cases where emission releases are not known (e.g., estimated leakage based on pipeline age or material).

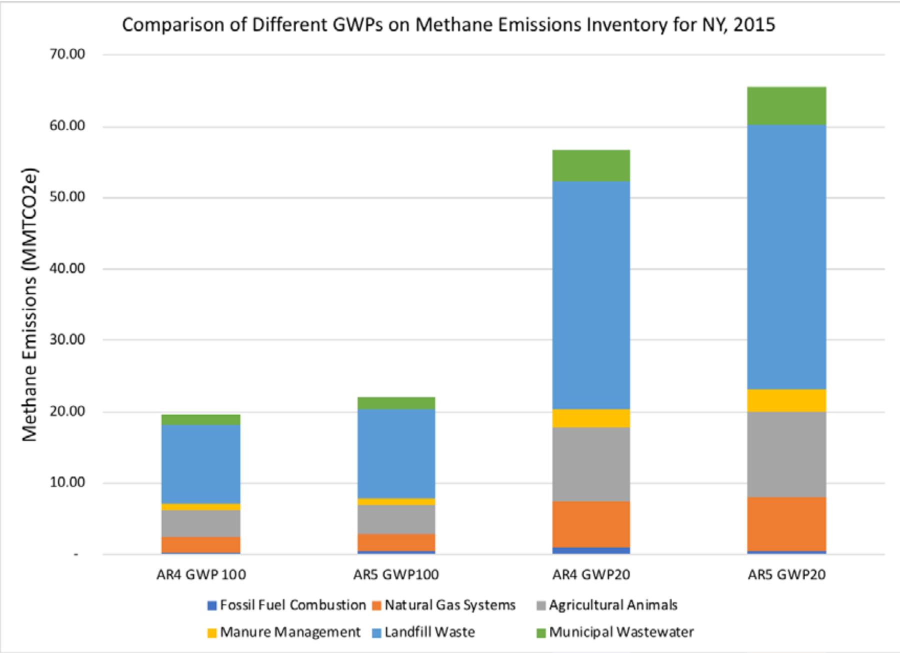
A.6 Selection of Global Warming Potential Factors

This section discusses the impact of GWP factors and recommends the use of at least two GWP values in future inventory development. A final issue raised in the assessment of the original inventory was the selection of an appropriate unit for inventory calculations. Over two decades ago, the IPCC recommended the GWP_{100} for converting CH_4 emissions to CO_2e for the purpose of governmental inventory reporting to the United Nations Framework Convention on Climate Change (UNFCCC). While this gives a long-range perspective, using GWP_{100} discounts important, near- term climate impacts (Alvarez et al. 2012). Some researchers are now suggesting the use of the GWP_{20} as an appropriate metric or at least reporting inventories using both GWP_{100} and GWP_{20} conversions (Balcombe et al. 2018; Alvarez et al. 2012; Ocko et al. 2017).

New York State used the IPCC GWP_{100} from the AR4 of the IPCC (IPCC 2006) in the 2017 New York State Oil and Gas Sector Methane Emissions Inventory (NYSERDA 2019) to be consistent with the U.S. National GHG Inventory, other national governmental inventories that follow UNFCCC protocols, and the SIT-based inventories reported by other states. For the 2020 inventory, emissions are reported using the AR5 GWP_{20} values The AR4 GWP_{100} for CH_4 is 25 and the GWP_{20} is 72, meaning that CH_4 is 25x more potent than CO_2 as a GHG over a 100-year time period and is 72x more potent over a 20-year time period. More recently, the IPCC significantly revised its GWP values in the 2013 Fifth Assessment Report [AR5 (Hartmann, Tank, and Rusticucci 2013)]. Under AR5, the GWP_{100} for CH_4 is 28 (a 12% increase) and the updated GWP_{20} is 84 (a 16.7% increase). The calculation of GWP with subsequent Assessment Reports is due in part to the changing concentration of GHGs in the atmosphere and updated modeling for their direct and indirect effects. Recent literature estimates indicate that the GWP for CH_4 may in fact be greater than reported in AR5 (Etminan et al. 2016). The 2021 Sixth Assessment Report differentiates CH_4 of fossil origin and non-fossil origin. Under AR6, the GWP_{20} was updated to 82.5 for fossil origin CH_4 and 80.8 for non-fossil origin CH_4 while the AR6 GWP_{100} is 29.8 for fossil CH_4 and 27.2 for non-fossil CH_4 (IPCC 2021). For this inventory update, NYS is reporting emissions using the AR5 GWP_{20} values to capture the near-term climate impacts of methane emissions most effectively.

The impact of the choice of GWP is illustrated in Figure A-4. Here we show CH_4 emissions converted to $MMTCO_2e$ under four different GWP values (GWP_{100} from AR4 and AR5, and GWP_{20} from AR4 and AR5). The emissions of CH_4 in $MMTCO_2e$ increase by more than a factor of three when using the near-term, 20-year GWP. If the 20-year GWP were applied to the total inventory of all GHGs, the sources of short-lived GHGs like CH_4 would become a larger portion of emissions. Thus, the choice of a GWP can increase our understanding of the relative importance of CH_4 emissions.

Figure A-4. Comparison of CH_4 Emissions ($MMTCO_2e$) in New York State under Different GWP Assumptions



A.7 Summary of Best Practices

In summary, characteristics of the New York State oil and natural gas industry differ from the national average. Therefore, using national estimates of the fraction of emissions attributed to each stage in the oil and natural gas system derives potentially spurious results for the State, and highlights the importance of performing a BU, activity-driven, component-level CH_4 emissions inventory for New York State. The development of such an inventory should focus on the (1) use of appropriately scaled activity data, (2) inclusion of state-of-the-science EFs, (3) geospatial resolution of activities and emissions, and (4) application and reporting of uncertainty factors, including high-emitting sources. The first iteration of the New York State Oil and Gas Sector Methane Emissions Inventory (1990–2017) and the second iteration of the New York State Oil and Gas Sector Methane Emissions Inventory (1990 –2020) follow these best practices.

Based on the four areas of best practices and recommendations developed under this project, the inventory presents a marked improvement compared to prior iterations of the oil and natural gas sector emissions in the New York State GHG Inventory. Table A-14 summarizes the best practice recommendations, implementation of these recommendations when developing the current inventory, and areas for future inventory improvements.

Table A-14. Summary of Best Practice Recommendations, Implementation of Best Practices, and Areas for Future Inventory Improvements

✓	**Recommendation #1** New York State should develop a more detailed set of activity data, including site- and component-level data, for its CH_4 inventory to create an inventory with the detail needed to capture the impacts of CH_4 mitigation strategies targeted at the site- or component-level. **Implementation in Current Inventory:** Applied the best available activity data, using publicly available inputs as well as data provided by New York State agencies. **Areas for Future Improvement:** • Collect/compile data on the number and location of transmission and storage compressor stations in New York State, including stations that only have electric compressors. • Collect/compile data on the county-level miles of distribution pipeline by pipeline material. • Collect/compile data on the county-level number of residential and commercial/industrial gas meters.
✓	**Recommendation #2** New York State should estimate and apply EFs for upstream and downstream oil and gas activities in the State using best available data, validated by both bottom-up and top-down studies, and specific to geographic location. **Implementation in Current Inventory:** Applied the best available EFs from the published literature. **Areas for Future Improvement:** • Develop New York State-specific EFs for well pads during production. • Develop New York State-specific EFs for transmission and storage compressor stations. • Develop an EF for fugitive emissions from storage reservoirs.
✓	**Recommendation #3** New York State should align available geospatial data with inventory data as much as possible to create a geospatial emissions inventory that allows greater consideration of identifying hot spots and air quality concerns, and verification of emission inventories with empirical data. **Implementation in Current Inventory:** Results are presented geospatially, allocated to the county level, with the ability to produce sub-county results for many segments. **Areas for Future Improvement:** • Collect air quality data on ambient CH_4 concentrations throughout New York State and use the observed concentrations to verify emission estimates.
✓	**Recommendation #4** New York State should conduct uncertainty analysis when calculating and reporting its CH4 inventory. At a minimum, that uncertainty analysis should account for uncertainties in published EFs, but it could also include an assessment of high emitting sources across the State. New York State should develop and apply models that help account for the existence of high-emitting sources either in cases where emission releases are known (e.g., reported leakage) or in cases where emission releases are not known (e.g., estimated leakage based on pipeline age or material). **Implementation in Current Inventory:** Assessed uncertainty in the applied EFs to identify the most likely range of CH4 emissions from the oil and natural gas sector. With better information on the statistical distribution of high-emitting sources, this inventory methodology may also be applied to explicitly include high-emitting sources. **Areas for Future Improvement:** • Develop a better understanding of the distribution of high-emitting sources and the frequency of operation in the high-emitting state.

Appendix B. Details of EPA Subpart W Methodology

This appendix provides a more detailed description of the EPA Subpart W methodology, along with tables detailing the Subpart W EFs.

B.1 Subpart W Industry Segments

Subpart W requires reporting of GHG emissions for each facility with emissions greater than 25,000 $MTCO_2e$ for the following 10 industry segments. Unless otherwise noted, each facility refers to an individual site. Tables show applicable source forms required for each facility.

Effective January 1, 2017, EPA updated the Subpart W methodology to align the leak detection methods and reporting requirements with those in New Source Performance Standards (NSPS) subpart OOOOa.

Emissions are estimated for each source type under one of four methodologies, including engineering estimates, direct measurement, leak detection and leaker EF, and equipment count and population EF. The breakdown of acceptable methodologies is shown in Table A-1, replicated from EPA's overview of Subpart W.[32] As shown, most of the emission estimates are informed by engineering estimates, with options to use direct measurements.

Table B-1. Breakdown of Subpart W Emissions Estimation Methodology by Source Type

Source Type	Engineering Estimates	Direct Measurement	Leak Detection and Leaker EF	Equipment Count and Population EF
Natural gas pneumatic device venting				X
Natural gas driven pneumatic pump venting				X
Well venting for liquids unloading	X	X		
Gas well venting during completions without hydraulic fracturing	X			
Gas well venting during completions with hydraulic fracturing	X	X		
Gas well venting during workovers without hydraulic fracturing	X			
Gas well venting during completions with hydraulic fracturing	X	X		

Table B-1 Continued

Source Type	Engineering Estimates	Direct Measurement	Leak Detection and Leaker EF	Equipment Count and Population EF
Onshore production storage tanks	X			X
Transmission storage tanks		X		
Reciprocating compressor venting	X	X		X
Well testing venting and flaring	X			
Associated gas venting and flaring	X			
Dehydrator vent stacks	X			X
EOR injection pump blowdown	X			
Acid gas removal vent stack	X	X		
EOR hydrocarbon liquids dissolved CO_2		X		
Centrifugal compressor venting	X	X		X
Other emissions from equipment leaks			X	X
Blowdown vent stacks	X			
Flare stacks emissions	X	X		
Onshore petroleum, natural gas production, and natural gas distribution combustion emissions	X	X		
Above ground M-R station and T-D transfer station equipment leaks			X	X
Below ground M-R station and T-D transfer station equipment leaks				X
Pipeline main equipment leaks				X
Service line equipment leaks				X

B.1.1 Onshore Petroleum and Natural Gas Production [98.230(a)(2)]

Per Subpart W guidelines, each owner or operator of onshore petroleum and natural gas production wells should report combined emissions for all wells operational within a given hydrocarbon basin. All wells owned or operated by a single entity in a given basin will be considered as one facility.

Table B-2. Sections Applicable to Onshore Petroleum and Natural Gas Production

Onshore Petroleum and Natural Gas Production [98.230(a)(2)]	Onshore Production [98.236(aa) (1)]
	Natural Gas Pneumatic Devices [98.236(b)]
	Natural Gas Driven Pneumatic Pumps [98.236(c)]
	Acid Gas Removal Units [98.236(d)]
	Dehydrators [98.236(e)]
	Well Venting for Liquids Unloading [98.236(f)]
	Completions and Workovers with Hydraulic Fracturing [98.236(g)]
	Completions and Workovers without Hydraulic Fracturing [98.236(h)]
	Atmospheric Storage Tanks [98.236(j)]
	Well Testing [98.236(l)]
	Associated Gas Venting and Flaring [98.236(m)]
	Flare Stacks [98.236(n)]
	Centrifugal Compressors [98.236(o)]
	Reciprocating Compressors [98.236(p)]
	Equipment Leaks Surveys and Population Counts [98.236(q,r)]
	Enhanced Oil Recovery Injection Pumps [98.236(w)]
	Enhanced Oil Recovery Hydrocarbon Liquids [98.236(x)]
	Combustion Equipment at Onshore Petroleum and Natural Gas Production Facilities, Onshore Petroleum and Natural Gas Gathering and Boosting Facilities, and Natural Gas Distribution Facilities [98.236(z)]

B.1.2 Offshore Petroleum and Natural Gas Production [98.230(a)(1)]

Offshore petroleum and natural gas production facilities are those comprised of any platform, fixed or floating, affixed to offshore submerged lands that houses equipment to extract oil and or natural gas from the ocean or lake floor, and processes and transfers those hydrocarbons ashore. Offshore facilities also include secondary structures, and storage and offloading equipment. All wells owned or operated by a single entity in a given basin will be considered as one facility.

Table B-3. Sections Applicable to Offshore Petroleum and Natural Gas Production

Offshore Petroleum and Natural Gas Production [98.230(a)(1)]	Facility Overview [98.236(aa) (2-11)]
	Offshore Petroleum and Natural Gas Production [98.236(s)]

B.1.3 Onshore Natural Gas Processing [98.230(a)(3)]

This segment refers to onshore plants that receive natural gas from gathering lines and separate natural gas liquids from raw produced natural gas. In some cases, processing plants also fractionate the removed natural gas liquids into their component parts. This segment includes all processing facilities that fractionate, and all processing facilities that do not fractionate but have a daily throughput of 25 MMscf or more.

Table B-4. Sections Applicable to Onshore Natural Gas Processing

Onshore Natural Gas Processing [98.230(a)(3)]	Facility Overview [98.236(aa) (2-11)]
	Acid Gas Removal Units [98.236(d)]
	Dehydrators [98.236(e)]
	Blowdown Vent Stacks [98.236(i)]
	Flare Stacks [98.236(n)]
	Centrifugal Compressors [98.236(o)]
	Reciprocating Compressors [98.236(p)]
	Equipment Leaks Surveys and Population Counts [98.236(q,r)]

B.1.4 Onshore Natural Gas Transmission Compression [98.230(a)(4)]

This section includes stationary compressors involved in moving natural gas from production, processing, and transmission facilities, through transmission pipelines. Compressors move gas through transmission pipelines to either distribution lines, LNG storage facilities, or underground storage. All compression equipment, dehydrators, and storage tanks are considered part of the facility.

Table B-5. Sections Applicable to Onshore Natural Gas Transmission Compression

Onshore Natural Gas Transmission Compression [98.230(a)(4)]	Facility Overview [98.236(aa) (2-11)]
	Natural Gas Pneumatic Devices [98.236(b)]
	Blowdown Vent Stacks [98.236(i)]
	Transmission Storage Tanks [98.236(k)]
	Flare Stacks [98.236(n)]
	Centrifugal Compressors [98.236(o)]
	Reciprocating Compressors [98.236(p)]
	Equipment Leaks Surveys and Population Counts [98.236(q,r)]
	Facility Overview [98.236(aa)(2-11)]

B.1.5 Underground Natural Gas Storage [98.230(a)(5)]

This source includes emissions from infrastructure associated with subsurface storage of natural gas in underground formations, depleted oil and gas reservoirs, and salt dome caverns. Operations include compressions, dehydration and flow measurement, as well as all injection or recovery wellheads connected to compression units at the facility.

Table B-6. Sections Applicable to Underground Natural Gas Storage

Underground Natural Gas Storage [98.230(a)(5)]	Facility Overview [98.236(aa)(2-11)]
	Natural Gas Pneumatic Devices [98.236(b)]
	Flare Stacks [98.236(n)]
	Centrifugal Compressors [98.236(o)]
	Reciprocating Compressors [98.236(p)]
	Equipment Leaks Surveys and Population Counts [98.236(q,r)]

B.1.6 Liquefied Natural Gas (LNG) Storage [98.230(a)(6)]

This source includes emissions from onshore LNG storage facilities and storage tanks located above ground, including associated equipment such as liquefaction equipment, compressors to capture and re-liquefy boil off, re-condensers, and vaporization units.

Table B-7. Sections Applicable to Liquefied Natural Gas (LNG) Storage

Liquefied Natural Gas (LNG) Storage [98.230(a)(6)]	Facility Overview [98.236(aa)(2-11)]
	Flare Stacks [98.236(n)]
	Centrifugal Compressors [98.236(o)]
	Reciprocating Compressors [98.236(p)]
	Equipment Leaks Surveys and Population Counts [98.236(q,r)]

B.1.7 LNG Import and Export Equipment [98.230(a)(7)]

This source refers to all equipment, both onshore and offshore, that receives or transfers LNG. Import equipment receives LNG from ocean-going vessels and provides storage before delivering gas to transmission or distribution systems. Export equipment receives, liquefies, and stores natural gas; and transfers the gas to ocean-going vessels.

Table B-8. Sections Applicable to LNG Import and Export Equipment

LNG Import and Export Equipment [98.230(a)(7)]	Facility Overview [98.236(aa)(2-11)]
	Blowdown Vent Stacks [98.236(i)]
	Flare Stacks [98.236(n)]
	Centrifugal Compressors [98.236(o)]
	Reciprocating Compressors [98.236(p)]
	Equipment Leaks Surveys and Population Counts [98.236(q,r)]
	Facility Overview [98.236(aa)(2-11)]

B.1.8 Natural Gas Distribution [98.230(a)(8)]

The natural gas distribution source includes reports from local distribution companies regarding emissions from distribution pipeline leaks, regulating equipment, and transfer stations. This segment also includes customer meters and regulators, infrastructure, and pipelines. For natural gas distribution, the facility is defined as all of a given utility's or operator's assets in a state.

Table B-9. Sections Applicable to Natural Gas Distribution

Natural Gas Distribution [98.230(a)(8)]	Facility Overview [98.236(aa)(2-11)]
	Equipment Leaks Surveys and Population Counts [98.236(q,r)]
	Combustion Equipment at Onshore Petroleum and Natural Gas Production Facilities, Onshore Petroleum and Natural Gas Gathering and Boosting Facilities, and Natural Gas Distribution Facilities [98.236(z)]

B.1.9 Onshore Petroleum and Natural Gas Gathering and Boosting [98.230(a)(9)]

This source includes gathering pipelines and associated equipment for collecting oil and natural gas from onshore production sites, and provides transport to processing facilities, transmission pipelines, or distribution pipelines. All gathering and boosting lines and facilities owned or operated by a single entity in a given basin are considered as one facility.

Table B-10. Sections Applicable to Onshore Petroleum and Natural Gas Gathering and Boosting

Onshore Petroleum and Natural Gas Gathering and Boosting [98.230(a)(9)]	Facility Overview [98.236(aa)(2-11)]
	Natural Gas Pneumatic Devices [98.236(b)]
	Natural Gas Driven Pneumatic Pumps [98.236(c)]
	Acid Gas Removal Units [98.236(d)]
	Dehydrators [98.236(e)]
	Blowdown Vent Stacks [98.236(i)]
	Atmospheric Storage Tanks [98.236(j)]
	Flare Stacks [98.236(n)]
	Centrifugal Compressors [98.236(o)]
	Reciprocating Compressors [98.236(p)]
	Equipment Leaks Surveys and Population Counts [98.236(q,r)]
	Combustion Equipment at Onshore Petroleum and Natural Gas Production Facilities, Onshore Petroleum and Natural Gas Gathering and Boosting Facilities, and Natural Gas Distribution Facilities [98.236(z)]

B.1.10 Onshore Natural Gas Transmission Pipeline [98.230(a)(10)]

This source delivers gas from processing facilities to local distribution facilities. Transmission pipelines often include compressor stations.

Table B-11. Sections Applicable to Onshore Natural Gas Transmission Pipeline

Onshore Natural Gas Transmission Pipeline [98.230(a)(10)]	Facility Overview [98.236(aa)(2-11)]
	Natural Gas Pneumatic Devices [98.236(b)]

B.2 Subpart W Emission Factors and Component Counts

This section details the default EFs for Subpart W for the eastern United States.

Table B-12. Leaker CH_4 Emission Factors from EPA's GHGRP Subpart W

Industry Segment	Major Equipment	Service	Component	CH_4 EF[a] (scf/hr-component)	
				Non-Method 21	Method 21
Onshore Petroleum and Natural Gas Production, Gathering, and Boosting	Onshore production or gathering and boosting components	Light crude	Valve	3.2	2.2
			Flange	2.7	1.4
			Connector (other)	1	0.6
			Open-ended line	1.6	1.1
			Pump	3.7	2.6
			Agitator seat	3.7	2.6
			Other	3.1	2
		Heavy crude	Valve	3.2	2.2
			Flange	2.7	1.4
			Connector (other)	1	0.6
			Open-ended line	1.6	1.1
			Pump	3.7	2.6
			Agitator seat	3.7	2.6
			Other	3.1	2
		Gas	Valve	4.9	3.5
			Flange	4.1	2.2
			Connector (other)	1.3	0.8
			Open-ended line	2.8	1.9
			Pressure relief valve	4.5	2.8
			Pump seal	3.7	1.4
			Other	4.5	2.8
Onshore Natural Gas Processing	Compressor components	Gas	Valve	14.84	N/A
			Connector	5.59	N/A
			Open-ended line	17.27	N/A
			Pressure relief valve	39.66	N/A
			Meter	19.33	N/A
	Non-compressor components	Gas	Valve	6.42	N/A
			Connector	5.71	N/A
			Open-ended line	11.27	N/A
			Pressure relief valve	2.01	N/A
			Meter	2.93	N/A
Onshore Natural Gas Transmission Compression	Compressor components	Gas	Valve	14.84	9.51
			Connector	5.59	3.58
			Open-ended line	17.27	11.07
			Pressure relief valve	39.66	25.42
			Meter/instrument	19.33	12.39
			Other	4.1	2.63

Table B-12 continued

Industry Segment	Major Equipment	Service	Component	CH_4 EF[a] (scf/hr-component)	
				Non-Method 21	Method 21
Onshore Natural Gas Transmission Compression	Non-compressor components	Gas	Valve	6.42	4.12
			Connector	5.71	3.66
			Open-ended line	11.27	7.22
			Pressure relief valve	2.01	1.29
			Meter/instrument	2.93	1.88
			Other	4.1	2.63
Underground Natural Gas Storage	Storage station	Gas	Valve	14.84	9.51
			Connector	5.59	3.58
			Open-ended line	17.27	11.07
			Pressure relief valve	39.66	25.42
			Meter/instrument	19.33	12.39
			Other	4.1	2.63
	Storage wellhead	Gas	Valve	4.5	3.2
			Connector	1.2	0.7
			Open-ended line	3.8	2
			Pressure relief valve	2.5	1.7
			Meter/instrument	4.1	2.5
			Other	4.1	2.5
LNG Storage LNG Import and Export Equipment	LNG storage LNG terminal	LNG terminal	Valve	1.19	0.23
			Connector	0.34	0.11
			Pump seal	4	0.73
			Other	1.77	0.99
		Gas	Valve	14.84	9.51
			Connector	5.59	3.58
			Open-ended line	17.27	11.07
			Pressure relief valve	39.66	25.42
			Meter/instrument	19.33	12.39
			Other	4.1	2.63
Natural Gas Distribution above Grade Transfer Stations	Local distribution company	Transmission-distribution stations	Connector	1.69	N/A
			Block valve	0.557	N/A
			Control valve	9.34	N/A
			Pressure relief valve	0.27	N/A
			Orifice meter	0.212	N/A
			Regulator	0.772	N/A
			Open-ended line	26.131	N/A

[a] Subpart W provides only one EF if no Method 21 emission factor is shown.

Table B-13. Population EFs from EPA's GHGRP Subpart W

Industry Segment	Major Equipment	Service	Component	EF	Units
Onshore Petroleum and Natural Gas Production, Gathering and Boosting	Onshore (eastern United States)	Light crude	Valve	0.05	Whole gas EF [standard cubic foot (scf)/hr-component]
			Flange	0.003	
			Connector	0.007	
			Open-ended line	0.05	
			Pump	0.01	
			Other	0.3	
		Heavy crude	Valve	0.0005	
			Flange	0.0009	
			Connector	0.0003	
			Open-ended line	0.006	
			Pump	0.003	
		Gathering pipelines	Protected steel	0.47	
			Unprotected steel	16.59	
			Plastic/composite	2.5	
			Cast iron	27.6	
		Gas	Valve	0.027	Whole gas EF (scf)/hr-component)
			Connector	0.003	
			Open-ended line	0.061	
			Pressure relief valve	0.04	
Underground Natural Gas Storage	Storage wellheads	Gas	Valve	0.1	Total hydrocarbon EF (scf-hr/ component)
			Connector	0.01	
			Open-ended line	0.03	
			Pressure relief valve	0.17	
LNG Storage and Import Export Equipment	LNG compressor		Vapor recovery compressor	4.17	CH_4 EF (scf-hr/ component)
Natural Gas Distribution	Below-grade M&R station	Inlet pressure	< 100 pounds per square inch gauge (psig)	0.1	CH_4 EF (scf/hr-station)
			100 to 300 psig	0.2	
			> 300 psig	1.3	
	Distribution mains	Gas	Cast iron	27.25	CH_4 EF (scf/hr-mile)
			Plastic	1.13	
			Protected steel	0.35	
			Unprotected steel	12.58	
	Distribution services	Gas	Copper	0.03	CH_4 EF (scf/hr-service)
			Plastic	0.001	
			Protected steel	0.02	
			Unprotected steel	0.19	

Table B-14. Major Equipment Component and Activity Count Data from EPA's GHGRP Subpart W for the Eastern United States

Industry Segment	Major Equipment	Valves	Connectors	Open-ended Lines	Pressure Relief Valves	Flanges
Crude Oil Production	Wellheads	5	4	0		10
	Separators	6	10	0		12
	Heater-treater	8	20	0		12
	Head er	5	4	0		10
Onshore Natural Gas Production, Gathering and Boosting	Wellheads	8	38	0.5	0	
	Separators	1	6	0	0	
	Meters/piping	12	45	0	0	
	Compressors	12	57	0	0	
	In-line heaters	14	65	2	1	
	Dehydrators	24	90	2	2	

Table B-15. EFs for Pneumatic Device and Pump Venting from EPA GHGRP Subpart W

Industry Segment	High-Bleed Pneumatic Devices	Intermittent Bleed Pneumatic Devices	Low-Bleed Pneumatic Devices	Natural Gas Driven Pneumatic Pumps
Onshore Petroleum and Natural Gas Production	37.3	13.5	1.39	13.3
Onshore Natural Gas Transmission Compression	18.2	2.35	1.37	
Underground Natural Gas Storage	18.2	2.35	1.37	
Onshore Petroleum and Natural Gas Gathering and Boosting	37.3	13.5	1.39	13.3

Appendix C. Supporting Tables from Literature Review

From Kirchgessner (1997), showing pre-1997 loss assumptions:

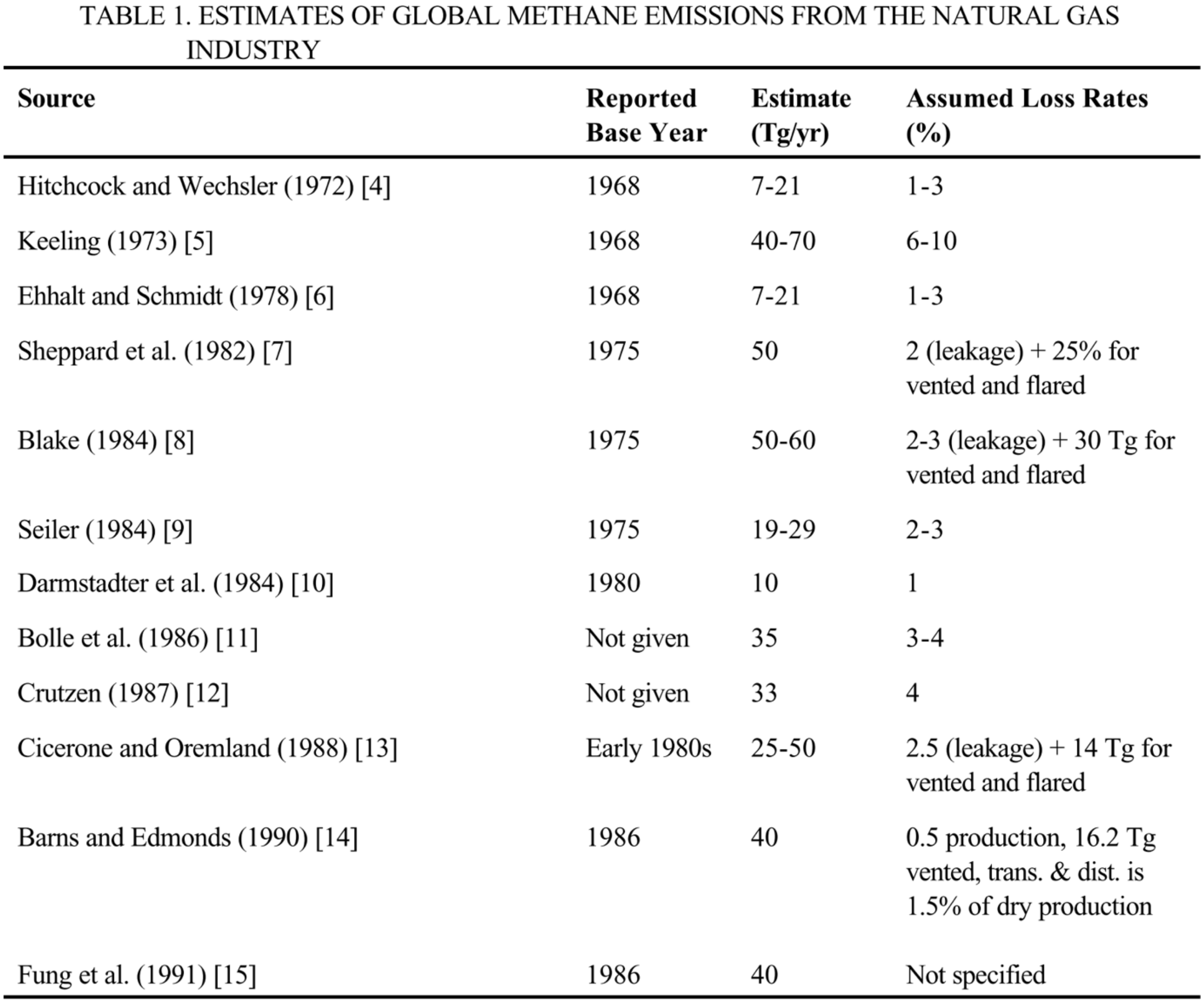


TABLE 1. ESTIMATES OF GLOBAL METHANE EMISSIONS FROM THE NATURAL GAS INDUSTRY

Source	Reported Base Year	Estimate (Tg/yr)	Assumed Loss Rates (%)
Hitchcock and Wechsler (1972) [4]	1968	7-21	1-3
Keeling (1973) [5]	1968	40-70	6-10
Ehhalt and Schmidt (1978) [6]	1968	7-21	1-3
Sheppard et al. (1982) [7]	1975	50	2 (leakage) + 25% for vented and flared
Blake (1984) [8]	1975	50-60	2-3 (leakage) + 30 Tg for vented and flared
Seiler (1984) [9]	1975	19-29	2-3
Darmstadter et al. (1984) [10]	1980	10	1
Bolle et al. (1986) [11]	Not given	35	3-4
Crutzen (1987) [12]	Not given	33	4
Cicerone and Oremland (1988) [13]	Early 1980s	25-50	2.5 (leakage) + 14 Tg for vented and flared
Barns and Edmonds (1990) [14]	1986	40	0.5 production, 16.2 Tg vented, trans. & dist. is 1.5% of dry production
Fung et al. (1991) [15]	1986	40	Not specified

From Littlefield et al. (2017), showing work by Allen on emissions from different components:

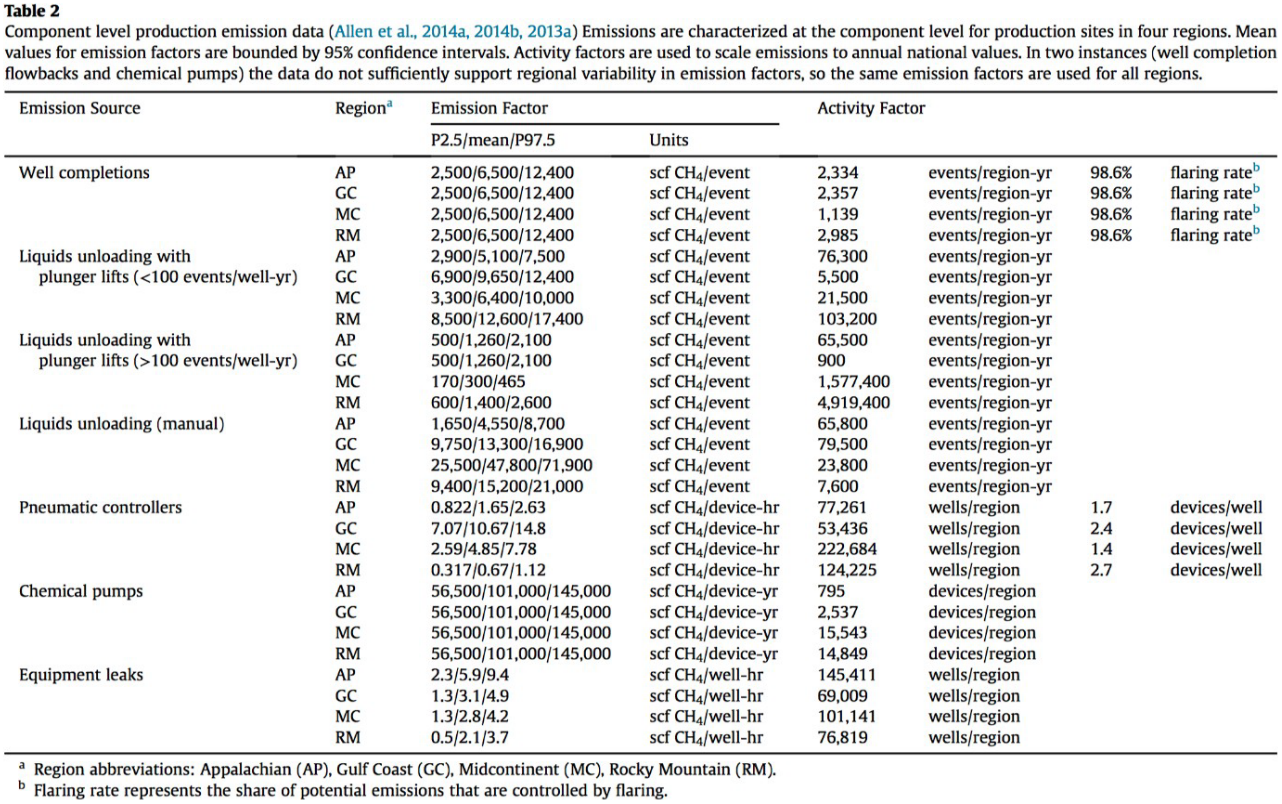


Table 2

Component level production emission data (Allen et al., 2014a, 2014b, 2013a) Emissions are characterized at the component level for production sites in four regions. Mean values for emission factors are bounded by 95% confidence intervals. Activity factors are used to scale emissions to annual national values. In two instances (well completion flowbacks and chemical pumps) the data do not sufficiently support regional variability in emission factors, so the same emission factors are used for all regions.

Emission Source	Region[a]	Emission Factor		Activity Factor			
		P2.5/mean/P97.5	Units				
Well completions	AP	2,500/6,500/12,400	scf CH_4/event	2,334	events/region-yr	98.6%	flaring rate[b]
	GC	2,500/6,500/12,400	scf CH_4/event	2,357	events/region-yr	98.6%	flaring rate[b]
	MC	2,500/6,500/12,400	scf CH_4/event	1,139	events/region-yr	98.6%	flaring rate[b]
	RM	2,500/6,500/12,400	scf CH_4/event	2,985	events/region-yr	98.6%	flaring rate[b]
Liquids unloading with plunger lifts (<100 events/well-yr)	AP	2,900/5,100/7,500	scf CH_4/event	76,300	events/region-yr		
	GC	6,900/9,650/12,400	scf CH_4/event	5,500	events/region-yr		
	MC	3,300/6,400/10,000	scf CH_4/event	21,500	events/region-yr		
	RM	8,500/12,600/17,400	scf CH_4/event	103,200	events/region-yr		
Liquids unloading with plunger lifts (>100 events/well-yr)	AP	500/1,260/2,100	scf CH_4/event	65,500	events/region-yr		
	GC	500/1,260/2,100	scf CH_4/event	900	events/region-yr		
	MC	170/300/465	scf CH_4/event	1,577,400	events/region-yr		
	RM	600/1,400/2,600	scf CH_4/event	4,919,400	events/region-yr		
Liquids unloading (manual)	AP	1,650/4,550/8,700	scf CH_4/event	65,800	events/region-yr		
	GC	9,750/13,300/16,900	scf CH_4/event	79,500	events/region-yr		
	MC	25,500/47,800/71,900	scf CH_4/event	23,800	events/region-yr		
	RM	9,400/15,200/21,000	scf CH_4/event	7,600	events/region-yr		
Pneumatic controllers	AP	0.822/1.65/2.63	scf CH_4/device-hr	77,261	wells/region	1.7	devices/well
	GC	7.07/10.67/14.8	scf CH_4/device-hr	53,436	wells/region	2.4	devices/well
	MC	2.59/4.85/7.78	scf CH_4/device-hr	222,684	wells/region	1.4	devices/well
	RM	0.317/0.67/1.12	scf CH_4/device-hr	124,225	wells/region	2.7	devices/well
Chemical pumps	AP	56,500/101,000/145,000	scf CH_4/device-yr	795	devices/region		
	GC	56,500/101,000/145,000	scf CH_4/device-yr	2,537	devices/region		
	MC	56,500/101,000/145,000	scf CH_4/device-yr	15,543	devices/region		
	RM	56,500/101,000/145,000	scf CH_4/device-yr	14,849	devices/region		
Equipment leaks	AP	2.3/5.9/9.4	scf CH_4/well-hr	145,411	wells/region		
	GC	1.3/3.1/4.9	scf CH_4/well-hr	69,009	wells/region		
	MC	1.3/2.8/4.2	scf CH_4/well-hr	101,141	wells/region		
	RM	0.5/2.1/3.7	scf CH_4/well-hr	76,819	wells/region		

[a] Region abbreviations: Appalachian (AP), Gulf Coast (GC), Midcontinent (MC), Rocky Mountain (RM).

[b] Flaring rate represents the share of potential emissions that are controlled by flaring.

From Alvarez et al. (2018), showing the data sets that were used for their assessment:

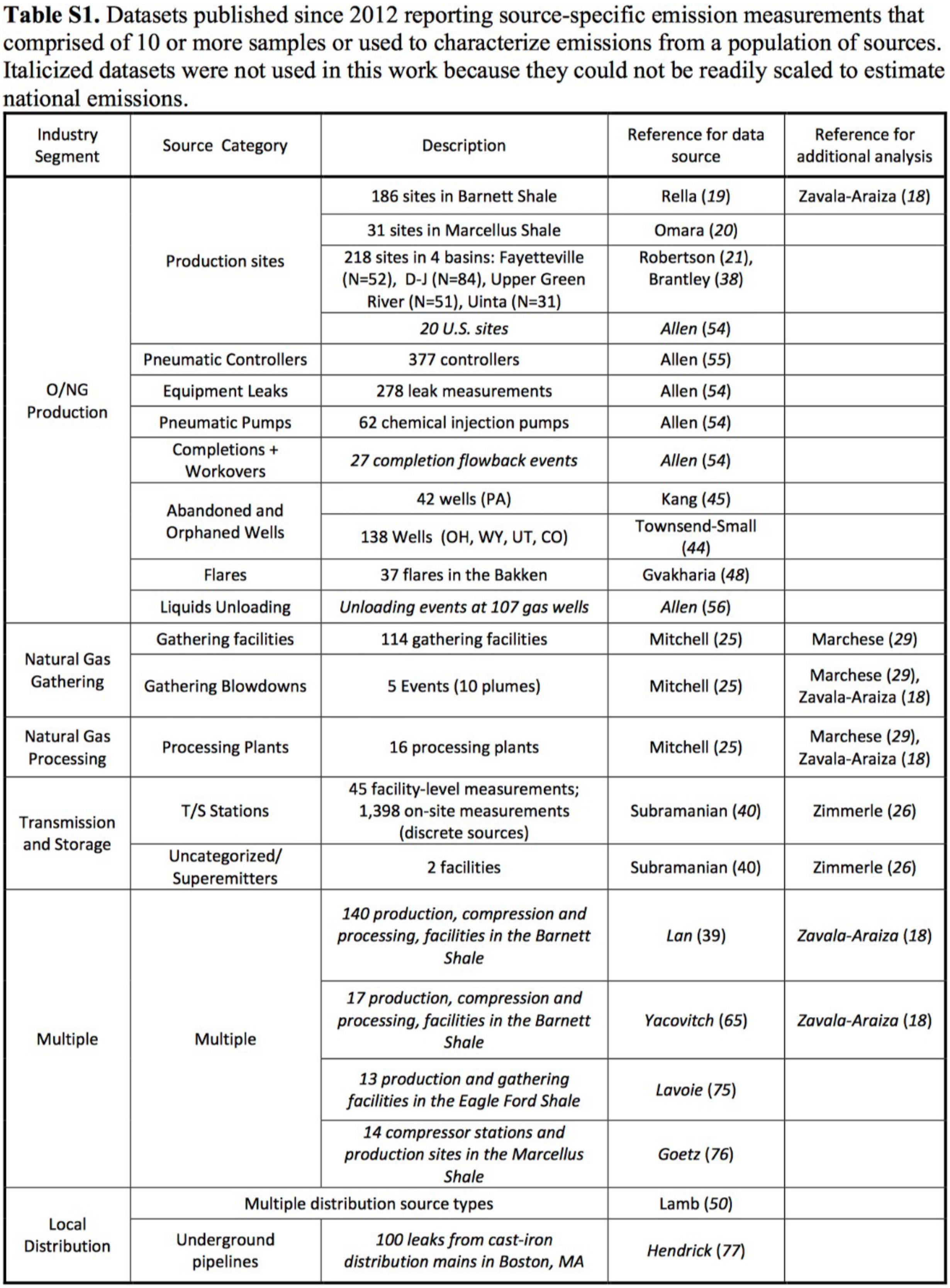


Table S1. Datasets published since 2012 reporting source-specific emission measurements that comprised of 10 or more samples or used to characterize emissions from a population of sources. Italicized datasets were not used in this work because they could not be readily scaled to estimate national emissions.

Industry Segment	Source Category	Description	Reference for data source	Reference for additional analysis
O/NG Production	Production sites	186 sites in Barnett Shale	Rella (*19*)	Zavala-Araiza (*18*)
		31 sites in Marcellus Shale	Omara (*20*)	
		218 sites in 4 basins: Fayetteville (N=52), D-J (N=84), Upper Green River (N=51), Uinta (N=31)	Robertson (*21*), Brantley (*38*)	
		20 U.S. sites	*Allen (54)*	
	Pneumatic Controllers	377 controllers	Allen (*55*)	
	Equipment Leaks	278 leak measurements	Allen (*54*)	
	Pneumatic Pumps	62 chemical injection pumps	Allen (*54*)	
	Completions + Workovers	*27 completion flowback events*	*Allen (54)*	
	Abandoned and Orphaned Wells	42 wells (PA)	Kang (*45*)	
		138 Wells (OH, WY, UT, CO)	Townsend-Small (*44*)	
	Flares	37 flares in the Bakken	Gvakharia (*48*)	
	Liquids Unloading	*Unloading events at 107 gas wells*	*Allen (56)*	
Natural Gas Gathering	Gathering facilities	114 gathering facilities	Mitchell (*25*)	Marchese (*29*)
	Gathering Blowdowns	5 Events (10 plumes)	Mitchell (*25*)	Marchese (*29*), Zavala-Araiza (*18*)
Natural Gas Processing	Processing Plants	16 processing plants	Mitchell (*25*)	Marchese (*29*), Zavala-Araiza (*18*)
Transmission and Storage	T/S Stations	45 facility-level measurements; 1,398 on-site measurements (discrete sources)	Subramanian (*40*)	Zimmerle (*26*)
	Uncategorized/ Superemitters	2 facilities	Subramanian (40)	Zimmerle (*26*)
Multiple	Multiple	*140 production, compression and processing, facilities in the Barnett Shale*	*Lan* (39)	*Zavala-Araiza* (18)
		17 production, compression and processing, facilities in the Barnett Shale	*Yacovitch* (65)	*Zavala-Araiza* (18)
		13 production and gathering facilities in the Eagle Ford Shale	*Lavoie* (75)	
		14 compressor stations and production sites in the Marcellus Shale	*Goetz* (76)	
Local Distribution	Multiple distribution source types		Lamb (*50*)	
	Underground pipelines	*100 leaks from cast-iron distribution mains in Boston, MA*	*Hendrick* (77)	

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Table S3. CH_4 emissions from the U.S. O/NG supply chain in 2015 as estimated in the 2017 U.S. EPA Greenhouse Gas inventory (GHGI) (*17*) and in this work based on source-based (i.e., individual components inside sites or facilities, Section S1.4) and site-based (i.e., all sources at a site, Section S1.2) methodologies. Bold categories denote emission sources for which recent measurements have been reported.

Industry Segment	Source Category	2015 U.S. Emissions (Gg CH_4 y^{-1})		
		GHGI	This work (source–based)	This work (site–based)
O/NG Production	**Pneumatic Controllers**	1,800	1,100 (1,100 - 1,200)	7,200 (5,600 - 9,100)
	Equipment Leaks* $	360	620 (570 - 670)	
	Liquids Unloading	210	170 (170 - 200)	
	Pneumatic Pumps*	210	190 (180 - 200)	
	Oil & Condensate Tanks	100	100 (97 - 120)	
	Produced Water Tanks	40	360 (340 - 380)	
	Fuel combustion	240	98 (91 - 210)	
	Associated gas flaring and venting	150	71 (69 - 86)	
	Other production sources*	40	60 (58 - 68)	
	Routine Operations Subtotal	3,100	2,800 (2,700 - 2,900)	7,200 (5,600 - 9,100)
	Completions + Workovers	100	86 (80 - 120)	
	Abandoned and Orphaned Wells	NA	61 (59 - 360)	
	Onshore Production Subtotal	3,200	2,900 (2,900 - 3,300)	7,300 (5,700 - 9,300)
	Offshore Platforms	300	300 (240 - 380)	
	Production Total	3,500	3,200 (3,100 - 3,600)	7,600 (6,000 - 9,600)
Natural Gas Gathering	**Gathering Stations**	2,000	2,100 (2,100 - 2,200)	
	Gathering Episodic Events	200	170 (7 - 750)	
	Gathering Pipelines	160	310 (300 - 330)	
	Gathering Total	2,300	2,600 (2,400 - 3,200)	
Natural Gas Processing	**Processing Plants**	410	680 (610 - 880)	
	Routine Maintenance	36	36 (29 - 46)	
	Processing Total	450	720 (650 - 920)	
Transmission and Storage (T/S)	**T/S Stations**	1,100	1,100 (860 - 1,400)	
	T/S Uncategorized/Superemitters	NA	440 (350 - 570)	
	Transmission Pipelines	220	220 (180 - 290)	
	LNG Storage and Import Terminals	70	67 (54 - 87)	
	T/S Total	1,300	1,800 (1,600 - 2,100)	
Local Distribution	All sources through customer meters	440	440 (220 - 950)	
Petroleum Midstream	Oil Transportation + Refining	34	34 (26 - 84)	
Total U.S. Oil and Gas Supply Chain		8,100 (6,800 – 10,000)	8,800 (8,400 - 9,700)	13,000 (12,000 - 15,000)

* Denotes multiple GHGI source categories are combined into this source type.

$ GHGI combines compressor venting with compressor fugitives, thus we combine 48 Gg derived from GHGRP for compressor venting with 523 Gg for equipment leaks.

Table S8. Sources of activity and emissions data used for the alternative, component-level estimates of source-specific methane emissions. Emission factor values are reported when applicable. Additional details are provided in the text description.

Sector	Source	Activity Data	Emissions Data	Emission Factors
Production	Associated Gas Venting	DI (*13*)	GHGRP (county-level CH4) (*46*)	NA
	Associated Gas Flaring			
	Liquids Unloading			
	Hydrocarbon Tanks			
	Centrifugal Compressors		GHGRP (basin-level CH4) (*46*)	
	Reciprocating Compressors			
	Dehydrators			
	Flares			
	Well Testing			
	Completions			
	Workovers			
	Combustion Exhaust		GHGRP (county-level CO2) (*46*); AP-42 (*57*)	100 (4 — 660) g CH4 MMBTU-1
	Equipment Leaks		Allen (*54*)	Zavala-Araiza (*18*)
	Pneumatic Controllers	DI production (*13*); GHGRP pump counts (*46*)	Allen (*55*)	High-bleed: 2.0 (1.5 – 2.5) MT CH4 yr-1
				Low-bleed: 0.42 (0.56 – 0.70) MT CH4 yr-1
				Intermittent-bleed: 0.15 (0.09 – 0.23) MT CH4 yr-1
				Malfunctioning: 7.3 (5.5 – 9.4) MT CH4 yr-1
				7% malfunctioning devices
	Pneumatic Pumps	DI production (*13*); GHGRP controller counts (*46*)	Allen (*54*)	1.9 (1.2 – 2.9) MT CH4 yr-1
	Produced Water Tanks	DI production (*13*); (*58*)	EPA O&G Tool (*59*)	Gas wells: 50 g CH4 bbl-1
				Oil wells: 14 g CH4 bbl-1
	Abandoned Wells	DI inactive wells (*13*)	Townsend-Small (*44*); Kang (*45*)	Plugged: 1.8 x 10-5 MT CH4 well-1 yr-1
				Unplugged: 8.8 x 10-2 MT CH4 well-1 yr-1
	Offshore	NA	GHGI (*17*)	NA
Gathering	Gathering Stations	DI gas production (*13*); Marchese (*29*)	Mitchell (*25*); Marchese (*29*); Zavala-Araiza (*18*)	NA
	Gathering Blowdowns	Gathering station emissions from Marchese (*29*)	Marchese (*29*); Zavala-Araiza (*18*)	10% (0.3 - 42%) station emissions
	Gathering Pipelines	DI gas producing wells (*13*)	GHGI (*17*)	0.95 miles pipeline well-1
				0.40 MT CH4 mile-1 yr-1
Processing		Maasakkers (*53*)	Marchese (*29*); Zavala-Araiza (*18*)	NA
Transmission & Storage	T&S Stations	Maasakkers (*53*)	GHGI (*17*); Zimmerle (*26*)	200 MT CH4 station-1 yr-1
	T&S Station Super-emitters		Zimmerle (*26*)	
	Transmission Pipelines		GHGI (*17*)	
	LNG Import and Export Terminals		GHGI (*17*)	
Local Distribution		Maasakkers (*53*)	GHGI (*17*); Lamb (*50*)	NA
Petroleum Transportation & Refining		Maasakkers (*53*)	GHGI (*17*); GHGRP (*46*)	NA
Other fossil and biogenic		Maasakkers (*53*)	GHGI (*17*)	NA

Endnotes

[1] "Unit Conversion Factors." Society of Petroleum Engineers. http://www.spe.org/industry/unit-conversion-factors.php

[2] "Number of New York Natural Gas Consumers." Natural Gas. EIA. https://www.eia.gov/dnav/ng/NG_CONS_NUM_DCU_SNY_A.htm

[3] "EPA FLIGHT Tool." Environmental Protection Agency. https://ghgdata.epa.gov/ghgp/main.do

[4] "Annual European Union Greenhouse Gas Inventory 1990–2016 and Inventory Report 2018." European Environment Agency, July 23, 2018. https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2018

[5] "2006 IPCC Guidelines for National Greenhouse Gas Inventories." IPCC. https://www.ipcc-nggip.iges.or.jp/public/2006gl/

[6] Zimmerle et al. 2015; Zavala-Araiza, Lyon, Alvarez, Palacios, et al. 2015; Zavala-Araiza et al. 2015, 2017; Yacovitch et al. 2015; Lavoie et al. 2015; Zavala-Araiza, Lyon, Alvarez, Davis, et al. 2015a; Lyon et al. 2016.

[vii] NPMS public viewer. National Pipeline Mapping System. https://pvnpms.phmsa.dot.gov/PublicViewer/

[8] "NYS Gas Utility Service Territories." State of New York. https://data.ny.gov/d/449k-yfe4?category=Energy-Environment&view_name=NYS-Gas-Utility-Service-Territories

[9] "New York Natural Gas Number of Residential Consumers (Number of Elements)." Natural Gas. EIA. https://www.eia.gov/dnav/ng/hist/na1501_sny_8a.htm

[10] Bureau, US Census. "About the American Community Survey." Census.gov. United States Census Bureau, June 2, 2022. https://www.census.gov/programs-surveys/acs/about.html

[11] Bureau, US Census. "County Business Patterns (CBP)." Census.gov. United States Census Bureau, October 18, 2022. https://www.census.gov//programs-surveys/cbp.html

[12] "Number of Natural Gas Commercial Consumers." Natural Gas. EIA. https://www.eia.gov/dnav/ng/ng_cons_num_a_EPG0_VN5_Count_a.htm. (Commercial and Industrial)

[13] EIA. Residential Energy Consumption Survey (RECS) Terminology: https://www.eia.gov/consumption/residential/terminology.php

[14] NYSERDA 2019 Single-Family Building Assessment Residential Building Stock Assessment: https://www.nyserda.ny.gov/-/media/Files/Publications/building-stock-potential-studies/2019-residential-building-stock-assessment-report-print-version.pdf

[15] United States Census Bureau National, State, and County Housing Unit totals: 2010-2019: https://www.census.gov/data/tables/time-series/demo/popest/2010s-total-housing-units.html

[16] U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration; Pipeline Mileage and Facilities: https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-mileage-and-facilities

[17] New York State Data; NYS Gas Utility Service Territories: https://data.ny.gov/d/449k-yfe4?category=Energy-Environment&view_name=NYS-Gas-Utility-Service-Territories

[18] EIA Independent Statistics and Analysis: Natural Gas; New York Number of Residential Customers https://www.eia.gov/dnav/ng/hist/na1501_sny_8a.htm

[19] United States Census Bureau American Community Survey (ACS): https://www.census.gov/programs-surveys/acs/)

[20] "2022 Pennsylvania Greenhouse Gas Inventory Report." Pennsylvania Department of Environmental Protection. https://www.dep.pa.gov/Citizens/climate/Pages/GHG-Inventory.aspx

[21] EIA. Natural Gas Gross Withdrawals and Production (Volumes in Million Cubic Feet). October 31, 2023. https://www.eia.gov/dnav/ng/ng_prod_sum_a_EPG0_VGM_mmcf_a.htm

[22] Pennsylvania Department Of Environmental Protection. "2020 Oil and Gas Annual Report.", July 1, 2021. https://storymaps.arcgis.com/stories/af368dfb17bd4f219ea0ee22bd4c514a

[23] "NJ Greenhouse Gas Emissions Inventory Report Years 1990-2019." New Jersey Department of Environmental Protection. https://dep.nj.gov/wp-content/uploads/ghg/2022-ghg-inventory-report_final-1.pdf

[24] "1990-2021 Connecticut Greenhouse Gas Emissions Inventory." CT.gov. Connecticut Department of Energy and Environmental Protection. https://portal.ct.gov/DEEP/Climate-Change/CT-Greenhouse-Gas-Inventory-Reports

[25] "Appendix C: Massachusetts Annual Greenhouse Gas Emissions Inventory: 1990-2020, with Partial 2021 & 2022 Data." Commonwealth of Massachusetts Department of Environmental Protection. https://www.mass.gov/lists/massdep-emissions-inventories.

[26] "Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990 – 2017." Vermont Department of Environmental Conservation. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf.

[27] U.S. Energy Information Administration (EIA) Natural Gas Explained: Use of Natural Gas Basics: https://www.eia.gov/energyexplained/natural-gas/use-of-natural-gas.php

[28] "U.S. Natural Gas Consumption by End Use." Natural Gas. EIA. https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm.

[29] "About SEDs." United States Profile State Profiles and Energy Estimates. EIA. https://www.eia.gov/state/seds/.

[30] "Resources by Subpart for GHG Reporting." Greenhouse Gas Reporting Program (GHGRP). Environmental Protection Agency. https://www.epa.gov/ghgreporting/resources-subpart-ghg-reporting.

[31] Note: The EPA SIT, an Excel-based tool for completing a governmental GHG inventory that complements the U.S. inventory and international GHG protocols, is separate from the EPA Oil and Gas Tool, which encompasses sectors other than the oil and natural gas sector and is meant for criteria pollutant inventories. https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool

[32] "Subpart W – Petroleum and Natural Gas Systems." Environmental Protection Agency. https://www.epa.gov/ghgreporting/subpart-w-petroleum-and-natural-gas-systems.

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