New York State Oil and Gas Sector: Methane Emissions Inventory 1990–2022

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NEW YORK STATE

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New York State Energy Research and Development Authority

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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, 1990–2022

Final Report

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Abstract

Methane (CH_4) is a greenhouse gas that contributes significantly to global climate change, second only to carbon dioxide (CO_2). Fossil fuel production and consumption, including the extraction, processing, and distribution of natural gas, are significant sources 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.

Using a literature review and best practices, Abt developed a geospatially resolved, bottom-up CH_4 emissions inventory for the oil and natural gas sector from 1990 to 2022. In 2022, CH_4 emissions from oil and natural gas activities in the State totaled 157,699 metric tons (MT) CH_4, equivalent to 13,246,755 metric tons of carbon dioxide equivalent (MT CO_2e) Fifth Assessment Report 20-year global warming potential (AR5 GWP20). Downstream emissions accounted for 5,539,359 MT CO_2e in 2022 (41.82%), midstream emissions for 4,816,982 MT CO_2e (36.36%), and upstream sources for 2,890,414 MT CO_2e (21.82%). These results demonstrate that the State is primarily a consumer of natural gas, with midstream and downstream source driving 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

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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.

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Acronyms and Abbreviations

~	approximately
±	plus or minus
AF	allocation factor
AR4	Fourth Assessment Report (2007)
AR5	Fifth Assessment Report (2014)
AWR	annual well report
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
Climate Act	New York State Climate Leadership and Community Protection Act
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CS	compressor station
DD	drilling days
DEC	New York State Department of Environmental Conservation
D-J	Denver-Julesburg
EDF	Environmental Defense Fund
EF	emissions factor
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ESOGIS	Empire State Organized Geologic Information System
EU Inventory	Annual European Union Greenhouse Gas Inventory 1990–2016 and Inventory Report 2018
EU	European Union
FLIGHT	Facility Level Information on GreenHouse Gases Tool

g	gram
g/GJ	grams per gigajoule
Gg	gigagram
Gg/yr	gigagram per year
GHG	greenhouse gas
GHGRP	Greenhouse Gas Reporting Program
GRI	Gas Research Institute
GWP	global warming potential
GWP100	global warming potential (100 year)
GWP20	global warming potential (20 year)
h	hour
H_2O	water
H_2S	hydrogen sulfide
HAP	hazardous air pollutants
hp	horsepower
hp-hr	horsepower hour
hr	hour
HVHF	high-volume hydraulic fracturing
IPCC	Intergovernmental Panel on Climate Change
ITRC	Interstate Technology and Regulatory Council
Kg	kilogram
kg/GJ	kilograms per gigajoule
kg/hr	kilograms per hour
kg/meter	kilograms per meter
kg/mi	kilograms per mile
kg/service	kilograms per service
kg/TJ	kilograms per terajoule
km	kilometer
L	liter
LAUF	lost and unaccounted-for
lb	pound
LNG	liquefied natural gas
m	meter
M&R	metering and regulating
Mcf	thousand cubic feet
Mg	megagram
Mg/L	milligrams/liter
MMBTU	million British thermal unit
MMcf	million cubic feet

MMscf	million standard cubic feet
MMT CO_2e	million metric tons of carbon dioxide equivalent
MMT	million metric ton (1 MMT = 1 teragram)
MT CO_2e	metric tons of carbon dioxide equivalent
MT	metric ton
MT/year	metric tons/year
N_2O	nitrous oxide
NAICS	North American Industry Classification System
NEI	National Emissions Inventory
NG	natural gas
NSPS	New Source Performance Standards
NYS GHG Inventory	New York State Greenhouse Gas Inventory
NYS	New York State
NYSERDA	New York State Energy Research & Development Authority
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
RBSA	Residential Building Stock Assessment
RECS	Residential Energy Consumption Survey
RSBS	Residential Statewide Baseline Study
SCC	Source Classification Code
scf	standard cubic foot
scf/hr	standard cubic foot per hour
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 noncatalytic reduction
TD	top-down
U.S. GHG Inventory	U.S. Greenhouse Gas Inventory
UNFCCC	United Nations Framework Convention on Climate Change
VOC	volatile organic compound

Summary

Methane (CH_4) is a greenhouse gas (GHG) that contributes to global climate change, second only to carbon dioxide (CO_2). 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" (AR5) of the Intergovernmental Panel on Climate Change (IPCC 2014). Fossil fuel production and consumption, including the extraction and processing of natural gas and the distribution of natural gas to homes and businesses, are significant sources of anthropogenic CH_4 emissions.

In 2019, New York State passed the Climate Leadership and Community Protection Act (Climate Act). The Climate Act is among the most ambitious climate laws in the world, requiring the State to reduce economywide greenhouse gas emissions by 40% by 2030 and by no less than 85% by 2050 from 1990 levels. This project aims to support CH_4 emission reduction efforts in New York State and help achieve the Climate Act's 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 works toward its ambitious climate goals.

The inventory developed under this project occurred in four iterations. The first iteration incorporated findings from empirical research and used the most accurate, current, and inventory-appropriate data sources available at the time. The application of state-of-the-art practices and emission factors (EFs) represented a significant methodological advancement over other available tools, which often rely on outdated 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 for New York State. This inventory focused on four best practices:

1. Using appropriately scaled activity data
2. Including state-of-the-art emission factors
3. Ensuring geospatial resolution of activities and emissions
4. Applying and reporting uncertainty factors, including high-emitting sources

The original iteration of this project sought to update the New York State Greenhouse Gas Inventory (NYS GHG 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) of experts on air pollutant emissions from the oil and natural gas sector provided technical oversight and peer review throughout the first iteration. The original report for the first iteration was published in 2019 and included data for 1990–2017.

Following the best practices established during the first iteration, the second iteration focused on updating activity data and EFs to the latest found in the literature and extending the most recent year to 2020. During the second iteration, source categories were added to the inventory to address identified gaps. These results provide essential resources for supporting rulemaking and regulations to reduce CH_4 emissions from the oil and natural gas sector. The inventory also 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 effects of current regulations, such as U.S. Environmental Protection Agency's (EPA) proposed changes to the 2016 New Source Performance Standards (NSPS) for the oil and gas industry or the EPA's 2022 Inflation Reduction Act. In addition, the inventory gives New York State the flexibility to revise the current inventory or generate future inventories by updating activity data and EFs as improved data become available and as technological changes in the industry occur. The inventory is now updated annually, with the most recent inventory estimating emissions through 2022.

The third iteration reflects changes made in response to the Climate Act. The Climate Act requires the State to report emissions in CO_2 equivalents (CO_2e) using the AR5 IPCC assessment report 20-year global warming potential (GWP20) values rather than AR4 100-year global warming potential (GWP100) values, which are typically used in national and state inventories and were used in the project's first iteration (IPCC 2007, 2014). Using GWP20 further emphasizes the contribution of methane to global climate change.

The current report represents the most recent inventory, with updates made to bring the data through 2022 and to improve EFs and additional sources based on more recent data and scientific studies.

Table S-1 compares emissions from key inventory years from the first NYS GHG Inventory (1990–2015) to the first iteration of the NYS Oil and Gas Sector Methane Emissions Inventory (1990–2017), the second iteration of the NYS Oil and Gas Sector Methane Emissions Inventory (1990–2020), the third iteration of the NYS Oil and Gas Sector Methane Emissions Inventory (1990–2021) and the most recent iteration (1990–2022).

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 of carbon dioxide equivalent (MMT CO_2e; AR4 GWP100). The first iteration's results estimated CH_4 emissions to be 27% higher than previous estimates for 2015 from natural gas systems (2.22 MMTCO_2e, AR4, GWP100), 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 MMT CO_2e (AR4 GWP100), or 8.951 MMT CO_2e (AR5 GWP20). The second iteration inventory estimates 2017 emissions to total 14.7 MMT CO_2e (AR5 GWP20), resulting in a 64% increase compared to the first iteration. This increase is due to the addition of beyond-the-meter sources and updates to distribution and conventional production EFs. When comparing the second iteration to the original 2015 inventory, emissions are approximately 113.5% higher after converting the 2015 estimates to AR5 GWP20.

The third iteration estimates CH_4 emissions to be 6.2% higher than in the second iteration. In 2021, CH_4 emissions from oil and natural gas activities in New York State totaled 176,051 MT CH_4, equivalent to 14.8 MMT CO_2e (AR5 GWP20). The fourth iteration estimates CH_4 emissions to be 11.39% lower than the third iteration. In 2022, CH_4 emissions from these activities in New York State totaled 157,699 MTCH_4, equivalent to 13.2 MMT CO_2e (AR5 GWP20).

Figure S-1 shows CH_4 emissions by source category broken out by upstream, midstream, and downstream categories, using AR5 GWP20 units. Downstream emissions totaled 5.539 MMT CO_2e, accounting for 41.82% of total CH_4 emissions. As in previous inventories, cast-iron steel mains are the largest single-source in the downstream category, followed by unprotected steel mains and services. Midstream emissions totaled 4.817 MMT CO_2e, accounting for 36.36% of emissions, with compressors (storage and transmission) comprising the largest source categories. In fact, storage and transmission compressor stations are two of the largest single-source categories identified in New York State, surpassed only by conventional gas wells, which dominate upstream emissions. Upstream emissions totaled 2.890 MMT CO_2e, accounting for 21.82% of total CH_4 emissions. These totals reflect the fact that the State is primarily a consumer of natural gas, so midstream and downstream source categories drive the majority of CH_4 emissions.

Table S-1. Comparison of Total Emissions across Key Inventory Years

Data was compiled from three inventories; emissions are reported in MMT CO_2e, using AR4 and AR5 GWP100 and GWP20 values.

Inventory	AR4 GWP100	AR4 GWP20	AR5 GWP100	AR5 GWP20
1990				
NYS GHG Inventory, 1990–2015	2.8	8.06	3.14	9.41
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	2.74	7.88	3.07	9.21
NYS Oil and Gas Methane Emissions Inventory, 1990–2020	5.17	14.89	5.80	17.40
NYS Oil and Gas Methane Emissions Inventory, 1990–2021	5.42	15.60	6.07	18.20
NYS Oil and Gas Methane Emissions Inventory, 1990–2022	4.97	14.33	5.57	16.71
2005				
NYS GHG Inventory, 1990–2015	3.5	10.07	3.93	11.76
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	3.52	10.12	3.95	11.83
NYS Oil and Gas Methane Emissions Inventory, 1990–2020	6.15	17.72	6.93	20.73
NYS Oil and Gas Methane Emissions Inventory, 1990–2021	6.42	18.48	7.19	21.56
NYS Oil and Gas Methane Emissions Inventory, 1990–2022	5.96	17.15	6.67	20.01
2015				
NYS GHG Inventory, 1990–2015	2.22	6.39	2.49	7.46
NYS Oil and Gas Methane Emissions Inventory, 1990– 2017	2.82	8.12	3.16	9.48
NYS Oil and Gas Methane Emissions Inventory, 1990– 2020	4.74	13.65	5.31	15.92
NYS Oil and Gas Methane Emissions Inventory, 1990–2021	4.98	14.34	5.58	16.73
NYS Oil and Gas Methane Emissions Inventory, 1990–2022	4.46	12.85	5.00	15.00

Figure S-1. Methane Emissions by Source Category in New York State, 2022

This figure shows CH_4 emissions by source category, grouped by upstream, midstream, and downstream stages.

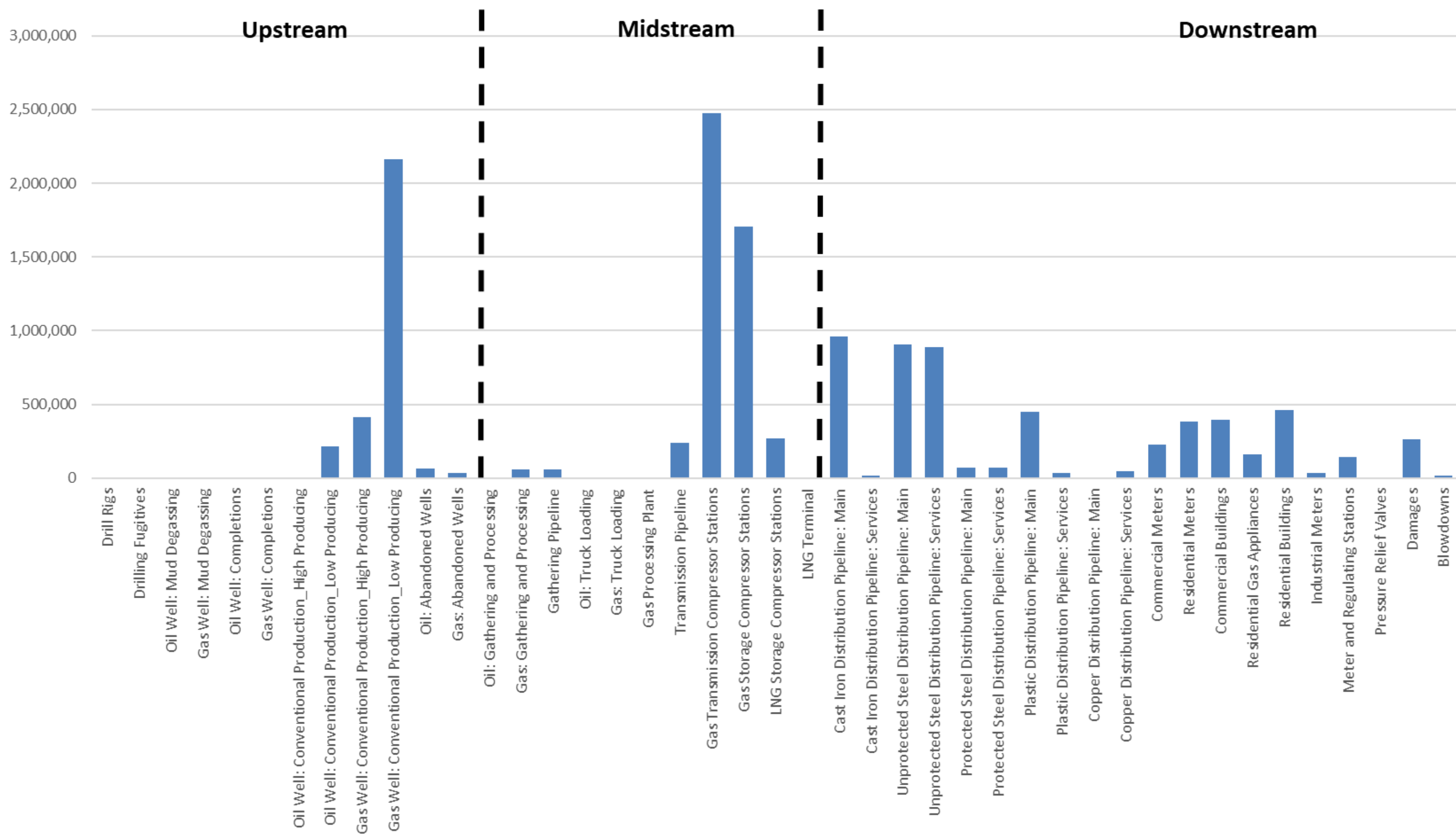


Figure S-2 shows the distribution of emissions by county. The counties with the largest emissions align with areas of high oil and natural gas exploration and production in Western New York and areas with high population, gas services, and consumption around New York City and Long Island. Downstream emissions in counties corresponding to New York City and Long Island (New York, Kings, Bronx, Richmond, Queens, Nassau, and Suffolk) total 4.44 MMT CO_2e, or approximately 75.8% of total downstream emissions. As shown in Figure S-2, Erie County had the highest total CH_4 emissions in 2022, accounting for 10.5% of statewide CH_4 emissions from the oil and natural gas sector, followed by Chautauqua County at 10.1%. Erie County ranked second in conventional gas production from low-producing wells in New York State, had the largest transmission pipeline (378 miles) and second-highest number of compressor stations (five gas transmission compressor stations and six gas storage compressor stations), contributing to high midstream emissions. Chautauqua County ranked highest in gas gathering and processing and low-producing conventional gas production, which led to high upstream and midstream emissions. The top five counties (Erie, Chautauqua, Kings, Steuben, and Queens) accounted for 40% of statewide CH_4 emissions in 2022.

Figure S-2. Map of Methane Emissions by County in New York State, 2022

Calculated using AR5 GWP20 values.

Source: Mapbox 2024; OpenStreetMap 2024.

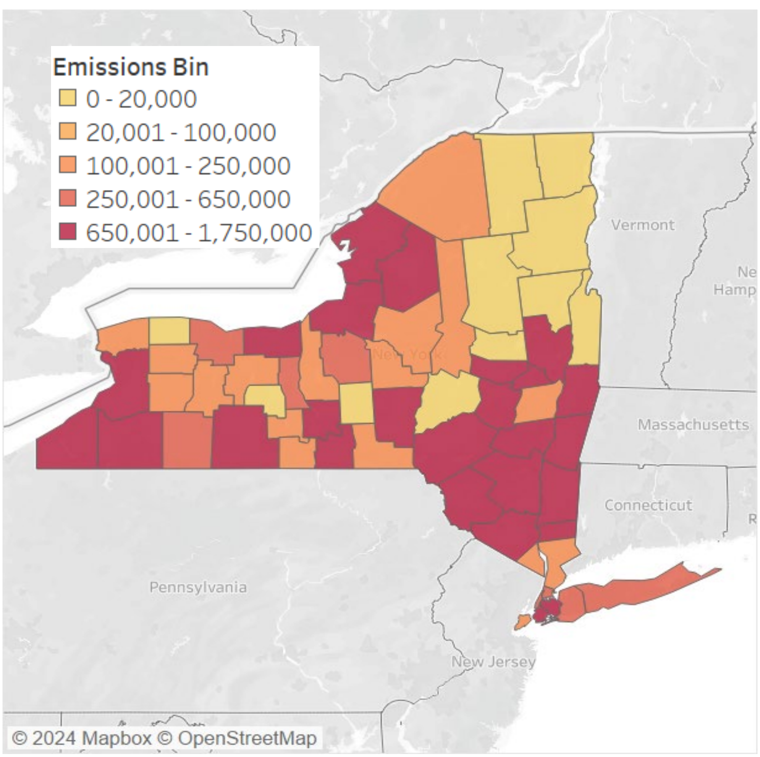
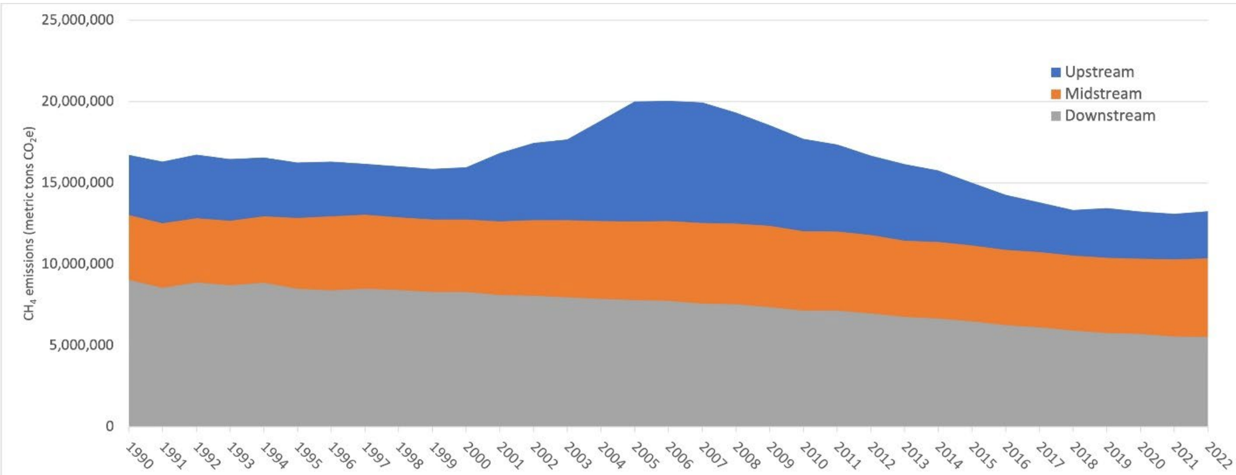


Figure S-3 shows that total CH_4 emissions in New York State from 1990 to 2022 generally increased until peaking at 21.564 MMT CO_2e in 2005. Since 2005, CH_4 emissions have decreased each year, except for a slight increase in 2019. Total CH_4 emissions have decreased 31.4% since their peak in 2005.

Figure S-3. Total Methane Emissions in New York State, 1990–2022

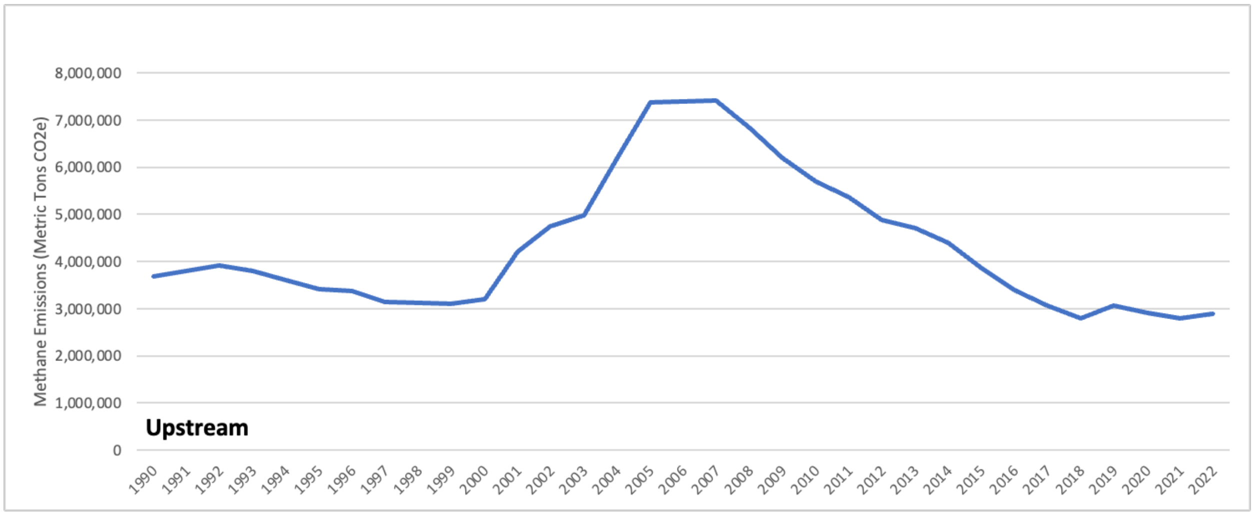
Calculated using AR5 GWP20 values.



Upstream CH_4 emissions (Figure S-4), though smaller than midstream and downstream emissions, have shown more significant 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 MMT CO_2e in 2007, corresponding with the peak in natural gas prices, production, and well completions. Since 2007, well completions have fallen to zero, and natural gas production is now around one-fifth of its peak, resulting in an overall decline in emissions from upstream source categories. Upstream emissions decreased 24% from 1990 to 2022 and 62.2% from 2007 to 2022.

Figure S-4. Upstream Methane Emissions in New York State, 1990–2022

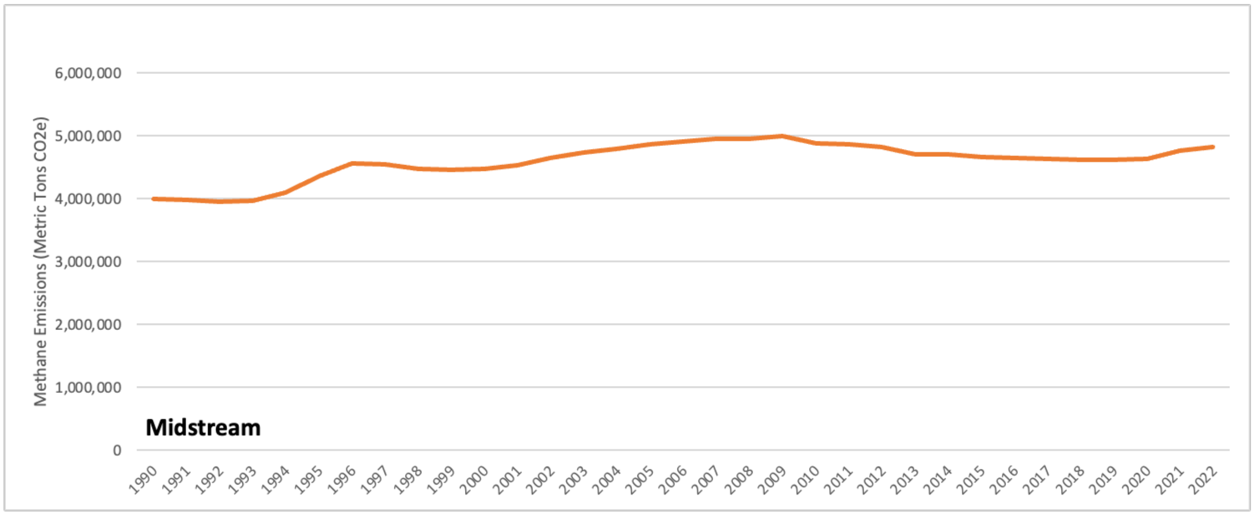
Calculated using AR5 GWP20 values.



Midstream CH_4 emissions (Figure S-5) increased from 1990 to 2022 by 16.8%. Midstream emissions are primarily a function of transmission and storage compressor stations and transmission pipelines. The 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, 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 2022. Correspondingly, midstream emissions peaked in 2009 from the addition of transmission compressor stations and transmission pipelines but have declined by 4.6% due to declining natural gas production and subsequent natural gas gathering in the State.

Figure S-5. Midstream Methane Emissions in New York State

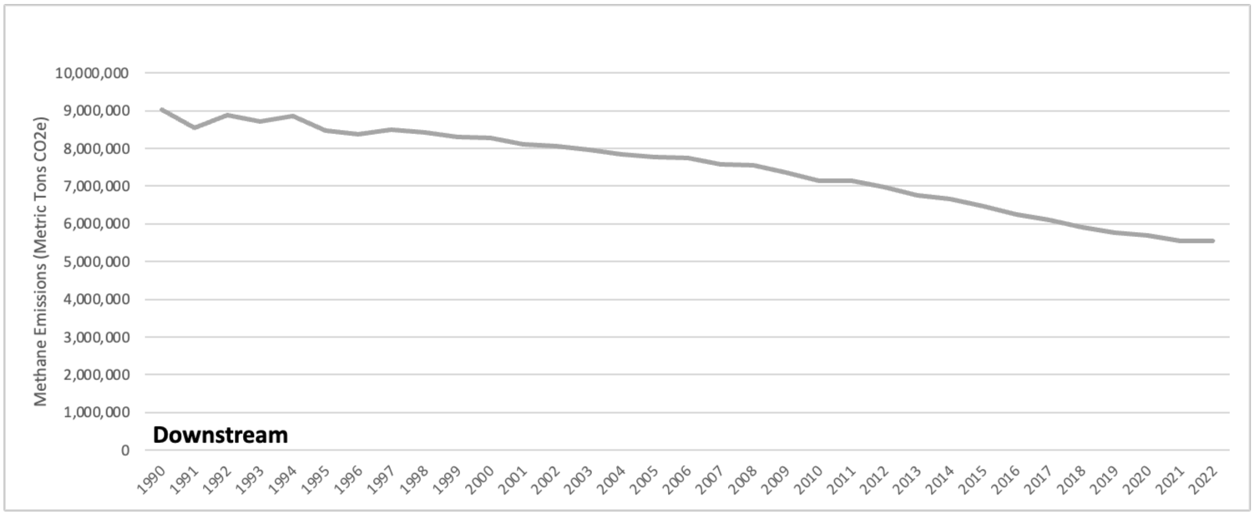
Calculated using AR5 GWP20 values.



Downstream CH_4 emissions (Figure S-6) decreased 36.8% from 1990 to 2022. The two largest source categories in downstream emissions, cast-iron and unprotected steel distribution main pipelines, have decreased since 1990 because they have been mainly 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. Although increasing consumption in New York State has led to growth in the number of residential services and meters, any emissions from these components are outweighed by the transition from cast-iron and unprotected steel distribution lines to plastic.

Figure S-6. Downstream Methane Emissions in New York State

Calculated using AR5 GWP20 values.



The identified activity patterns align with national trends in CH_4 emissions. To validate this emission inventory, comparisons were made with the EPA's nationwide and adjacent state inventories. A comparison with the national inventory shows that New York State CH_4 emissions account for 6.39% of the total national oil and natural gas emissions. A comparison with inventories from adjacent states shows that NYS oil and gas emissions are approximately one-third of those from Pennsylvania, which has much higher upstream production and similar downstream consumption.

1 Introduction

In 2019, New York State (NYS) passed the Climate Leadership and Community Protection Act (Climate Act). The Climate Act is among the most ambitious climate laws in the world and requires the State to reduce economywide greenhouse gas (GHG) emissions by 40% by 2030 and by no less than 85% by 2050, compared to 1990 levels. The project aims to support methane (CH_4) emission reduction efforts in New York State and help achieve the Climate Act goals by improving the State's understanding of CH_4 emissions and accounting methodologies for the oil and natural gas sector. Improved accounting methodologies are needed to develop an activity-driven, site-level CH_4 emissions inventory for upstream, midstream, and downstream sources. This inventory will inform mitigation strategies and measure progress in reducing fugitive CH_4 emissions from the oil and natural gas sector as the State works toward its climate goals. Therefore, the inventory developed under this project incorporates findings from the latest empirical research and uses the most accurate and current data sources to create an activity-driven, site-level CH_4 emissions inventory.

The inventory developed under this project occurred in four iterations. The project's original iteration aimed to update the New York State Greenhouse Gas (NYS GHG) Inventory for 1990–2015 and implement best practices to improve and develop an activity-driven, geospatially-resolved, CH_4 emissions inventory for the oil and natural gas sector. These practices include:

1. Using appropriately scaled activity data
2. Including state-of-the-art emission factors (EFs)
3. Ensuring geospatial resolution of activities and emissions
4. Applying and reporting uncertainty factors, including for high-emitting sources

To ensure project rigor, a six-member Project Advisory Committee (PAC) of experts with knowledge of air pollutant emissions from the oil and natural gas sector provided technical oversight and peer review throughout the first iteration. The report for this iteration was published in 2019, covering data years 1990–2017; the second report, published in 2022, covered 1990–2020; and the third iteration, published in 2023, covered 1990–2021. The current report, the fourth iteration, published in 2024, brings the data up to date through the 2022 current inventory year, improves emissions factors, and incorporates additional sources.

The first iteration, completed in 2019, had four specific objectives:

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 related studies
3. Developing an improved CH_4 emission-accounting methodology
4. Implementing the methodology to create an updated CH_4 emissions inventory for the oil and natural gas sector in the State

For the second iteration, the project made further updates on the initial assessment and development of the NYS oil and gas CH_4 inventory. Additional objectives for the second, third, and fourth iterations included:

1. Assessing areas for improvement in NYS's oil and natural gas sector CH_4 emissions inventory
2. Reviewing the latest data on fugitive oil and gas CH_4 emissions in the State
3. Incorporating this data to create an updated CH_4 emissions inventory

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

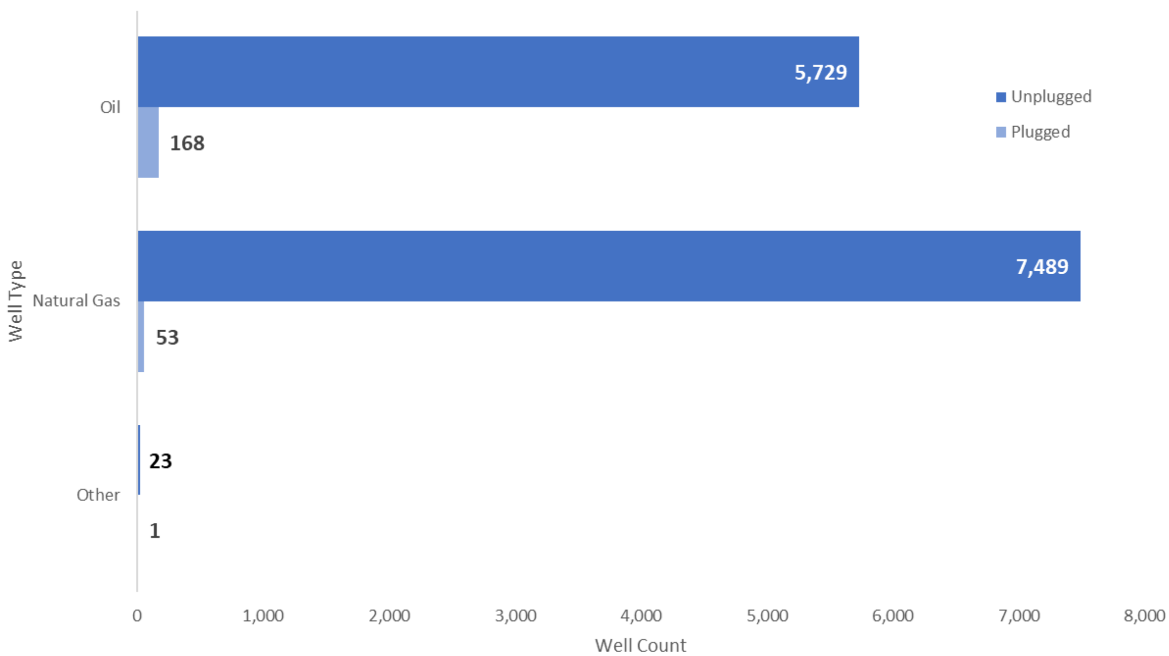
This section characterizes oil and gas wells, discusses oil and gas production, and provides an overview of the associated oil and gas infrastructure.

2.1 Oil and Gas Wells in New York State

In 2022, New York State had 7,489 unplugged natural gas wells and 53 plugged natural gas wells (DEC 2024a). In addition, the State had 5,729 unplugged oil wells and 168 plugged oil wells (Figure 1), along with 23 unplugged wells of other types and 23 plugged wells of other types. Plugged wells are no longer in use, and the borehole is sealed with cement or another impermeable substance to prevent contamination of the environment by the underlying hydrocarbon formation.

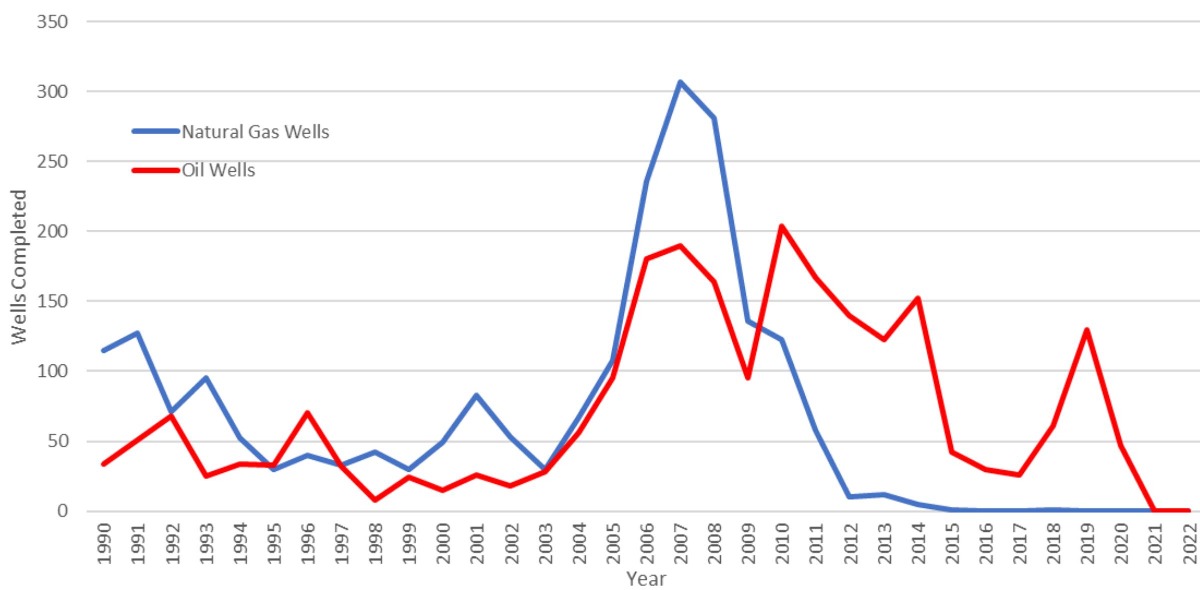
Figure 1. Open Hole and Plugged Wells in New York State, 2022

Source: NYS DEC 2024a.



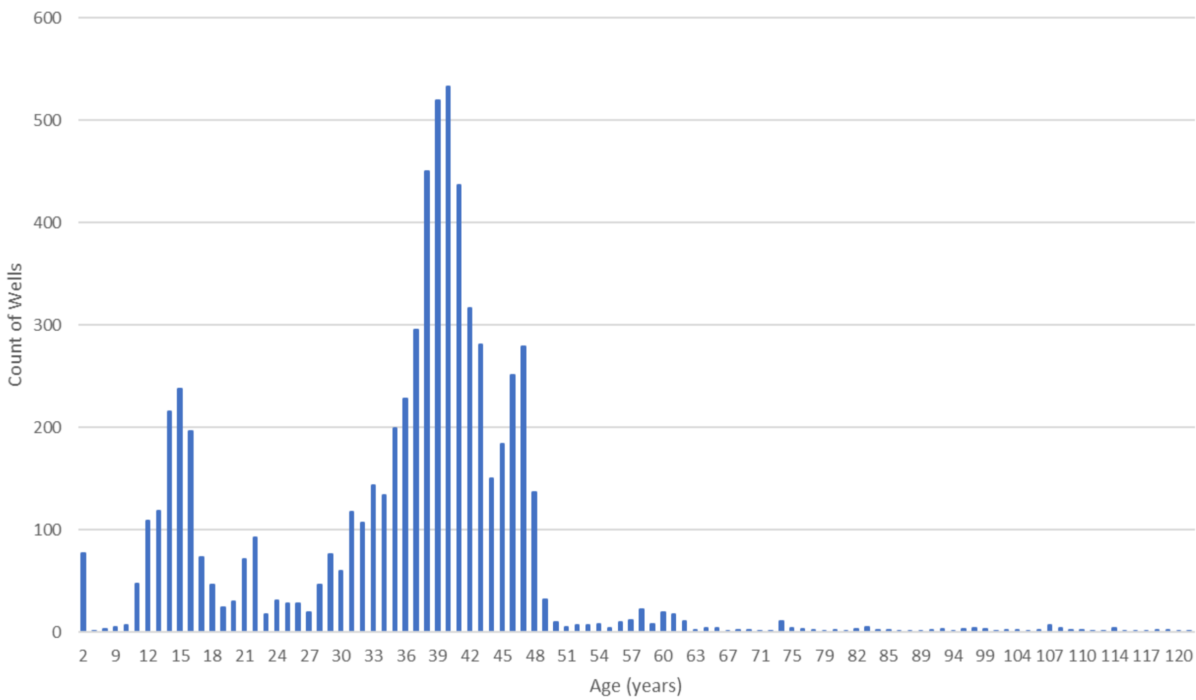
Gas well development in New York State increased significantly in the 1970s, peaking in 1982 when 611 wells were drilled and put into production, followed by a decline until the mid-2000s. A secondary installation spike occurred between 2006 and 2008 (Figure 2). After 2008, natural gas well completions dropped to fewer than 10 per year. High-volume hydraulic fracturing (HVHF), or fracking, was banned in the State in 2014. Oil well completions followed a similar cyclical pattern, with increased activity from 1973 to 1985 and 2006 to 2014. Both sectors correlate with oil and natural gas price fluctuations, with higher activity during high fuel prices and lower activity during low fuel prices. The deregulation of oil and natural gas markets also contributed to increased production and consumption of natural gas while reducing prices.

Figure 2. Oil and Natural Gas Wells Completed per Year in New York State, 1990–2022



The age distribution of natural gas wells producing in New York State in 2022 (Figure 3) followed a bimodal pattern similar to that seen in Figure 2. The data show a primary peak of wells aged 12 and 13 years and a secondary peak aged 37 and 38 years. Comparing Figures 2 and 3, well age and completions follow a similar bimodal pattern, suggesting that older wells can remain in production for many years. Although more completions occurred in the 1970s and 1980s, 14.7% of currently operational wells were completed in the last 15 years, and 88.4% of wells younger than 45 years.

Figure 3. Age Distribution of Gas Wells Producing, 2022



2.2 New York State Oil and Natural Gas Production

Natural gas production in New York State far outweighs oil production, 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. However, natural gas production declined to 9.44 Bcf, or 1.67 million BOE in 2022. Oil production also fell to 265,835 bbl in 2022. Because New York State lacks in-state oil refineries, all the oil produced is refined out of State, primarily in Pennsylvania (DEC 2006).

As shown in Figure 5, 650 out of 9,359 wells (6.95%) accounted for 50% of natural gas production in New York State in 2022, 23.26% of the wells accounted for 75% of natural gas production, and nearly all (99%) of production came from 6,932 wells (74.07%). These data demonstrate that a comparatively small number of wells produce most natural gas and that production is not evenly distributed across those wells. A similarly skewed distribution occurred in oil production, with 340 out of 3,557 wells (9.56%) accounting for 50% of production, 825 wells (23.19%) accounting for 75%, and 2,012 wells (56.56%) accounting for 99% of production in 2022.

Figure 4. Oil and Natural Gas Production in New York State, 2000–2022

The scale for natural gas production (left) is 10 times larger than oil production (right).
1 BOE = 5.65853 Mcf natural gas.

Source: DEC 2022.

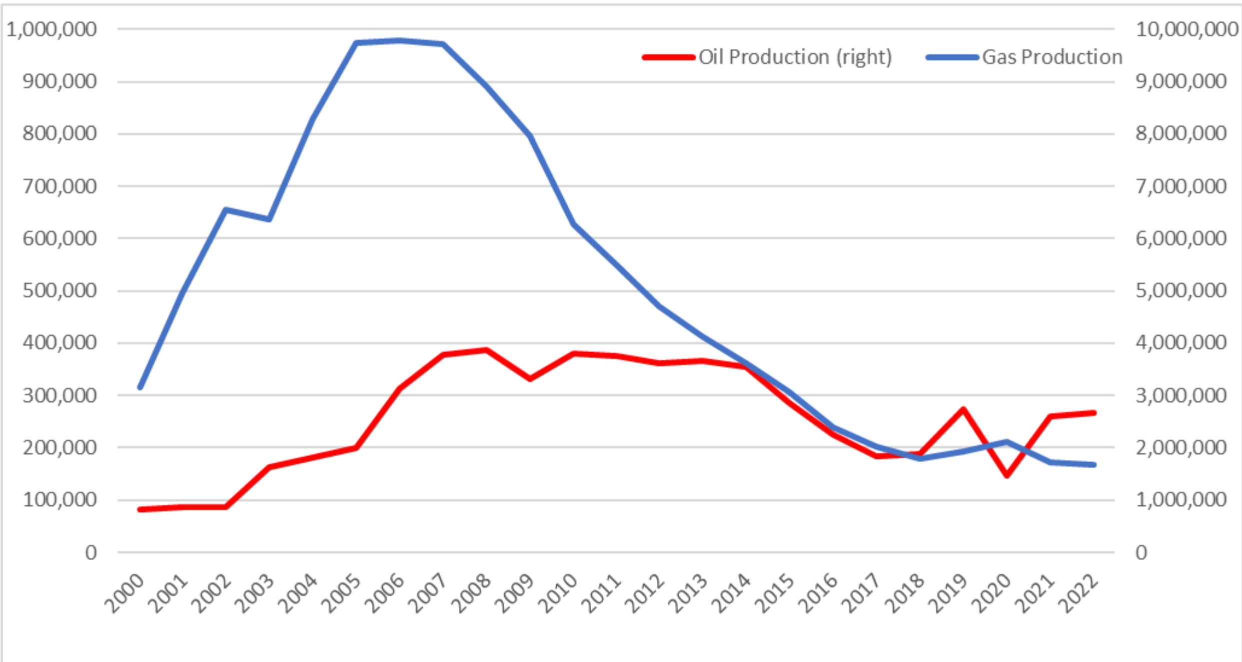


Figure 5. Relationship between Percent of Total Cumulative Oil and Natural Gas Production and Well Count in New York State, 2022

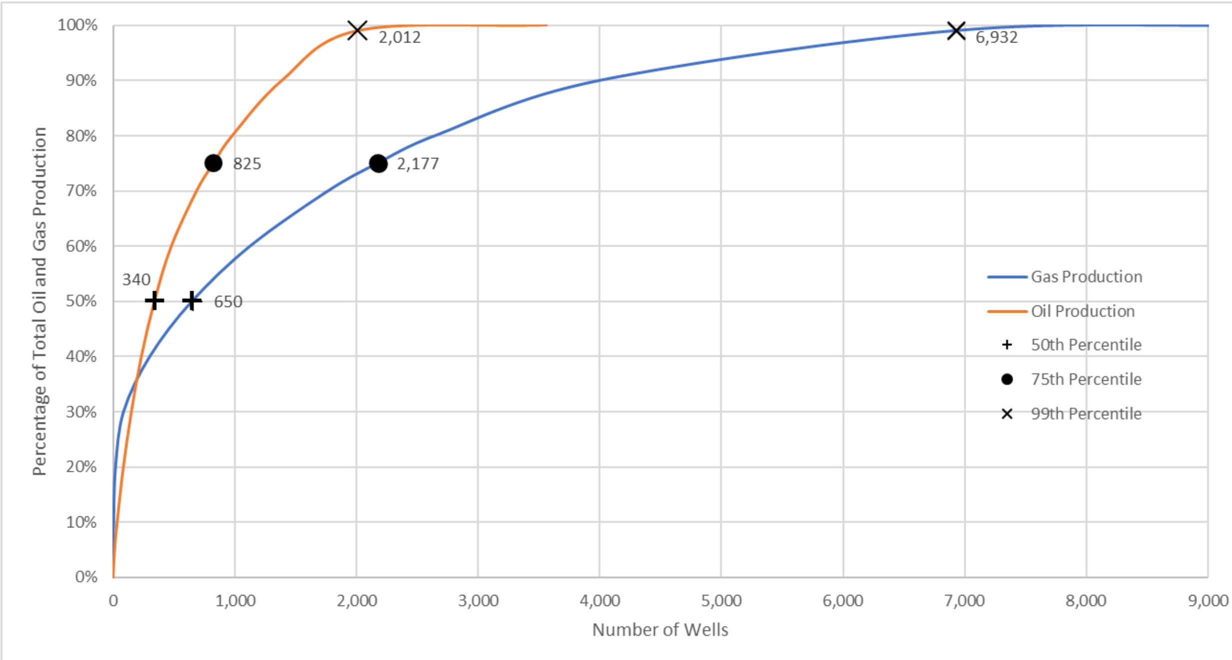
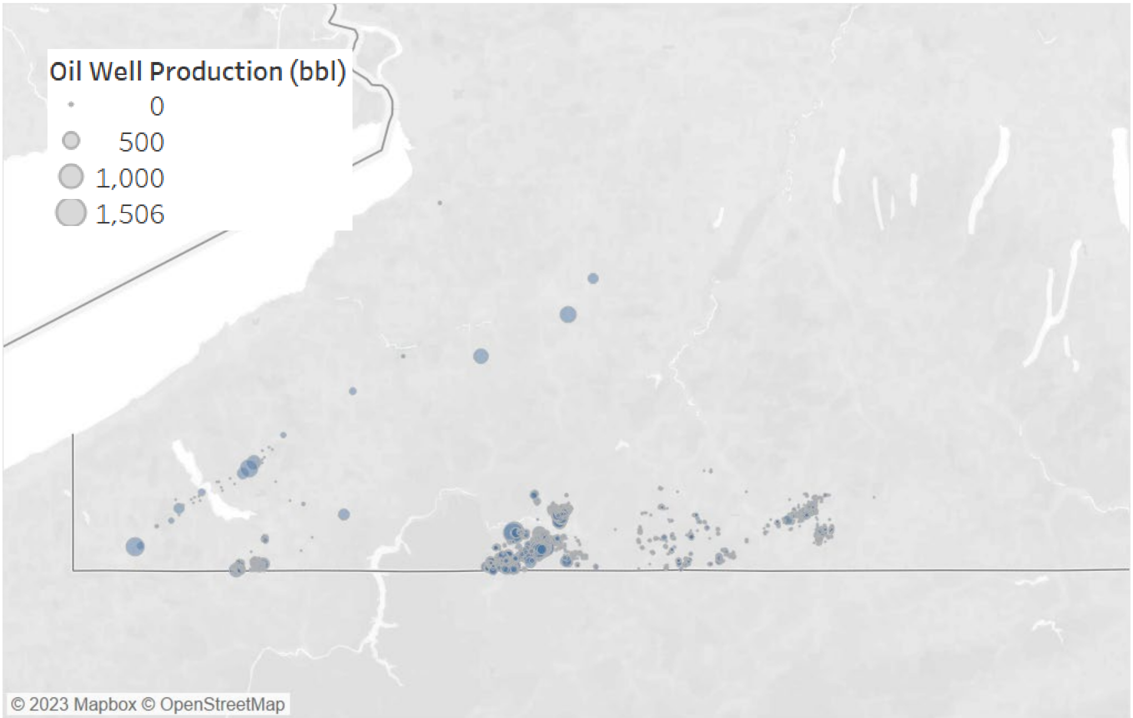


Figure 6 shows that oil and natural gas production in New York State is mainly concentrated in Western New York, west of the line delineating the eastern boundary of Broome, Chenango, Madison, Oneida, and Lewis counties. Oil production is mainly concentrated in the far west of New York State, in Allegany, Cattaraugus, Chautauqua, Erie, and Steuben counties.

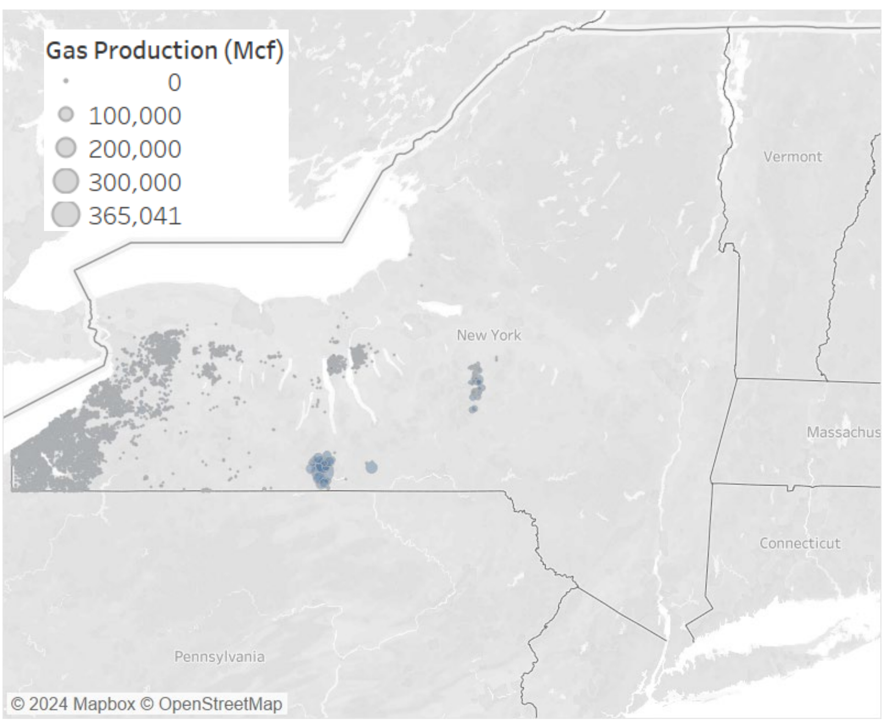
Figure 6. Oil and Natural Gas Well Locations and Production in New York State, 2022

Oil Map: No oil-producing wells are located outside of Western New York.

Source: Mapbox 2024; OpenStreetMap 2024.



Natural Gas Map

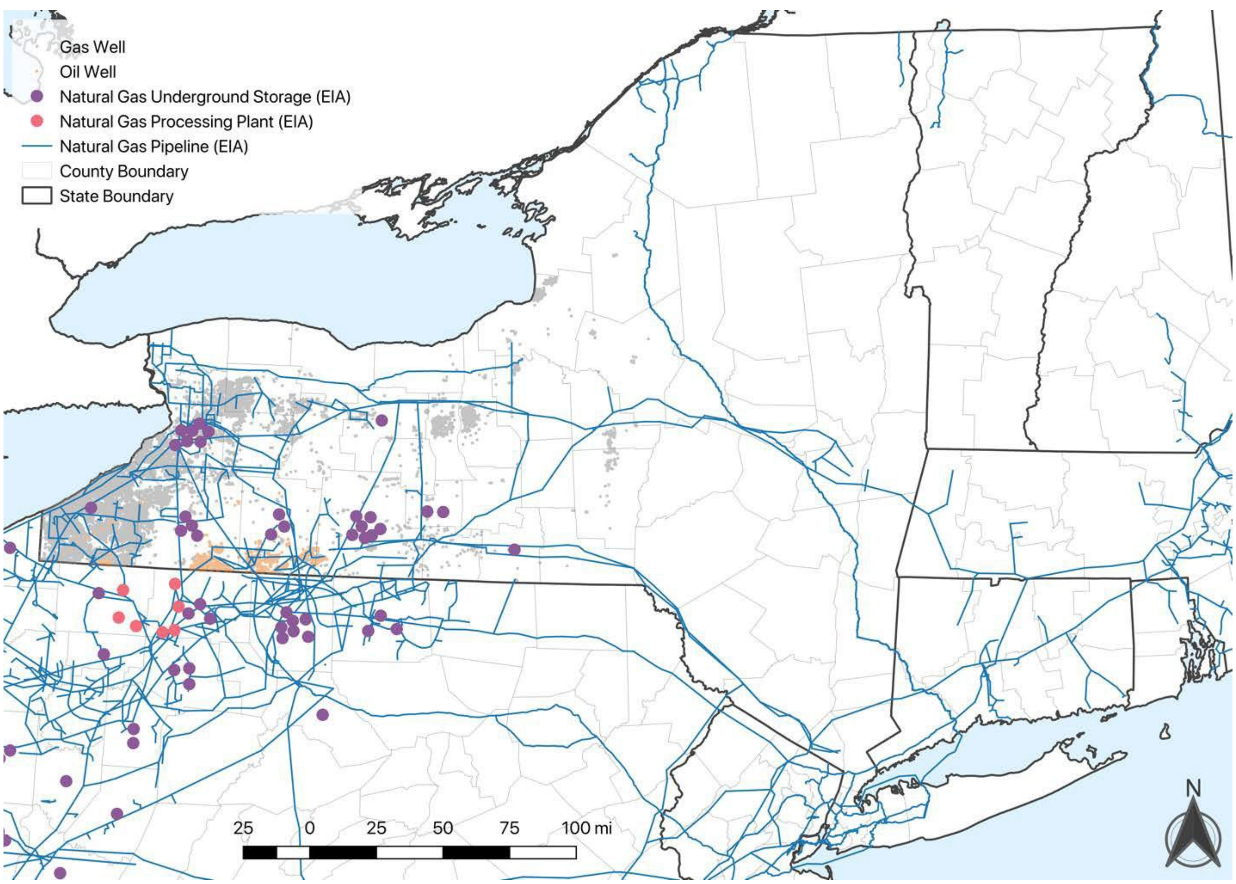


2.3 New York State Oil and Natural Gas Infrastructure

Figure 7 shows that oil and natural gas activities are concentrated in Western New York, where the density of wells and underground natural gas storage facilities is highest. These storage fields are located in former solution salt caverns and depleted reservoirs. According to data from the U.S. Energy Information Administration (EIA), no natural gas processing plants exist in New York State, with the nearest plants in northwestern Pennsylvania. EIA also identifies the greatest density of interstate and intrastate natural gas transmission pipelines in Western New York, near the production and storage wells, for removal and delivery. These pipelines are well-connected to Pennsylvania and link to Canada to the west and north. Two main pipeline trunks extend east-west across the State, one along the southern Pennsylvania border, connecting to New York Metropolitan Area pipelines, and another connecting farther north to the Albany and Buffalo regions.

Figure 7. Oil and Gas Locations and Infrastructure in New York State and Surrounding States

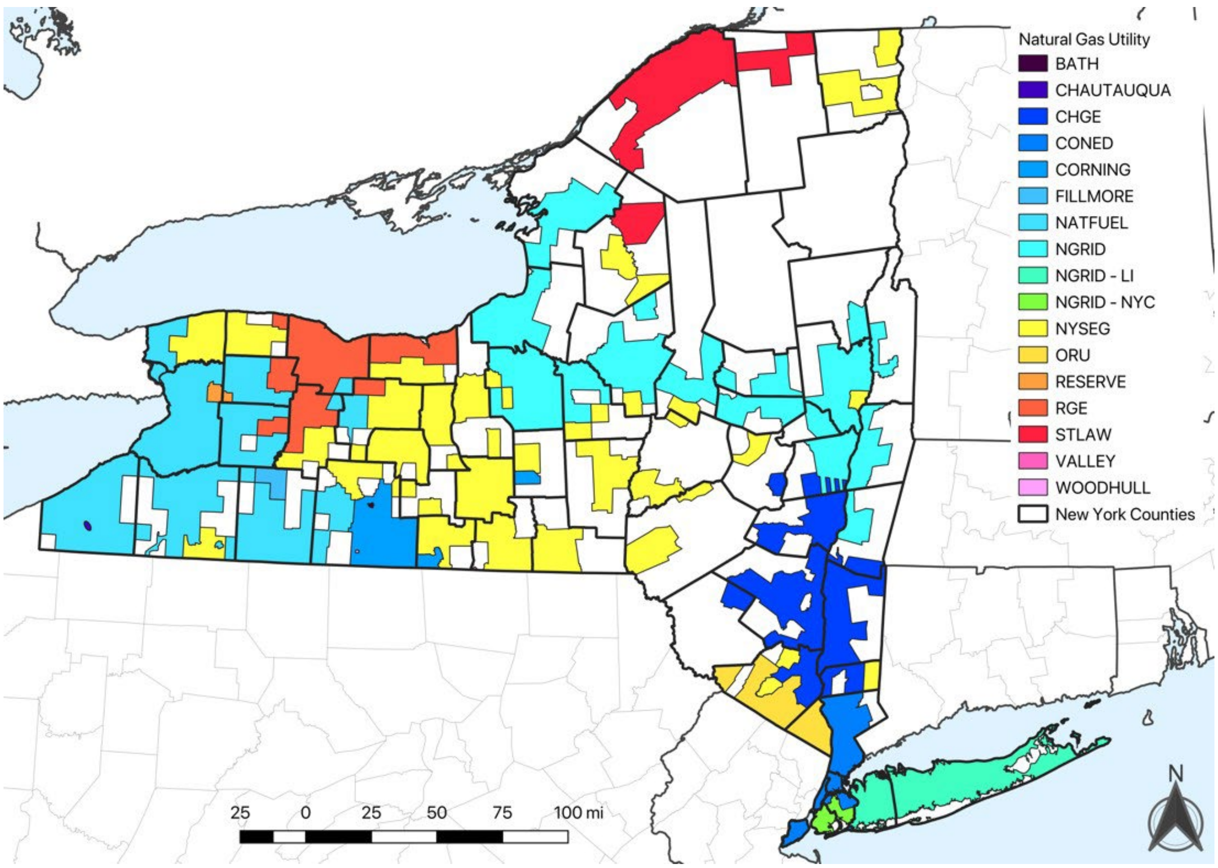
The map shows oil and gas well locations, processing plants, pipelines, underground storage, and shale plays in New York and surrounding states.



New York State has 17 natural gas utility service territories (Figure 8), covering about 94% of the households identified by the U.S. Census Bureau. According to the census data, 54% of households within natural gas utility service areas use natural gas as their primary home heating source. In addition, EIA data show 430,368 commercial and industrial end users of natural gas in the State. According to census data, 537,369 registered businesses in 2020; 96.9% are located within natural gas utility service areas. Of these businesses, 80.1% use natural gas.

Figure 8. Gas Utility Service Territories in New York State

Source: State of New York Open Data. 2023



3 Methane Emissions Inventory Development

3.1 Methane Emissions Literature Review

3.1.1 Overview

This section presents the results of a literature review, primarily conducted during the project's first iteration, to identify best practices for developing CH_4 inventory development and to provide inputs for improving the State's inventory models in the future.

During the first iteration, the team reviewed more than 100 peer-reviewed articles, reports, and tools focused on state-of-the-art CH_4 inventory development in the U.S. and internationally. The review emphasized emissions in the oil and natural gas sector. The team gave specific attention to three primary sources of information: (1) EPA's GHGRP (Greenhouse Gas Reporting Program) Subpart W (2017), (2) the EPA's "Facility Level Information on GreenHouse Gases Tool (FLIGHT; 2024)," and (3) the Environmental Defense Fund's (EDF's) 16 Study Series (2018). The team also reviewed the European Union's (EU's) most recent inventory report (European Environment Agency 2018) to explore differences between international and U.S.-centric inventory methodologies.

The literature highlights the rapid advancement of CH_4 inventory development. In the past decade, new data have enabled more geographically specific inventory development and greater certainty in emission estimates, ranging from routine leaks to episodic releases. The literature also discusses identifying the role of high-emitting sources, which have often previously been overlooked in conventional CH_4 inventories, but which can play a significant role in regional emission levels. The team used the literature review to inform the first iteration of the NYS Oil and Gas Methane Emissions Inventory (NYSERDA 2019a).

Section 3.1.2 presents key terminology to help readers better understand the following sections. Section 3.1.3 reviews existing CH_4 inventory approaches for oil and natural gas systems. Section 3.1.4 discusses key findings on EFs, spatial variability, and high-emitting sources.

3.1.2 Key Terminology

3.1.2.1 Oil and Natural Gas Supply Chain

The U.S. oil and natural gas supply chain is divided into nine main segments. For oil development, CH_4 emissions occur across four stages: (1) exploration, (2) production, (3) gathering and boosting, and (4) transmission. For natural gas development, CH_4 emissions occur across nine stages: (1) exploration,

(2) production, (3) gathering and boosting, (4) processing, (5) transmission, (6) underground storage, (7) liquefied natural gas (LNG) import and export terminals, (8) LNG storage, and (9) distribution, as shown in Figure 9 (Harrison et al. 1997a; Howarth 2014). These stages are grouped into three major categories: (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 during exploration are well completions and testing.
- **Production** refers to extracting crude oil or raw natural gas from underground formations using conventional drilling or unconventional methods. Emissions in the oil production stage typically come from leaks, pneumatic devices, storage tanks, and flaring of associated gases. Emissions during natural gas production depend on the extraction technology but typically include leaks, pneumatic controllers, unloading liquids from wells, storage tanks, dehydrators, and compressors. Because many wells produce oil and natural gas, distinguishing between oil and gas production is not always clear.
- **Gathering and boosting** stations receive natural gas from production sites/wells and via gathering pipelines, transferring the gas to transmission pipelines and/or processing facilities and distribution systems. Compression, dehydration, and sweetening (removal of foul-smelling sulfur compounds) occur in this segment. Emission sources include gathering stations, pneumatic controllers, natural gas engines, gathering pipelines, liquids unloading, and flaring.

3.1.2.3 Midstream Stages

- **Natural gas processing** removes impurities and other hydrocarbons, including liquids, from raw natural gas, producing pipeline-grade natural gas. Emissions from processing originate from reciprocating and centrifugal compressors, blowdowns, venting, and leaks.
- **Transmission and compression** involve moving natural gas from gathering lines and processing plants to city gates or high-volume industrial users through main transmission pipelines. Compressor stations along the pipelines maintain high pressure to move gas. Emission sources in this segment include compressor stations, venting from pneumatic controllers, uncombusted engine exhaust, and unburned and pipeline venting.
- **Underground storage** involves injecting natural gas into underground formations during periods of low demand and withdrawing it during periods of high demand. Emission sources include compressors and dehydrators.
- **LNG import/export terminal activities** involve the receiving and delivering LN for storage and eventual delivery.
- **LNG storage** entails storing LNG until it is ready for final distribution.

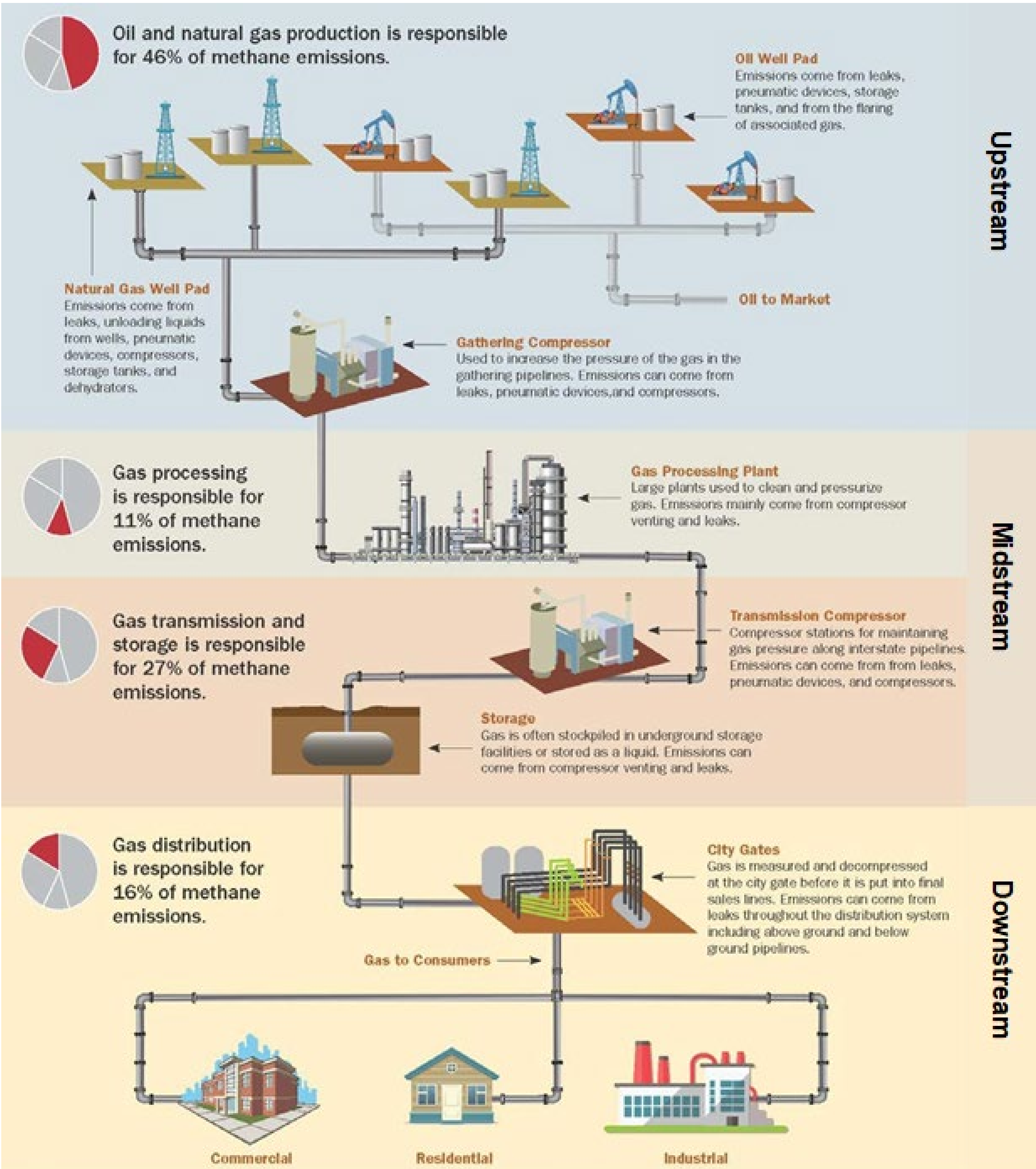
3.1.2.4 Downstream Stage

- **Distribution** 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 pressure is reduced. The gas is distributed through underground mains and service pipelines to the customer’s meter, marking the end of the downstream stage. Primary emission sources from this segment include leaks from pipes and metering and regulating (M&R) stations. Fugitive emissions after the customer meter are not considered here since they should be accounted for in the residential or commercial sector inventory.
- **Beyond-the-meter** end-use sources account for emissions from natural gas appliances and commercial and residential buildings. Discrepancies between top-down (TD) and bottom-up (BU) methodologies (see section 3.1.2.6) suggest that beyond-the-meter sources are a significant contribution to CH_4 emissions.

Figure 9. Oil and Natural Gas System Stages

Depiction of the oil and gas system, including upstream, midstream, and downstream stages. The fraction of emissions is based on the U.S. GHG Inventory (EPA 2014).

Source: McCabe et al. 2015.



3.1.2.5 Emission Source Categories

Emissions from oil and natural gas production systems fall into three main categories: (1) fugitive emissions, (2) vented emissions, and (3) combustion emissions (Kirchgessner 1997). These categories are defined as follows:

- **Fugitive emissions** are unintended emissions from equipment leaks (e.g., 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** are intentional releases of CH_4 (e.g., through pneumatics, dehydrator vents, regular maintenance, and chemical injection pumps).
- **Combustion emissions** are unburned CH_4 emitted during any production process (e.g., compressor exhaust or flares).

The following sections discuss these emissions types in the context of inventory development.

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 TD or BU methodologies. Definitions of these methodologies are as follows:

- **TD studies** calculate CH_4 emissions using observational techniques, such as airborne measurements, satellites, mobile measurement devices, and stationary sensors. These methods estimate aggregate CH_4 emissions from all sources in a region and then attempt to apportion emissions to different source categories. Allen (2014) notes that challenges 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 oil and natural gas activities. Generating EFs can be challenging and usually involves in situ or laboratory measurements, which are then extrapolated to develop 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, diverse equipment and activities population. Other uncertainties stem from inaccurate activity data, malfunctioning equipment, or poorly operated equipment (Allen 2016). Furthermore, emissions from various sources are not normally distributed, meaning using an "average" EF may lead to overestimation and underestimation (Littlefield et al. 2017). BU inventories are typically estimated at the component or site level. Estimating emissions from high-emitting sources is particularly challenging in BU studies because an accurate estimate requires prior knowledge of which sources are likely to be high-emitting or obtaining

a statistically representative sample, which is difficult to achieve without a large sample size. Finally, 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 (Miller et al. 2013; Brandt et al. 2014, 2016; Heath et al. 2015; Alvarez et al. 2018).

- **Site-level estimates** use a methodology similar to TD estimates, often estimating emissions from atmospheric concentrations, but then applying those estimates using a BU approach. These estimates are generated for each site (e.g., wellhead, compressor station). They are conducted at a smaller geographic scale than TD estimates, but at a larger scale than component-level BU estimates.

Uncertainty exists in both BU and TD approaches, and the literature suggests that national-level CH_4 inventories likely underreport actual emissions by 50% or more (Miller et al. 2013; Brandt et al. 2014). At the 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 nearly twice as large as the EPA reported, accounting for approximately 1.5% of natural gas production. This 1.5% may be on the low end because other studies have observed regional losses of 2%12% or more in the natural gas sector, suggesting that national CH_4 emissions could be three times higher than the EPA reports (Pétron et al. 2012; Karion et al. 2013; Caulton et al. 2014). The upper limit for fugitive emissions can be considered the difference between aggregated meter readings in the distribution segment and gas input 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

The 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 more than 25,000 metric tons of carbon dioxide equivalent (MT CO_2e) per year, using the GWP100 from AR4 (IPCC 2006) to convert CH_4 and other GHGs to CO_2e. Facilities self-identify and report annually. Owners and operators of these facilities calculate CO_2e emissions, file their results with the EPA, and maintain records.

Subpart W of the GHGRP specifically focuses on facilities in the oil or gas sectors (EPA 2018a). It includes emission sources from the following oil and natural gas segments. Definitions for Subpart W facilities vary across the following 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 MMT CO_2e, of which 186.7 MMT CO_2e was CO_2, 96.0 MMT CO_2e was CH_4, and 0.2 MMT CO_2e nitrous oxide (N_2O). Although the GHGRP data and the U.S. GHG Inventory are not directly comparable, total emissions in the U.S. for all sectors in 2016 was 6,511 MMT CO_2e (EPA 2018a), meaning Subpart W emitters contributed about 4.3% of total emissions nationally.

GHGRP facilities must report emissions greater than 25,000 MT CO_2e for specific source categories. Facilities report emissions data to the EPA through an electronic submission. The team reviewed the spreadsheet tool the EPA used for this purpose, the Subpart W Tool. The Subpart W Tool is a BU approach that captures emissions from different oil and natural gas system components. The Subpart W forms are embedded in an Excel spreadsheet and require facilities to provide input at the operational level. For example, the forms ask for information on the quantity of oil and natural gas produced and stored, the number and type of pneumatic devices, pumps, dehydrators, well venting for liquids unloading, blowdown vent stacks, well completions, atmospheric storage units, flare stacks, and estimates of unplanned emission leaks.

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

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

The EPA's FLIGHT provides access to GHG data reported through the Subpart W reporting system and other GHGRP subparts. In addition to offering data access in geospatial, graphical, and tabular formats, FLIGHT does not advance inventory methodology (EPA 2024a).

Data in FLIGHT are submitted periodically under the GHGRP (typically in March following the reporting year) by more than 8,000 facilities, including Subpart W and non–Subpart W facilities. These data are submitted by large emitters (greater than 25,000 MMT $CO_2e.yr^{-1}$) and cover an estimated 85%–90% of total GHG emissions in many U.S. sectors, 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 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. Available sectors in FLIGHT include power plants, petroleum and natural gas systems, refineries, chemicals, minerals, waste, metals, other, and pulp and paper.

The EPA's Envirofacts (EPA 2024c), which draws on GHGRP data and provides an alternative path to accessing FLIGHT data, shows that CH_4 emissions from all sources in New York State in 2016 totaled 3,082,129 MT CO_2e (using AR4 GWP100 values), which 1,334,090 MT CO_2e from the oil and natural gas sector and 1,716,960 MT CO_2e from waste facilities, primarily landfills (the agriculture sector was not included). These two sectors account for 98.98% of nonagriculture-based CH_4 emissions reported in the State, 43.28% and 55.70%, respectively.

3.1.3.3 EPA's Greenhouse Gas Emissions Inventory

The 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 (2018a). The approach for calculating emissions from natural gas systems generally applies EFs to activity data. For most sources, the approach uses technology-specific EFs or EFs that vary over time, accounting for changes in technologies and practices. These are used to calculate net emissions directly. For others, the approach uses "potential methane factors" and reduction data to calculate net emissions.

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

In the production segment, the EPA's GHGRP data (EPA 2017) were used to develop EFs 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, GHGRP data were used to develop EFs for fugitives, compressors, flares, dehydrators, and blowdowns and venting. In the transmission and storage segment, GHGRP data were used to create 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 the EPA adjusts the U.S. GHG Inventory methodology, it also updates inventories from prior years to maintain consistency.

3.1.3.4 Environmental Defense Fund's 16 Study Series

The EDF has led investigations into CH_4 emissions in the oil and natural gas sector (EDF 2018). These studies have highlighted factors such as leakage rates from aging equipment or poor operations, episodic emissions from equipment failures, and high-emitting sources. The EDF has also advocated for considering alternative GWP values when conducting GHG emission analyses. The selection of an appropriate GWP depends on the environmental issues being addressed, and the GWP100 may be inferior to a GWP20, particularly when considering short-term climate impacts (Alvarez et al. 2018).

Since 2012, the EDF led multiple peer-reviewed studies to assess CH_4 emissions in natural gas supply systems. These efforts, known as the "16 Study Series," focus on key issues, EFs, and uncertainties relevant to future inventory work in New York State. This section summarizes EDF's findings (2018) to date, with Table 1 providing an overview of all 16 studies.

Table 1. 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). CH_4 emissions over an entire completion flowback event ranged from less than 0.1 megagrams (Mg) to more than 17 Mg, with a mean of 1.7 Mg, 0.67 Mg–3.3 Mg with a 95% CI. Results show that wells with CH_4 capture and/or control devices captured 99% of the potential emissions. Additionally, 3% of the wells account for 50% of estimated emissions during unloading.	Allen et al. 2013
	Identified that the Bacharach Hi Flow® Sampler (BHFS) may underestimate CH_4 emissions by as much as 40%–80% due to possible malfunctions. The authors constrained the potential underestimate and, given differences in flow rates and CH_4 content across sites, 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 and a few oil production sites. Found that 19% of devices accounted for 95% of total gas emissions, with significant geographic variation. Gulf Coast CH_4 emission rates were the highest at 10.61 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 exhibited behaviors inconsistent with their design specifications.	Allen, Pacsi, et al. 2015
	Investigated CH_4 emissions from wells during liquid unloading events. Liquid unloading, which clears wells of accumulated liquids to increase production, may be necessary when a gas well produces water. Wells with plunger lifts unload far more frequently than those without plunger lifts (thousands of times per year versus fewer than 10 times per year). Although wells without plunger lifts emit more CH_4 per unloading event (0.4 Mg–0.7 Mg) than wells with plunger lifts (0.02 Mg–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 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 Data Analysis	Developed a multivariate linear regression to test the relationship between well age, gas production, and oil or condensate production to CH4 emissions: $log(CH4) = \beta\beta 1 log(gas) + \beta\beta 2 log(oil) + \beta\beta 3\ age$ Age was not significantly correlated with CH4 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 kg/hr to 700 kg/hr. Thirty percent of gathering facilities contributed 80% of total emissions. Normalized emissions were negatively correlated with facility throughput, although higher throughput was positively correlated with CH_4 emissions. Venting from liquids storage tanks occurred at ~20% of facilities, which exhibited 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. The study estimated total annual CH_4 emissions of 2,421 (+245/-237) Gg, representing a CH_4 loss rate of 0.47% (±0.05%) when normalized by annual CH_4 production. Ninety percent of these emissions were attributed to the normal operation of gathering facilities. CH_4 emissions from gathering facilities were 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 the estimated number of U.S. gathering stations (4,459 facilities) from this study were incorporated into the U.S. GHG Inventory in April 2016.	Marchese et al. 2015
Transmission and Storage Study	Data from 45 CSs in the transmission and storage sector showed highly skewed site-level CH_4 emissions, with 10% of sites contributing 50% of CH4 emissions. Emissions rates ranged from 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 generally showed 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, which exhibited site-level emission rates much higher than their aggregate component-level emission rates. These high-emitting sources showed anomalous operations, such as leaking isolation valves. Overall, emissions per station were 847 $Mg\cdot station^{-1}\cdot yr^{-1}$ (+53%/-35%) for underground storage CSs and 670 $Mg\cdot station^{-1}\cdot yr^{-1}$ (+53%/-34%). for transmission stations. Super-emitters contribute 39% of transmission fugitives and 36% of storage station fugitives, highlighting the importance of observing high-emitting sources. Modeled super-emitters are better represented as a 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		
Multicity Local Distribution Study	Direct measurements of 230 underground pipeline leaks and 229 M&R facilities showed that emissions from leaks were generally lower (~ 2 times) than those described 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 accounted for 70% of Eastern U.S. and almost half of total U.S. emissions.	Lamb et al. 2015
Boston Study	An atmospheric study showed overall emissions of 18.5 ±3.7 g CH_4 m^{-2} r^{-1}. The natural gas emission rate is 2.7 ±0.6% of consumed natural gas in Boston, MA, which is ~ 2-3 times greater than prior estimates.	McKain et al. 2015
Indianapolis Study	An atmospheric study observed emissions from distribution, metering, regulating, and pipeline leaks. It showed that 48% of emissions were from biogenic sources, and 52% were from natural gas usage. Mean observed leak rates from pipelines were 2.4 g/min (ranging from 0.013 g min^{-1} to 22.3 g min^{-1}).	Lamb et al. 2015
Methane Mapping	Mobile analysis using vehicle-based sensors showed that cities with a greater prevalence of corrosion-prone distribution lines had emissions up to ~ 25 times larger. Eliminating 8% of leaks could 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	Ground-based and airborne measurements of the D-J Basin (CO) 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 measured CH_4 emissions. Non–oil and gas sources included animals, animal waste, landfills, municipal wastewater plants, and industrial wastewater plants.	Pétron et al. 2014
Barnett Study	This extensive study used air and ground measurements to develop CH_4 emission estimates for oil and gas wells in the Barnett Shale (TX). Results indicated emissions were 50%–90% higher than 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 LNG and compressed natural gas refueling. CH_4 emissions from vehicle tailpipes (30%) and crankcases (39%) were the dominant emission sources, while refueling emissions were relatively low (12% of transport segment emissions).	Clark et al. 2017
Pilot Projects	The EDF funded several pilot projects informing the research threads in this table. Although no specific references are provided for these pilot projects, the results 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. It also estimated the contribution of CH_4 emissions from abandoned wells using data from 138 abandoned oil and gas wells in 4 basins. These high-emitting sources represent a disproportionate contribution to emission inventories. Lyon et al. (2016) concluded that high-emitting sources are “widespread and unpredictable” but can be easily identified 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, concluded that actual emissions of CH_4 may be ~ 60% higher than currently reported in official U.S. inventories. The study also indicated 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

The team reviewed the inventory approaches the EU implemented, as discussed in the "Annual European Union Greenhouse Gas Inventory 1990–2016 and Inventory Report 2018" (EU Inventory; European Environment Agency 2018). The EU Inventory applies methodologies the IPCC outlined in 2006 and uses GWP information in the Fourth Assessment Report (AR4, IPCC 2006). It combines the inventories of the 28 EU member nations and Iceland. Each country has flexibility in its methodological approach as long as it follows IPCC guidance, which 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 such as million British thermal units (MBTU) of natural gas consumed. After reviewing the EU Inventory and country-specific EFs, the team found that EFs from the U.S. are more applicable to the NYS context. Tier 2 uses more nationally focused EFs and activity data but still follows a TD approach. Tier 3 involves significant BU analysis, where production and consumption systems are well-defined at the equipment level. Emissions are calculated through equations that depict activity at the microlevel, similar to the Subpart W analysis previously mentioned (IPCC 2006, vol 2, ch. 4). The following describes the Tiers 1, 2, and 3 approaches.

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: 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 of the U.S. Oil and Natural Gas Production and Infrastructure sector. According to the EU GHG Inventory, 70.6% of emissions from Source Category 1.B come from fugitive CH_4 emissions, while 29.3% are fugitive CO_2 emissions.

The Tier 1 methodology applies default EFs to a representative activity parameter, often natural gas throughput, for each segment or subcategory of a country's oil and natural gas industry. This approach scales activity estimates by an EF, summed across industry segments. A significant limitation of this approach is that emissions result in efficiency improvements or infrastructure upgrades over time.

The Tier 2 methodology follows the general approach as Tier 1 but uses country-specific EFs developed from studies and measurement programs specific to the country's infrastructure. Best practices recommend periodically updating Tier 2 EFs. Where reliable venting and flaring data are available, countries may use an alternative Tier 2 approach that factors in emissions from these sources through defined equations (IPCC 2006). This alternative approach can be used to estimate emissions from oil production.

The Tier 3 methodology involves a rigorous BU assessment of primary emission sources at the facility level. It requires detailed data on facilities, wells, flare and vent processes, production, planned and unplanned releases, and country-specific EFs. EU countries typically produce Tier 3 inventories periodically, using these detailed studies to back-calculate the EFs, which can then be applied in interim Tier 2 studies.

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

Data for Source Category 1.B.2.b were calculated at the EU country level using IPCC (2006) Tier 1 and Tier 3 methods. For Source Category 1.B.2.a, Tier 1 and Tier 2 methods were used. Figures 10 and 11 show decision trees from the IPCC for determining which methodology to apply for each source category. These decision trees may offer useful guidance as the State considers different approaches to inventory development.

Figure 10. Decision Tree for Estimating Natural Gas Fugitive Methane Emissions

Source: IPCC 2006, Figure 4.2.1.

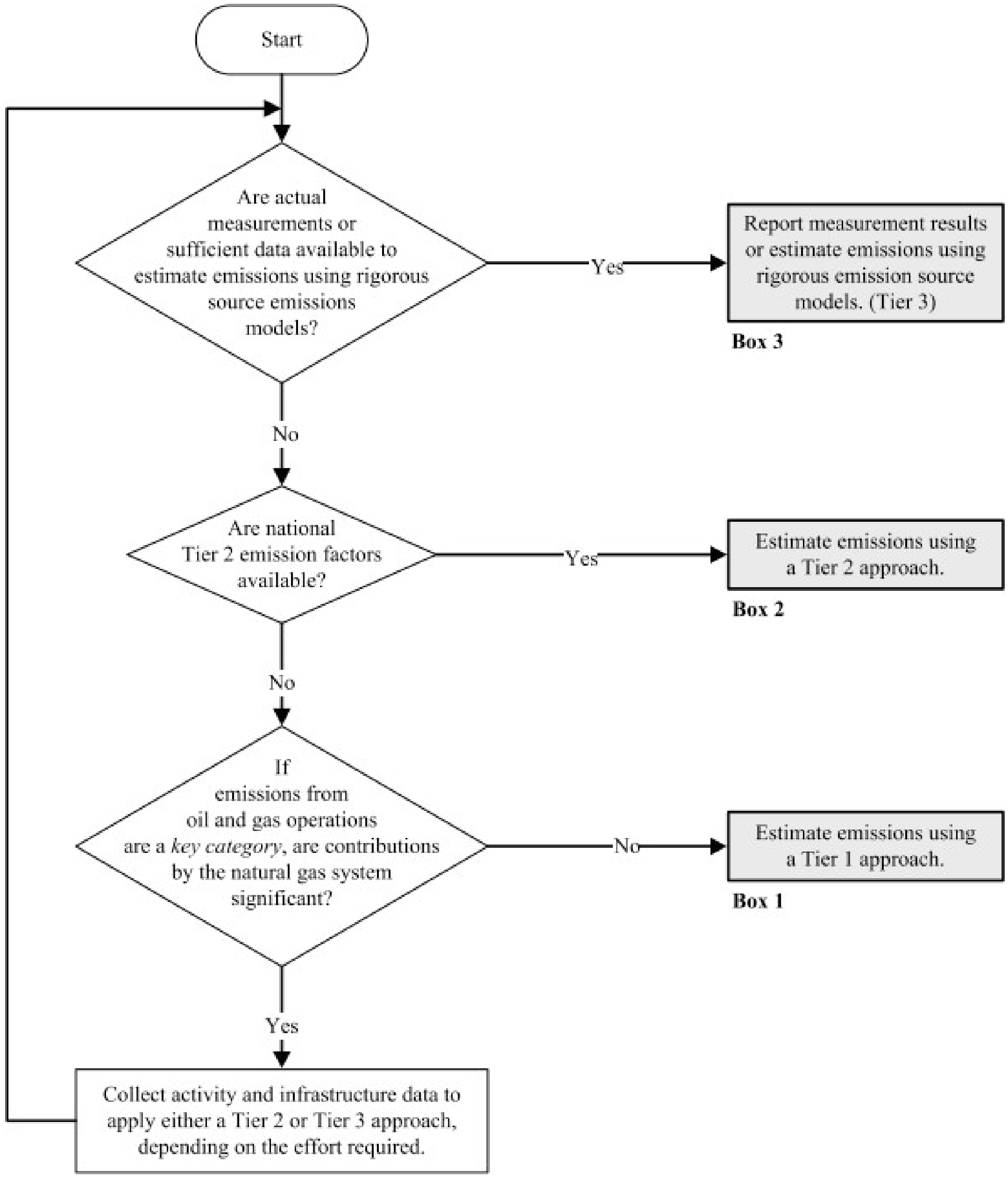
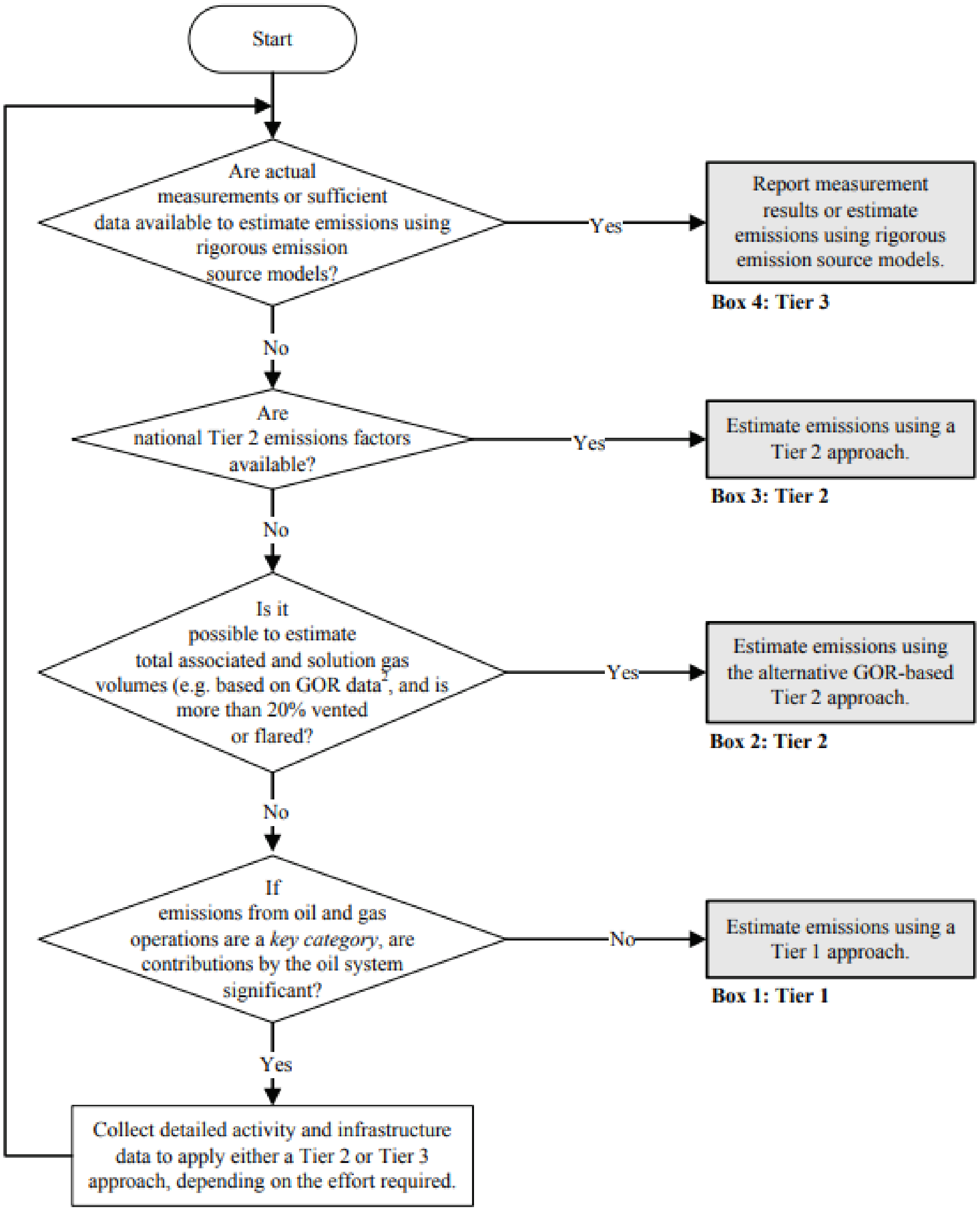


Figure 11. Decision Tree for Estimating Oil Fugitive Methane Emissions

Source: IPCC 2006, Figure 4.2.2.



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

3.1.4.1 Emission Factors

A crucial element for CH_4 inventories is identifying appropriate EFs for BU analyses. These EFs are applied to various activities to calculate emission inventories at either a national, regional, or state level (Tier 2 analyses), or at a process and system level (Tier 3 analyses). In its simplest form, a Tier 2 calculation is represented by 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 prepare inventories easily, even when data is limited. 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 for broader applications. Although simple to use, the drawback is that EFs are averages based on sample testing and may not reflect the actual emissions of the specific facility or region under study.

Tier 3 analyses, in contrast, are more site-specific, estimating emissions at the facility level using operational data. A typical example of a Tier 3 analysis is shown in the following equation, which facilities use to estimate emissions from three types of pneumatic devices using EPA's Subpart W inventory tool.

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), the EFs used may not reflect actual EFs for the facility. Thus, selecting an appropriate EF in Tier 2 and Tier 3 analyses is critically important, as emissions are directly and proportionally related to these values.

The literature has evolved, with ongoing research, testing, and demonstration projects influencing EFs. Table 2 reproduces an example of this variability, which summarizes CH_4 emissions as a percentage of natural gas throughput by process stage (upstream/downstream) and type of natural gas extraction (conventional/unconventional), based on Howarth (2014).

Table 2. Emission Factors as a Percentage Loss for Upstream, Downstream, and Total

Source: 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–S2.6
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) compiled data from 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, et al. 2015), 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 of CH_4 emissions from the natural gas supply chain, demonstrating that site-based analyses estimate CH_4 emission levels 1.2 to 2 times higher than the EPA's estimates. The EFs from this literature inform BU inventory development for New York State.

During the second iteration of this project, the team conducted a literature review to incorporate beyond-the-meter sources into the inventory. Appendix A.2.2 has more information.

3.1.4.2 Spatial Variability

CH_4 emissions from natural gas production and distribution are also affected by location, as seen in Table A-13, derived from Alvarez et al. (2018). The table shows estimated CH_4 emissions from oil and natural gas production across nine production basins. Emissions as a percentage of total production vary significantly, ranging from 0.4% (northeast Pennsylvania) to 9.1% (west Arkoma).

Allen (2016) explains that variability is influenced by factors such as reservoir characteristics, production systems used for oil or natural gas extraction, and regional air quality regulations. This variability is reflected in BU analyses that evaluate emissions from equipment and devices, which can differ by an order of magnitude across regions (Zavala-Araiza, Allen, et al. 2015).

Regional variability also occurs throughout the natural gas supply chain. For example, older distribution systems in some regions may exhibit much higher leakage rates than national average values suggest (Brandt et al. 2016). Therefore, BU analyses must account for regional variability when developing inventories.

3.1.4.3 Comparison Across Historical Methane Loss Rates

Kirchgessner (1997) reviews past studies on assumed loss rates, which is useful for hindcasting emissions using the updated methodology. In the 1970s, assumed loss rates, generally measured as unaccounted-for gas, ranged from 1%–3% to 6%–10%, with the higher rate considered exceptionally high. By the 1980s, assumed CH_4 loss rates were generally 2%–4%, including 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 variability in historical loss rates, determining a trend toward increasing or decreasing CH_4 loss rates from the oil and natural gas sector over the 1968–1992 time period is difficult.

3.1.4.4 High-Emitting Sources

An emerging focus in the inventory literature is high-emitting sources, or "super-emitters," (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) which are a small group of emission sources that contribute disproportionately to emissions across the natural gas supply chain (Allen 2016). High-emitting sources may vary over time and be better understood as a statistical characteristic. If a set of hundreds of sites is observed, a fraction may be high emitters. However, on a subsequent observation, the high-emitting sources may not be correlated to the same sites.

High-emitting sources can be planned and episodic, such as during 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). They can also result from unplanned events, such as equipment malfunction (Allen 2016; Conley et al. 2016).

To illustrate, Allen (2016) notes that 50,000 wells vent CH_4 during liquid unloadings, contributing 259 $Gg \cdot yr^{-1}$ of CH_4 emissions (EPA 2018a). Experts believe 3%–5% of these wells account for ~ 50% of these emissions. Similar effects occur with 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 3 summarizes other studies on high-emitting sources.

Table 3. Examples of High-Emitting Sources in the Natural Gas Supply Chain

This table highlights examples from the literature demonstrating the disproportionate emissions 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 well pads	51/16/30 well pads in Upper Green River/DJ/Uinta, respectively. 20% of the well pads contributed ~ 72-83% of emissions. 53 well pads in Fayetteville; 20% of the well pads 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 well pads	Highest emitting 1% and 10% of sites accounted for roughly 44% and 80%, respectively, of total CH4 production emissions from ~ 17,000 production sites.
Frankenberg 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).

Table 3. (continued)

Citation	Segment	Sample Size	Result
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% accounted for ~ 50%.
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% are responsible for 90%.
Zimmerle et al. 2015	Gas Transmission CSs, 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 and Meters	257 pipe leakage measurements, 693 metering and regulator measurements	3 large leaks accounted for 50% of total measured emissions from pipeline leaks.
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%.
Yacovitch et al. 2015	Oil and Gas Producing Wells, Gas Gathering and 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 and Boosting Compressor Stations	114 CSs	25 CSs vented > 1% of gas processed, 4 CSs vented > 10% of gas processed.
Mitchell et al. 2015	Gas Gathering and 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 CSs	47 CSs	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

The literature review identified five major issues with the 2015 CH_4 emissions inventory for the oil and natural gas sector, addressed in the 2017 inventory.

1. Activity-based, component-level analysis: Ensuring alignment with the highest IPCC and EPA standards for accuracy.
2. Region-specific EFs: Accounting for variations in gas pressure, composition, equipment, material, and infrastructure age to improve accuracy.
3. Geospatial allocation: Identifying hot spots and integrating inventories with chemical fate, transport, and health models.
4. Uncertainty analysis: Incorporating uncertainty quantification to enhance emissions estimation reliability.
5. High-emitting sources: Evaluating their causes and impact on overall emissions to refine inventory assessments.

Given the variability in emission inventory calculations, customizing emission inventories for specific geographies and infrastructure is essential. The lessons from this literature review can also inform similar reviews for other major CH_4, such as agriculture, landfills, wastewater management, and wetlands.

3.2 Methods and Data

3.2.1 Overview

This section details the emissions inventory development methodology, informed by the initial assessment, literature review, and updates for 2022. The sources included in the inventory are listed with EFs in the published literature typically represent averages of available data considered acceptable quality and are assumed to represent long-term averages for similar facilities. However, variations in operational conditions and emission controls across facilities can significantly affect emissions. Thus, the development of local, source-specific EFs is highly desirable.

Table 4 outlines the sources of CH_4 emissions included in the improved NYS inventory, categorized by their respective segments. Each source section in the table consists of 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.

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 represent averages of available data considered acceptable quality and are assumed to represent long-term averages for similar facilities. However, variations in operational conditions and emission controls across facilities can significantly affect emissions. Thus, the development of local, source-specific EFs is highly desirable.

Table 4. Sources of Methane 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 CSs
13	Midstream	Underground natural gas storage	Gas storage CSs
	Midstream	Underground natural gas storage	Storage reservoir fugitives
14	Midstream	LNG storage	LNG storage CSs
15	Midstream	LNG import/export	LNG terminal

Table 4 (continued)

Section	Category	Segment	Source
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 NYS approach for constructing the statewide CH_4 inventory had limitations. Although the highly aggregated, sectoral analysis aligns with the U.S. GHG Inventory and captures all source activities broadly, it does not provide detailed information about these source activities in a meaningful and actionable way. An alternative approach would refine the data and improve spatial and temporal resolution to better reflect State conditions, account for uncertainty, and yield results that enable New York State to focus programs and policies on areas where the greatest emission reductions can be realized.

In summary, the characteristics of New York State's oil and natural gas industry differ from the national average. Using national estimates of emissions attributed to each stage in the oil and natural gas system can lead to potentially inaccurate results. This underscores the importance of conducting a BU, activity-driven, component-level CH_4 emissions inventory for the State. The development of such an inventory should focus on (1) using appropriately scaled activity data, (2) incorporating state-of-the-art EFs, (3) improving the geospatial resolution of activities and emissions, and (4) applying and reporting uncertainty factors, including high-emitting sources. Table 5 summarizes all iterations of the NYS Oil and Gas Sector Methane Emissions Inventory best practices recommendations, their implementation status, and areas identified for future improvements in inventory processes.

Table 5. Best Practice Recommendations and Future Inventory Improvements

Recommendation	Implementation in Current Inventory	Areas for Future Improvement
Recommendation 1 Develop a more detailed set of activity data, including site- and component-level data, to capture the impacts of CH_4 mitigation strategies targeted at the site or component level.	Applied best available activity data using public inputs and NYS agency data	• Collect data on transmission and storage CSs, including those with electric compressors. • Collect county-level data on distribution pipeline miles by pipeline material. • Collect county-level data on residential, commercial, and industrial gas meters. • Identify additional CH_4 emissions sources and compile county-level data.
Recommendation 2 Estimate and apply EFs for upstream and downstream oil and gas activities in the State using: • Best available data • Validation by both BU and TD studies • Specific geographic location	• Applied best available EFs from the published literature	• Develop NYS-specific EFs for: o Well pads during production o Transmission and storage CSs o Fugitive emissions from storage reservoirs • Identify EFs for: o Various types of commercial buildings o Industrial buildings o Additional residential appliances
Recommendation 3 Align available geospatial data with inventory data to create a geospatial emissions inventory to: • Enhance ability to identify hot spots and air quality concerns • Allow verification of emission inventories with empirical data	• Collect and use air-quality data: • Measure ambient CH_4 concentrations throughout NYS • Verify emission estimates using observed concentrations • Compare TD measurements: • Gather data as it becomes available • Analyze CH_4 emissions in comparison to the inventory • Verify inventory and identify areas for potential improvement	• Collect and use air-quality data: o Measure ambient CH_4 concentrations throughout NYS o Verify emission estimates using observed concentrations • Compare TD measurements: o Gather data as it becomes available o Analyze CH_4 emissions in comparison to the inventory o Verify inventory and identify areas for potential improvement
Recommendation 4 • Conduct uncertainty analysis when calculating and reporting its CH_4 inventory: o Account for uncertainties in published EFs o Could include assessment of high-emitting sources across the State • Develop and apply models to account for high-emitting sources: • For known emission releases (e.g., reported leakage) • For estimated releases (e.g., leakage based on pipeline age or material).	• Assessed uncertainty in applied EFs • Identified most likely range of CH_4 emission from the oil and natural gas sector • Applied inventory methodology to potentially include high-emitting sources • Recognized need for better information on statistical distribution of such sources	• Develop better understanding of high-emitting sources • Distribution across the State • Frequency of operation in the high-emitting state

3.2.3 Emissions Factor Confidence

The EFs used in this inventory are derived from a comprehensive literature review and selected based on expert judgment and the best available data. In most cases, these EFs are transferred from studies conducted outside New York State, which use varying methodologies and are not all peer-reviewed. In addition, some of the EFs applied in this inventory come from empirical studies or engineering estimates conducted in the past, which may not reflect current conditions. Therefore, describing the certainty of the EFs when applying to the State is essential. This section outlines the four metrics used to evaluate the EFs applied: geography, recency, study methodology, and publication status. Each metric is presented equally and independently without judgment regarding the relative importance of each category.

3.2.3.1 Geography

Geography plays a vital role in evaluating EFs. Selecting EFs that most closely reflect local conditions results in the most robust estimates, as these EFs are likely to account for similar local environmental conditions and regulations that can influence average EFs. As discussed in Appendix A and Section 3.1.4.1, site-level EFs show significant geographic variation, ranging from 0.4% of production in the Marcellus Basin to 9.1% in the West Arkoma Basin. This variation highlights the need to select EFs that are geographically specific whenever possible.

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

3.2.3.2 Recency

Many EFs used in the EPA's Oil and Gas Tool and State Inventory Tool (SIT) are based on older studies, some first published in 1977. The oil and natural gas sector has undergone significant changes since then, including the transition to plastic pipelines with lower leak rates and the adoption of centrifugal compressors with greater throughput and lower leak rates, among other changes. Therefore, using EFs that closely reflect the industry's current state is essential 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 various methodologies. At their simplest, EF estimates come from engineering estimates, which rely on assumptions about equipment throughputs and leak rates to estimate EFs when empirical observations are not available. More advanced methodologies involve component- or site-level sampling methods to empirically observe emission rates. Empirical observations of EFs represent the best available data because they reflect real-world operations and uncertainties that engineering estimates may not capture.

Empirical Observation	Engineering Estimate

3.2.3.4 Publication Status

The EFs in this inventory are derived from two primary sources: grey literature and peer-reviewed literature. Grey literature estimates are typically from government publications and reports. Experts prepare these documents and often provide valuable information on well-documented EFs, but they do not undergo formal external peer review. On the other hand, peer-reviewed literature includes EFs that have been reviewed and vetted by experts before publication. These EFs are derived using robust scientific methodologies and represent the best available data.

Peer-Reviewed Literature	Grey Literature

3.2.3.5 Summary Table

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

Table 6. Emission Factor Confidence Assessment for New York State Inventory

This table assesses the confidence levels for the 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)
	4.1	7.2	13.7						> 10 MSCFD (bottom; Omara et al. 2016)
Gas Well: Conventional Production	9.4	25.4	60.7	% of throughput					≤ 10 MSCFD (top)
	4.1	7.2	13.7						> 10 MSCFD (bottom; Omara et al. 2016)
Oil Well: Unconventional Production	0.1	0.15	0.26	% of throughput					≤ 10,000 MSCFD (top)
	0.018	0.03	0.178						> 10,000 MSCFD (bottom; Omara et al. 2016)
Gas Well: Unconventional Production	0.1	0.15	0.26	% of throughput					≤ 10,000 MSCFD (top)
	0.018	0.03	0.178						> 10,000 MSCFD (bottom) Omara et al. (2016)

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 CSs	442.2	670	1,018.4	$MTCH_4$ $station^{-1}$ yr^{-1}					Zimmerle et al. 2015

Table 6. (continued)

Emissions Source	EF Low	EF Mid	EF High	EF Unit	Geography	Recency	Methodology	Status	Source
Gas Storage CSs	550.6	847	1,295.1	$MTCH_4$ station^{-1} yr^{-1}					Zimmerle et al. 2015
Storage Reservoir Fugitives	—	—	—	—	—	—	—	—	—
LNG Storage CSs	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, 2021
Cast-Iron Distribution Pipeline: Services	1.1573	1.1573	4.5974	$MTCH_4$ mile^{-1} yr^{-1}					Lamb et al. 2015; EPA 2018b, 2021
Unprotected Steel Distribution Pipeline: Main	0.8613	0.8613	2.1223	$MTCH_4$ mile^{-1} yr^{-1}					Lamb et al. 2015; EPA 2018b, 2021
Unprotected Steel Distribution Pipeline: Services	1.1987	1.1987	2.7116	$MTCH_4$ mile^{-1} yr^{-1}					Lamb et al. 2015; EPA 2018b, 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	MTCH 4 mile^{-1} yr^{-1}					Lamb et al. 2015; EPA 2018b, 2021
Protected Steel Distribution Pipeline: Services	0.0946	0.0946	0.2474	MTCH 4 mile^{-1} yr^{-1}					Lamb et al. 2015; EPA 2018b, 2021
Plastic Distribution Pipeline: Main	0.0288	0.0288	0.1909	MTCH 4 mile^{-1} yr^{-1}					Lamb et al. 2015; EPA 2018b, 2021
Plastic Distribution Pipeline: Services	0.0136	0.0136	0.0136	MTCH 4 mile^{-1} yr^{-1}					Lamb et al. 2015; EPA 2018b, 2021
Copper Distribution Pipeline: Main	—	—	—	—	—	—	—	—	NYS has no copper distribution mains.
Copper Distribution Pipeline: Services	0.4960	0.4960	0.4960	MTCH 4 mile^{-1} yr^{-1}					Lamb et al. 2015; EPA 2018b, 2021
Pressure Relief Valves	—	0.96	—	kg CH_4 mile^{-1} year^{-1}					EPA 2024b
Blowdowns	—	1.96	—	kg CH_4 mile^{-1} year^{-1}					EPA 2024b

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 2024b
Metering and Regulating Stations—M&R >300	—	2,142.70	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b
Metering and Regulating Stations—M&R 100–300	—	995.40	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b
Metering and Regulating Stations—M&R <100	—	727.20	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b
Metering and Regulating Stations—Reg >300	—	868.90	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b
Metering and Regulating Stations—R-vault >300	—	50.60	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b
Metering and Regulating Stations—Reg 100-300	—	143.40	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b
Metering and Regulating Stations—R-vault 100–300	—	50.60	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b

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 2024b
Metering and Regulating Stations—R-vault 40–100	—	50.60	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b
Metering and Regulating Stations—Reg <40	—	22.40	—	kg CH_4 station^{-1} year^{-1}					EPA 2024b
Meters: Residential	—	0.0015	—	$MTCH_4$ meter^{-1} yr^{-1}					EPA 2024b
Meters: Commercial	—	0.0097	—	$MTCH_4$ meter^{-1} yr^{-1}					EPA 2024b
Industrial Meters	—	105.00	—	kg CH_4 meter^{-1} year^{-1}					EPA 2024b
Residential Appliances—Natural Gas Furnace	0.14	0.22	0.51	kg CH_4 appliance^{-1} year^{-1}					Merrin and Francisco 2019
Residential Appliances—Natural Gas Boiler	0.15	0.32	0.75	kg CH_4 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—Natural Gas Storage Water Heater	0.02	0.077	0.084	kg CH_4 appliance^{-1} year^{-1}					Merrin and Francisco 2019
Residential Appliances—Natural Gas Tankless Water Heater	0.98	1.2	41	kg CH_4 appliance^{-1} year^{-1}					Merrin and Francisco 2019
Residential Appliances—Natural Gas Stove	0.04	0.056	0.071	kg CH_4 appliance^{-1} year^{-1}					Merrin and Francisco 2019
Residential Appliances—Natural Gas 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, 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	—	$MTCH_4$ building^{-1} year^{-1}					ICF 2020
Commercial Buildings—Office	—	0.00645	—	$MTCH_4$ building^{-1} year^{-1}					ICF 2020
Commercial Buildings—Warehouse	—	0.005605	—	$MTCH_4$ building^{-1} year^{-1}					ICF 2020
Commercial Buildings—Retail	—	0.0009898	—	$MTCH_4$ building^{1} year^{-1}					ICF 2020

3.2.4 Activity Data Summary

Table 7 presents activity data descriptions and data sources by emissions source, along with flags indicating 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 New York State Inventory

Activity data used in the improved New York State inventory, detailing key data sources and methodologies.

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 CSs	Count of gas transmission CSs	X			PHMSA 2022, DEC permitting database
Gas Storage CSs	Count of gas storage CSs				DEC permitting database
Storage Reservoir Fugitives	TBD—no data available				
LNG Storage CSs	Count of LNG Storage CSs				DEC 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
Plastic Distribution Pipeline: Main	Miles of pipeline		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: 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 2024b
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 range from massive to small or medium-sized structures. The size and type of rigs depend on factors such as whether directional drilling is being performed, the size of the operation, the anticipated duration and intensity of the operation, and the depth and range of the well. Smaller to medium-sized rigs, or mobile rigs, are mounted on trucks or trailers and can be easily relocated. Two primary rig types exist: mechanical rigs and those combining diesel and electric power. Major components of drill rigs include 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 result from on-site power generation and correlate with the cumulative feet drilled.

Emission Factors

<table>
<tr><th>Drill Rig Engine Power (hp)</th><td>300 to 600</td><td colspan="3">600 to 750</td><td colspan="2">750 to 3000</td></tr>
<tr><th>Default EF (g/hp-hr)</th><td>0.004</td><td colspan="3">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 colspan="2">Geography:
Marcellus/
Appalachian Basins</td><td>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, based on CenSARA (2012) study data. 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 the 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>

In calculating activity data for drilling rigs, the approach does not distinguish between oil- and gas-directed rigs because a well, once completed, may produce both oil and gas. The activity data, expressed 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 by subtracting the spud date from the completion 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 for a well exceeded 50, the drilling days were set to 22. This 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. After calculating the drilling days for each well, the total drilling days were summed to the county level.

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

The team converted CH_4 emissions from grams to metric tons (MTs) using a conversion factor of $1e^{-6}$ and converted MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 4 CH_4 emissions (MT CO_2e) = DD x 24 hr/day x hp x EF x CF x AR5 GWP20

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 = $1e^{-6}$
- AR5 GWP20 = GWP = 84

For example, in 2010. Cattaraugus County had 3,974 drilling days, resulting in 3.83 MT CO_2e:

- Drill rig CH_4 (MT CO_2e) = 3,974 x 24 hr/day x 402 x 0.004 x $1e^{-6}$ x 25
- Drill rig CH_4 (MT CO_2e) = 3.83 MT CO_2e

Limitations and Uncertainties

The CenSARA study applies EFs derived from EPA's NONROAD2008 model, which updates the NONROAD2005 model without significant changes for drill rigs. As a result, these EFs are based on data from more than a decade ago. Although the CenSARA study and NONROAD models are not NYS-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 uses an average drill rig engine power of 402 hp, derived from the EPA's Oil and Gas Tool and based on the CenSARA study. Updating this value to better reflect New York State would improve accuracy, particularly with more specific information on the sizes, loads, and primary engine types. In addition, as noted, these EFs, widely used in the EPA's Oil and Gas Tool, are more than a decade old and may need updating.

3.2.5.2 Fugitive Drilling Emissions

Source Category Description

The first step in well completion is casing the hole to prevent it from closing after drilling fluids are removed and to protect the well stream from contaminants like water or sand. The next step is cementing the well, which involves pumping cement slurry to displace existing drilling fluids and fill the space between the casing and the sides of the drilled well. At the reservoir level, two types of completion methods are used on wells: open- and cased-hole completions. An open-hole completion involves drilling a well to the top of the hydrocarbon reservoir, casing the well at this level, and leaving the bottom open. Cased-hole completions require running casing into the reservoir. The casing and cement are perforated to allow hydrocarbons to enter the well stream.

Emission Factors

Source Category	Fugitive Drilling Emissions			
Default EF ($MT\ CH_4\ well^{-1}$)	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 comes from the EPA's 2018 U.S. GHG Inventory (EPA 2018a) and is 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. Well completions are based on the reported well completion date for various 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 was summed by year of completion at 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 (MT CO_2e) = well completions x EF x CF x AR5 GWP20**

where:

- Well completions = count of well completions
- EF = CH_4 EF (MTCH_4 well^{-1}) = 0.0521
- AR5 GWP20 = GWP = 84

For example, in 2023, Cattaraugus County saw 45 well completions, resulting in 660.8 MT CO_2e:

Fugitive drilling CH_4 (MT CO_2e) = 45 x 0.0521 x 84 Fugitive drilling CH_4 (MT CO_2e) = 660.8 MT CO_2e

Limitations and Uncertainties

The EF for fugitive emissions from well drilling is based on an older study, which may not reflect current best practices for CH_4 capture during drilling. The study may also not account for borehole conditions in New York State, which could differ in pressures and porosity.

Potential Areas of Improvement

This estimate could be improved by updating the EF based on an empirical study of fugitive emissions during drilling operations in the Northeast or Appalachian Basin, ideally using data from NYS wells.

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, and they act as a suspension tool to prevent cuttings from refilling the borehole and to control pressure in a well by providing hydrostatic pressure to counteract 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 ensure that the rock formation does not absorb the drilling fluid and that the pores in the rock formation are not clogged. The deeper the well, the more drill pipe is needed. As the drill pipe gets heavier, the drilling fluid adds buoyancy, reducing stress. Additionally, drilling fluid helps reduce heat by minimizing friction with the rock formation, which prolongs the life of the drill bit.

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

Emission Factors

Source Category	Mud Degassing: Gas and Oil Wells			
Default EF ($MTCH_4$ drillingday^{-1})	0.2605			
Source	EPA Oil and Gas Tool			
EF Confidence	Geography: Rest of the Country	Recency: 15 + Years	Methodology: Engineering Estimate	Status: Grey Literature
Source Description	This is the default EF from the EPA Oil and Gas Tool, based on CenSARA (2012) study data. The CenSARA study domain covers basins in Texas, Louisiana, Oklahoma, Arkansas, Nebraska, Kansas, and Missouri. The CenSARA study derives default EFs from 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 was 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. Though derived from older engineering estimates, this EF has been widely applied to national and state-level emission inventories, and communication with experts indicates that no more recent estimates are available.			

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 team calculated the number of drilling days per well by subtracting the spud date from the completion date. For estimating oil well drilling days, the well types included were oil development, oil extension, oil wildcat, and enhanced oil recovery-injection. For estimating 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, the team set drilling days to 22 if the calculated exceeded 50 for a given well. The average drilling time of 22 days is based on an assessment of peer-reviewed literature, including Roy et al. (2014), and engineering judgment, reflecting on the observed drilling days in the New York State well data. After calculating the drilling days for each well, the team summed the total of the drilling days at the county level.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 6 **CH_4 emissions (MT CO_2e) = DD x EF x AR5 GWP20**

where:

- DD = drilling days
- EF = CH_4 EF (MTCH_4 drilling day^{-1}) = 0.2605
- AR5 GWP20 = GWP = 84

For example, in 2010, Cattaraugus County saw 230 days of natural gas well drilling, resulting in 1,498 MT CO_2e:

Equation 7 **Mud degassing CH_4 (MT CO_2e) = 230 x 0.2605 x 84 = 1,498 MT CO_2e**

Limitations and Uncertainties

The EF for mud degassing is based on the best guess specific to offshore oil and gas development from 1977 data. The limitations and uncertainty of applying this estimate involve appropriateness for onshore formations, bore diameters, and depths, as well as porosity and reservoir pressures in the State. The uncertainty in these calculations is a function of the CH_4 fraction of total hydrocarbon emissions from mud degassing, 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 could be improved by tailoring the total gaseous hydrocarbon emissions estimate to NYS-specific bore depths, diameters, reservoir porosity, pressures, and the CH_4 fraction of total gaseous hydrocarbons.

3.2.5.4 Well Completion

Source Category Description

Well completion is the process of preparing an oil or natural gas well 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 final step in completing a well is installing 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 Basins	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 U.S. 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 MgCH_4– 3.3 MgCH_4 per well completion). Emissions were estimated over 27 events using direct measurements at the flowback tank and tracer-ratio measurements to produce site-level EFs. This widely-cited peer-reviewed study 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 team counted the wells by county and year based on type. For oil wells, the well types included were oil development, oil wildcat, oil extension, and enhanced oil recovery. For gas wells, the well types included were gas development, gas wildcat, gas extension, gas wildcat, dry hole, monitoring storage, and storage.

The team calculated CH_4 emissions by multiplying the well count by the EF and then converted MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 8 CH_4 emissions (MT CO_2e) = well count x EF x AR5 GWP20

where:

- well count = number of wells
- EF = CH_4 EF (MTCH_4 completion^{-1}) = 1.7
- AR5 GWP20 = GWP = 84

For example, in 2010, Cattaraugus County had seven natural gas well completions, resulting in 298 MT CO_2e:

Equation 8 (continued)

Natural gas well completion CH_4 (MT CO_2e) = 7 x 1.7 x 84 Natural gas well completion CH_4 (MT CO_2e) = 298 MT CO_2e

Limitations and Uncertainties

This EFs' primary source of uncertainty stems from a limited sample size. The mean value is based on measurements from five completion flowbacks in the Appalachian region, seven in the Gulf region, five in the Mid-Continent, and ten in the Rocky Mountain region. The duration of well completion flowbacks also affected the magnitude of emissions per well completion.

Potential Areas of Improvement

The central estimate for emissions per well completion flowback event comes from a rigorous peer-reviewed study of well completions nationwide. Hourly CH_4 emission rates varied widely, highlighting the importance of estimating uncertainty using 95% confidence intervals (CIs). Additionally, this estimate could be improved by evaluating emissions from NYS wells during completion because many of the wells observed were hydraulically fractured.

3.2.5.5 Conventional Production

Source Category Description

Conventional oil and gas production involves extracting oil and gas using the natural pressure of the wells after the drilling operations. Unconventional resources require pumping or compression operations to release resources from formations with insufficient borehole pressure. After depleting maturing fields, well pressure may become too low to produce significant quantities of oil and gas. Production may be boosted through water-and-gas injection or depletion compression techniques, but the resources remain conventional. Oil and gas production is classified as unconventional only when enhanced oil recovery or artificial life methods are used. New York State has unconventional oil and gas production.

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 et al. 2016			
EF Confidence	Geography: Marcellus/ Appalachian Basins	Recency: 6–15 Years	Methodology: Empirical Observation	Status: Peer-Reviewed
Source Description	Omara et al. (2016) measured facility-level emissions by comparing conventional and unconventional natural gas sites in West Virginia and Pennsylvania. Emissions varied widely across the 18 conventional and 13 unconventional sites, with unconventional sites generally producing more natural gas but having lower emission rates than production. The 25th and 75th percentile represent the upper and lower bounds for uncertainty analysis. The median EFs presented here were used in the NYS inventory.			

Activity Data

The team derived the activity data, calculated as the volume of associated gas production from oil wells and the gas production from natural gas wells, 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. The team estimated the quantity of natural gas produced by basing the volume produced on well type and well status for each county and year. For oil wells, the team included well types such as oil development, oil extension, and enhanced oil recovery-injection, and well statuses such as 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 well statuses included active, drilled deeper, drilling completed, plugged back, and plugged back multilateral. After identifying wells in the ESOGIS database as producing associate gas or natural gas, the team classified them 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).

The team calculated CH_4 emissions by converting the natural gas production volume to mass using the ideal gas law, multiplied by the EFs, and then converted MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 9 CH_4 emissions (MT CO_2e) = production x CF x EF x AR5 GWP20

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
- AR5 GWP20 = GWP = 84

For example, in 2020, Cattaraugus County had 531,298 Mcf of natural gas produced from low-producing natural gas wells, resulting in 217,476 MT CO_2e, as shown:

Low-producing conventional gas well CH_4 (MT CO_2e) = 531,298 x 0.019185 x 0.254 x 84
Low-producing conventional gas well CH_4 (MT CO_2e) = 217,476 MT CO_2e

Limitations and Uncertainties

Omara et al. (2016) show significant differences in emissions between conventional and high-volume hydraulic fracturing emissions from shale gas formations. These estimates highlight the importance of accounting for natural gas production in emission estimation. The sample size for conventional and unconventional wells is small, so increasing the sample would improve uncertainty around central estimates.

Potential Areas of Improvement

The team derived these EFs from a broad population but are not NYS-specific. As such, while these estimates may encompass the State EFs, further study of these wells is necessary to determine NYS-specific estimates of production emissions.

3.2.5.6 Abandoned Wells

Source Category Description

When a well is finished producing oil and/or gas it is typically abandoned. Each state has requirements for well as abandonment, including regulations around plugging the well to prevent air and water pollution. NYS regulations mandate that certain wells be plugged once operations cease. The plugs prevent the migration of residual oil and gas to other zones, aquifers, or the surface. 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. Abandoned wells, especially orphaned ones abandoned without the proper regulations—can continue to emit CH_4. These orphaned wells are often from the late 1800s and early 1900s, with unknown operators and inadequate maintenance, posing a risk for air and water contamination.

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 Basins	Recency: 6–15 Years	Methodology: Empirical Observation	Status: Peer Reviewed
Source Description	Kang et al. (2014) measured CH_4 emissions from Pennsylvania's abandoned oil and gas wells. Mean emissions were 0.27 kg well^{-1} day^{-1} or 0.09855 MTCH4 well^{-1} yr^{-1}. The team used a static flux chamber methodology to measure gaseous emissions from abandoned wellheads, surrounding soil-plant systems, and controls containing no wellhead. This widely cited, peer-reviewed study provides recent EF estimates from empirical observations from abandoned oil and gas wells in two Pennsylvania counties bordering NYS.			

Source Category	Gas: Abandoned Wells			
Default EF ($MTCH_4$ 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}. The team measured emissions from pressurized and leaking wellhead components 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

The team derived activity data, calculated as the number of abandoned wells, from ESOGIS. This database contains information on all wells in the State, including county location, well type, and well status. The team counted wells by county and year based on well type and well status to estimate the number of abandoned wells. For oil wells, the well types included oil development, oil extension, oil wildcat, and enhanced oil recovery-injection, and the well status included inactive, not reported on the annual well report (AWR), shut-in, temporarily abandoned, and unknown. For natural gas wells, the well types 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.

The team calculated CH_4 emissions as the well count multiplied by the EFs and then converted the MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 10 CH_4 emissions (MT CO_2e) = well count x EF x AR5 GWP20

where:

- well count = number of wells
- EF = CH_4 EF (MTCH_4 abandoned well^{-1} yr^{-1})
- AR5 GWP20 = GWP = 84

For example, in 2020, Cattaraugus County had 55 abandoned natural gas wells, resulting in 405.6 MT CO_2e, as shown:

Equation 11 Abandoned natural gas well CH_4 (MT CO_2e) = 55 x 0.0878 x 84
Abandoned natural gas well CH_4 (MT CO_2e) = 405.6 MT CO_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 the available information, Kang et al. (2014) could not distinguish between oil and gas wells and did not find a significant difference between plugged, 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 the 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 often not distinct from one another in the State. 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, the inventory should exclude shut-in or temporarily abandoned wells from the abandoned well category because these status types apply to idle-producing wells. This inventory classifies these wells as abandoned wells because no data on EFs for idle-producing wells exist in the research literature. Including 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 (e.g., another gathering facility, transmission line, or processing plant). These stations often include inlet separators to remove water and/or hydrocarbon condensate, dehydration systems to remove gaseous water (H_2O), and amine treatment systems. Processing plants often include these same operations, and 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 Basins	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 U.S. using downwind tracer flux methodology. Emission rates varied widely from 2 kg 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 NYS, providing empirically observed regional emissions estimates from gathering and processing facilities. These results are validated by findings from Mitchell et al. (2015), who reported CH_4 emissions of 0.2% of throughput in Pennsylvania gathering facilities.			

Activity Data

The team assumed throughput to be equal to production. As such, the team derived activity data, which was calculated as the volume of associated gas production from oil wells and the natural gas production 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 team based the volume produced by county and year on well type and well status. For oil wells, the well types 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 types included gas development, gas extension, and gas wildcat, and the well status included active, drilled deeper, drilling completed, plugged back, and plugged back multilateral.

The team calculated the CH_4 emissions as the volume of natural gas production converted from volume to mass using the ideal gas law times the EFs, then converted the MTs of CH_4 to MT CO2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 12 CH_4 emissions (MT CO_2e) = production x CF x EF x AR5 GWP20

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
- AR5 GWP20 = GWP = 84

For example, in 2020, Cattaraugus County had 633,693 Mcf of natural gas produced from gas wells, resulting in 4,278.3 MT CO_2e, as shown:

Equation 13

Gathering and processing station CH4 (MT CO_2e) = 663,693 x 0.019185 x 0.004 x 84
Gathering and processing station CH4 (MT CO_2e) = 4,278.3 MT CO_2e

Limitations and Uncertainties

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

Potential Areas of Improvement

These estimates can be improved by better understanding the frequency of high-emitting sites in the State, which complicates applying 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 production sources (well pad) to storage tanks, processing facilities, refineries, or transmission lines. Flowlines commonly feed gathering pipelines, each connected to individual wells in the ground. In a gathering pipeline, raw gas is usually carried at pressures ranging from 0 pounds (lbs) to 900 lbs per square inch (psi). Compared to other pipelines, lengths in this category are relatively short—approximately 200 meters.

Emission Factors

Source Category	Gathering Pipeline			
Default EF ($MTCH_4$ mile^{-1} yr^{-1})	0.4			
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 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 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.			

Activity Data

The activity data for gathering pipelines consist of miles of pipeline. The team derived state-level data on the gathering pipeline mileage from the Pipeline and Hazardous Materials Safety Administration (PHMSA) Pipeline Mileage and Facilities database. Based on guidance from the NYS Department of Environmental Conservation (DEC), the team scaled up the miles of gathering pipelines from PHMSA to account for only 7.5% of gathering pipeline miles reported under PHMSA.

The team calculated CH_4 emissions as the miles of pipeline times the EF and then converted the MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

The team allocated the adjusted state-level miles of gathering pipeline to the 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 team derived production data 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 team based the volume produced by county and year on well type and well status. For associated gas from oil wells, the well types 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 types 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 14 CH_4 emissions (MT CO_2e) = pipeline miles x SF x AF x EF x AR5 GWP20

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 the 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
- AR5 GWP20 = GWP = 84

For example, according to the PHMSA data, in 2020, New York State had 81 miles of gathering pipeline. In addition, in 2020, Cattaraugus County had 809,264 Mcf of natural gas production and 10,986,744 Mcf of natural gas production in the State. After applying the scaling and allocation f actors, the team calculated that in 2020. Cattaraugus County had 79.31 miles of gathering pipeline, resulting in 2,672.2 MT CO_2e, as shown:

Equation 15 **Gathering pipeline CH_4 (MT CO_2e) = 81 x 13.33 x 809,264/10,986,744 x 0.4 x 84**
Gathering pipeline CH_4 (MT CO_2e) = 2,672.2 MT CO_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 the team applied here aligns with the 2018 EPA GHG Inventory EF, but peer-reviewed literature (Zimmerle et al. 2017) shows EFs approximately three times 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 NYS–specific emissions estimates. Reported lost and unaccounted-for (LAUF) gas in PHMSA data could help generate state-level emission estimates. However, 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, operators vented this CH_4 to the atmosphere to prevent the internal tank pressure from rising. Emissions can be significant since a loading cycle may occur every three to five days or approximately 100 loading transfers per year. Many operations now use closed-loop systems, where a vapor recovery line connects to the tank, vapor recovery unit, or flare stack, eliminating CH_4 emissions.

Truck loading of crude oil may also release CH_4. Additionally, the team assumed that natural gas in New York State is transported by pipeline, so truck loading does not occur for natural gas.

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, chapter 5, Table 5.2-5, lists between 240 mg and 580 mg organic emissions lost per L of crude oil transferred into tank trucks. The source assumes that ~ 15% of the total organic emissions is CH_4/ethane combined, and 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 NYS wells, so we alternatively use 36 x 0.936 = 33.70 mg/L as the CH_4 EF during loading. Because data on emissions from tank loading are sparse, the team used AP-42 air EFs, which derive from two industry studies performed in 1977 by Chevron, U.S.A, but align with the EPA's recommended methodology.			

Activity Data

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

Pipelines transport natural gas.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 16 CH_4 emissions (MT CO_2e) = gas condensate loaded x CF1 x EF x CF2 x AR5 GWP20

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 = $1e^{-9}$
- AR5 GWP20 = GWP = 84

For example, in 2020, Allegany County saw 19,875 bbl of oil produced, resulting in 0 MT CO_2e from truck loading, as shown:

Equation 17 Truck loading of crude oil CH_4 (MT CO_2e) = 19,875 x 158.987 x 0 x 1e-9 x 84
Truck loading of crude oil CH_4 (MT CO_2e) = 0 MT CO_2e

Limitations and Uncertainties

Based on the boiling points of CH_4 and ethane, much of the CH_4/ethane present in crude will likely be released when exposed to atmospheric temperature and pressure conditions during storage. Therefore, the team identified 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, so emissions are included/embedded in site-level EFs.
- Assume that none of the CH_4 evaporates prior to truck tank loading, so 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. Satellite views make assessing whether these are oil storage tanks or other tanks, such as water or separators, difficult. The team assumed that all CH_4 evaporates while stored in atmospheric tanks for this inventory.

Potential Areas of Improvement

The team can improve emissions estimates from truck loading by better understanding the quantities of oil transferred from wellheads to processing sites by truck in New York State, and confirming whether all CH_4 has evaporated before truck loading. The lack of good activity data requires the team to use bounding conditions, where all or none of the CH_4 has evaporated before loading.

3.2.6.4 Gas Processing Plants

Source Category Description

Raw natural gas comes from three types of wells: oil, gas, and condensate. Natural gas from oil wells, known as associated 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 containing 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 and semiliquid hydrocarbon condensate. After separation from crude oil (if present), natural gas 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, which removes water, and the amine process, which sweetens 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 Basins	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}. Based on recent, rigorous, empirical observation and statistical modeling, this estimate is a downward revision of the EPA SIT default value 1,249.95 $MTCH_4$ plant^{-1} yr^{-1}.			

Activity Data

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

Geospatial Data and Allocation Methodology

This does not apply to New York State.

Sample Calculations

Equation 18 CH_4 emissions (MT CO_2e) = gas processing plants x EF x AR5 GWP20

where:

- gas processing plants = number of gas processing plants
- EF = CH_4 EF (MTCH_4 plant^{-1} yr^{-1}) = 1,249.95
- AR5 GWP20 = GWP = 84

For example, in 2020, Cattaraugus County had no natural gas processing plants, resulting in 0 MT CO_2e, as shown:

Equation 19 Natural gas processing plant CH_4 (MT CO_2e) = 0 x 1,249.95 x 84
Natural gas processing plant CH_4 (MT CO_2e) = 0 MT CO_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, performing sensitivity analysis around the central estimate is useful.

3.2.6.5 Gas Transmission Pipelines

Source Category Description

Transmission pipelines transport natural gas long distances across states, moving the product from the production regions to distribution centers. Transmission pipelines operate at high pressures, ranging from 200 psi to 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 Cooperative Leak Measurement Program data. 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 most recent EPA GHG Inventory updates are not documented, so the team used the EPA/GRI (1996) estimate, which documents the methodology.			

Activity Data

The activity data for transmission pipelines consists of miles of pipeline. The team used state-level data on the transmission pipeline mileage from the PHMSA Pipeline Mileage and Facilities database (U.S. Department of Transportation 2023). Due to suspected anomalies in the PHMSA pipeline data, the team applied corrections based on guidance from the DEC. The team used the data reported in the PHMSA database for 2002–2017 to develop a trendline and estimate emissions for 1990–2001. Additionally, the team applied PHMSA data from 2002 to estimate emissions for 2003–2005, PHMSA data for 2008 to estimate emissions for 2009–2012, and PHMSA data for year 2013 to estimate emissions for 2014–2017. The team calculated CH_4 emissions by multiplying the pipeline miles by the EFs. The team converted MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

The team estimated transmission pipeline miles per county by summing reported line segments from PHMSA's public viewer (PHMSA 2022). They allocated the state-level miles reported in the PHMSA database to the county level by using the 2017 ratio of the estimated transmission pipeline miles in each county to the estimated miles in New York State, calculated by summing the transmission line segments from the map.

Sample Calculations

Equation 20 CH_4 emissions (MT CO_2e) = pipeline miles x AF x EF x AR5 GWP20

where:

- pipeline miles = state-level miles of transmission pipeline
- AF = allocation factor based on the ratio of county-level miles of pipeline in 2017 to state-level miles of pipeline in 2017
- EF = CH_4 EF (MTCH_4 mile^{-1} yr^{-1}) = 0.62
- AR5 GWP20 = GWP = 84

For example, in 2017, New York State had 4,536 miles of transmission pipeline. The data from summing line segments on the PHMSA map indicated that in 2020, Albany County had 124.28 miles of transmission pipeline out of 3,939 miles in the State. Applying the allocation factor, the team determined that in 2020, Albany County had 143.12 miles of transmission pipeline, resulting in 7,453.5 MT CO_2e, as shown.

Equation 21 Transmission pipeline CH_4 (MT CO_2e) = 4,536 x 124.28/3,939 x 0.62 x 84
Transmission pipeline CH_4 (MT CO_2e) = 7,453.5 MT CO_2e

Limitations and Uncertainties

These per-mile emission rates come from an older study with embedded leak frequencies that reflect past conditions 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 could reach 1,122.7 kg mile^{-1} year^{-1} (Annex Table 3.6-2), which is 81% higher than the SIT default value.

Potential Areas of Improvement

The team could use PHMSA pipeline statistics to derive NYS–specific emission estimates. PHMSA's reported LAUF gas could help generate state-level emissions estimates, but county-specific transmission line mileage and throughput are necessary to attribute emissions at the county level.

3.2.6.6 Gas Transmission Compressor Stations

Source Category Description

Transmission compressor stations are facilities located approximately every 104 miles along a natural gas pipeline to boost the pressure lost by friction as natural gas moves through the pipeline. This assumption is based on data from the DEC's permitting database and PHMSA's data on transmission pipeline miles.

Natural gas enters a compressor station through station yard piping, where s Scrubbers and filters remove any liquids, solids, or other particulate matter. The gas is then directed to individual compressors. Most compressor stations have an aerial cooler system to cool the gas stream before it leaves 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 Basins	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%), 32% lower than the default SIT value. The team derived the estimate applied here from a peer-reviewed study of 823 transmission CSs using empirical observations and statistical modeling techniques.			

Activity Data

The DEC provided data on natural gas transmission compressor stations from their permitting database, which provides compressor stations by county. The team determined the type of compressor station by reviewing permits and publicly available information. 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 do not require permits and are not included in the permitting database.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary because the DEC permitting database and the EIA dataset provide county-level information for all analysis years.

Sample Calculations

Equation 22 CH_4 emissions (MT CO_2e) = compressor stations x EF x AR5 GWP20

where:

- compressor stations = number of natural gas transmission compressor stations
- EF = CH_4 EF (MTCH_4 station^{-1} yr^{-1}) = 670
- AR5 GWP20 = GWP = 84

For example, in 2020, Cattaraugus County had two natural gas transmission compressor stations, resulting in 112,560 MT CO_2e, as shown:

Equation 23 Natural gas transmission compressor station CH_4 (MT CO_2e) = 2 x 670 x 84
Natural gas transmission compressor station CH_4 (MT CO_2e) = 112,560 MT CO_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 in many other areas, super-emitting sites comprised a small fraction of the total number of sites but accounted for a large fraction of the total emissions, resulting in wide uncertainty bands. This study also shows differences between reciprocating and centrifugal compressor stations.

Potential Areas of Improvement

Given that the differences in compressor engine emissions are unlikely to vary significantly, the most pressing need 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 and withdrawn during winter 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 and during withdrawal to move natural gas to the distribution system.

Emission Factors

Source Category	Natural Gas Storage Compressor Station			
Default EF ($MTCH_4$ station^{-1} yr^{-1})	847			
Source	Zimmerle et al. 2015			
EF Confidence	Geography: Marcellus/ Appalachian Basins	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 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 CSs using 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 CSs 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). Super-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 CSs because it has a larger sample size. However, the literature indicates that understanding compressor types and distribution of emissions is critical to robustly estimating emissions from CSs.			

Activity Data

The DEC provided the number of natural gas storage compressor stations from their permitting database, which lists compressor stations by county. The team determined the type of compressor station by reviewing permits and publicly available information.

Geospatial Data and Allocation Methodology

No allocation methodology was necessary because the DEC database on permits and the EIA dataset provide information at the county level for all analysis years.

Sample Calculations

Equation 24 CH_4 emissions (MT CO_2e) = compressor stations x EF x AR5 GWP20

where:

- compressor stations = number of natural gas storage compressor stations
- EF = CH_4 EF ($MTCH_4$ station^{-1} yr^{-1}) = 847
- AR5 GWP20 = GWP = 84

For example, in 2020, Cattaraugus County had three natural gas storage compressor stations, resulting in 213,444 MT CO_2e, as shown:

Equation 25 Natural gas storage compressor station CH_4 (MT CO_2e) = 3 x 847 x 84
Natural gas storage compressor station CH_4 (MT CO_2e) = 213,444 MT CO_2e

Limitations and Uncertainties

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

Potential Areas of Improvement

As noted, reciprocating and centrifugal compressors show different average emission rates. However, when normalized by horsepower, centrifugal compressors show much lower emissions; therefore, emissions per unit throughput are lower for centrifugal compressors. Additionally, high-emitting sources are a concern for compressors, with inconclusive evidence suggesting that high-emitting sources are more likely in standby or operational modes. This again highlights the importance of improving 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 later use. 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. The team recommends including storage reservoir fugitive emissions 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 economical way to store natural gas for vaporization and distribution later when demand increases. The LNG storage tanks at these stations can be above ground or in-ground, and LNG can be stored at very low temperatures to maintain the gas in a liquid form. The storage tanks are insulated to limit evaporation, but a small amount of heat can still penetrate the tanks, causing evaporation and resulting in boil-off gas. This gas is captured and fed back into the LNG flow using compressor and recondensing systems, preventing the venting of natural gas. However, during maintenance periods, the flare stack must burn off boil-off gas.

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 Basins	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 and guidance from Dr. Anthony Marchese, as follows: • 3.85 reciprocating compressors per station (rounded up to 4) • 0.91 centrifugal compressors per station (rounded 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 four 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

Three large LNG storage facilities currently operate in New York State (Astoria, Greenpoint, and Holtsville), all of which have been operational since 1990. The DEC provided the location of the facilities.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 26 CH_4 emissions (MT CO_2e) = compressor stations x EF x AR5 GWP20

where:

- compressor stations = number of LNG storage compressor stations
- EF = CH_4 EF (MTCH_4 station^{-1} yr^{-1}) = 1,077.48
- AR5 GWP20 = GWP = 84

For example, in 2020, Kings County had one LNG storage compressor station, resulting in 2,262,708 MT CO_2e, as shown:

Equation 27

$$\text{LNG storage compressor station } CH_4 \text{ (MT } CO_2e) = 1 \times 1{,}077.48 \times 84$$
$$\text{LNG storage compressor station } CH_4 \text{ (MT } CO_2e) = 2{,}262{,}708 \text{ MT } CO_2e$$

Limitations and Uncertainties

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

Potential Areas of Improvement

The team made several assumptions estimating the EF for LNG storage compressor stations. This estimate may be improved by validating the assumptions 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 regasifying the LNG transported from production zones. LNG terminals berth LNG tankers, unload or reload cargo, store LNG in cryogenic tanks, regas LNG, and/or send gas into the transmission grid. New York State has no LNG terminals.

3.2.7 Downstream Stages

3.2.7.1 Distribution Pipelines

Source Category Description

Distribution pipelines comprise mains and service lines that distribution companies use to deliver natural gas to homes and businesses. Mains connect high-pressure transmission lines to low-pressure service lines. Materials used for these pipes include steel, cast iron, plastic, and copper. Pressures vary considerably, with some reaching 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. The gas pressure in these pipes is low at around 6 psi.

Emission Factors

EFs 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).

<table>
<tr><th colspan="2">Source Category</th><th>Cast Iron</th><th>Unprotected Steel</th><th>Protected Steel</th><th>Plastic</th><th>Copper</th></tr>
<tr><td rowspan="2">Default EF ($MTCH_4$ $mile^{-1}$ yr^{-1})</td><td>Main</td><td>4.5974</td><td>2.1223</td><td>0.0588</td><td>0.1909</td><td>0.4960</td></tr>
<tr><td>Services</td><td>4.5974</td><td>2.7115</td><td>0.2473</td><td>0.0135</td><td>0.4960</td></tr>
<tr><td>Source</td><td colspan="6">Lamb et al. 2015; EPA 2018,[a] 2021</td></tr>
<tr><td>EF Confidence</td><td colspan="2">Geography: NYS</td><td>Recency: ≤ 5 Years</td><td colspan="2">Methodology: Empirical Observation</td><td>Status: Peer-Reviewed</td></tr>
<tr><td>Source Description</td><td colspan="6">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 most emissions.</td></tr>
</table>

[a] The EF for cast-iron services is assumed to be equal to the EF for cast-iron mains.

Activity Data

The team measured the activity data for main and service distribution pipelines by miles of pipeline, categorized by material type. The team pulled operator-level data on the pipeline mileage by type from the PHMSA Pipeline Mileage and Facilities database (U.S. Department of Transportation 2023). To correct for potential outliers in the PHMSA data, likely due to incomplete reporting, the team made the following data adjustments:

- **Cast-iron mains**: 1991 averages 1990 and 1992 PHMSA data.
- **Cast-iron service**s: 1990 to 2003 are based on a trendline from 2004 to 2017 PHMSA data.
- **Unprotected steel services**: 1991, 1998, and 2009 are the average PHMSA data from 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 PHMSA data from 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 PHMSA data from adjacent years.

The team calculated CH_4 emissions by multiplying miles of pipeline, by pipeline type, by the EFs, and then converted the MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

The team allocated the operator-level miles of distribution pipelines reported in the PHMSA database to the county level based on the number of services. Section 3.2.12.6 discusses the methodology for estimating the number of services.

Sample Calculations

Equation 28 CH_4 emissions (MT CO_2e) = pipeline miles$_{type}$ x AF x EF x AR5 GWP20

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
- AR5 GWP20 = GWP = 84

For example, according to the PHMSA data, in 2020, New York State had 4,263.04 miles of unprotected steel distribution service pipeline. According to the allocation method, in 2020, Albany County had a total of 109,358 natural gas services, while the State had 4,559,150 natural gas services for the same period. Applying the allocation factor, in 2020, Albany County had 102.17 miles of unprotected steel distribution service pipeline, resulting in 23,290.1 MT CO_2e, as shown:

Equation 29

$$\text{Unprotected steel distribution pipeline } CH_4 \text{ (MT } CO_2e) = 4{,}263 \times 109{,}358/4{,}559,\ 150 \times 2.7115 \times 84$$
$$\text{Unprotected steel distribution pipeline } CH_4 \text{ (MT } CO_2e) = 23{,}290.1 \text{ MT } CO_2e$$

Limitations and Uncertainties

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

Potential Areas of Improvement

Conducting a survey of actual miles of pipeline by 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 as the pressure of the gas flowing through the pipeline increases. When the valve opens for routine maintenance, it may emit gas.

Emission Factors

Source Category	Pressure Relief Valves			
Default EF ($MTCH_4$ $mile^{-1}$ yr^{-1})	0.00096			
Source	EPA 2024b, 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 2024b), based on EPA/GRI (1996) data.			

Activity Data

The team used total miles of distribution pipeline mains and services, summed across all types of materials, as the blowdown activity data. Section 3.2.7.1 describes the methodology for deriving the miles of distribution pipeline mains.

Geospatial Data and Allocation Methodology

The team allocated operator-level miles of distribution pipelines reported in the PHMSA database to the county level based on the number of services. Section 3.2.12.6 discusses the methodology for estimating the number of services.

Sample Calculations

Equation 30 **CH_4 emissions (MT CO_2e) = pipeline miles x EF x AR5 GWP20**

where:

- pipeline miles = state-level miles of distribution pipeline mains
- EF = CH_4 EF (MTCH_4 mile^{-1} yr^{-1}) = 0.00096
- AR5 GWP20 = GWP = 84

For example, in 2020, Albany County had 1,192.64 miles of pipeline mains, resulting in emissions of 96.2 MT CO_2e, as shown:

Equation 31 **Pressure Relief Valve CH_4 (MT CO_2e) = 1,192.64 x 0.00096 x 84**
Pressure Relief Valve CH_4 (MT CO_2e) = 96.2 MT CO_2e

Limitations and Uncertainties

The EFs for this category are based on older studies that are not local to New York State, so they may not accurately represent conditions and emissions in the State.

Potential Areas of Improvement

Conducting a survey of actual miles of pipeline by 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 releases gas into the atmosphere to relieve pressure in the pipeline and allow for pipeline maintenance.

Emission Factors

Source Category	Blowdowns			
Default EF ($MTCH_4$ $mile^{-1}$ yr^{-1})	0.00196			
Source	EPA 2024b, 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 2024b), based on EPA/GRI (1996) data.			

Activity Data

The team used total miles of distribution pipeline mains and services, summed across all types of materials, as the blowdown activity data. Section 3.2.7.1 describes the methodology for deriving the miles of distribution pipeline mains.

Geospatial Data and Allocation Methodology

The team allocated operator-level miles of distribution pipelines reported in the PHMSA database to the county level based on the number of services. Section 3.2.12.6 discusses the methodology for estimating the number of services.

Sample Calculations

Equation 32 **CH_4 emissions (MT CO_2e) = pipeline miles x EF x AR5 GWP20**

where:

- pipeline miles = state-level miles of distribution pipeline mains and services
- EF = CH_4 EF ($MTCH_4$ $mile^{-1}$ yr^{-1}) = 0.00196
- AR5 GWP20 = GWP = 84

For example, in 2020 Chemung County had 658 miles of pipeline mains and services, resulting in emissions of 108 MT CO_2e, as shown:

Equation 33 **Blowdown CH_4 (MT CO_2e) = 658 x 0.00196 x 84**
Blowdown CH_4 (MT CO_2e) = 108 MT CO_2e

Limitations and Uncertainties

The EFs for this category are based on older studies not local to New York State, so they not accurately represent conditions and emissions in the State.

Potential Areas of Improvement

Conducting a survey of actual miles of pipeline by 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 release gas into the atmosphere.

Emission Factors

Source Category	Damages			
Default EF ($MTCH_4$ $mile^{-1}$ yr^{-1})	0.03062			
Source	EPA 2024b, 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 2024b), based on EPA/GRI (1996) data.			

Activity Data

The team used total miles of distribution pipeline mains and services, summed across all types of materials, as the data for blowdowns. Section 3.2.7.1 describes the methodology for deriving the miles of distribution pipeline mains.

Geospatial Data and Allocation Methodology

The team allocated operator-level miles of distribution pipelines reported in the PHMSA database to the county level based on the number of services. Section 3.2.12.6 discusses the methodology for estimating the number of services.

Equation 34 **CH_4 emissions (MT CO_2e) = pipeline miles x EF x AR5 GWP20**

where:

- pipeline mile = state-level miles of distribution pipeline mains and services
- EF = CH_4 EF (MTCH_4 mile^{-1} yr^{-1}) = 0.03062
- AR5 GWP20 = GWP = 84

For example, in 2020, Chemung County had 658 miles of pipeline mains, resulting in emissions of 1,692 MT CO_2e, as shown:

Equation 35 **Damages CH_4 (MT CO_2e) = 658 x 0.03062 x 84**
Damages CH_4 (MT CO_2e) = 1,692 MT CO_2e

Limitations and Uncertainties

The EFs for this category are based on older studies that are not local to New York State, so they may not accurately represent conditions and emissions in the State.

Potential Areas of Improvement

Conducting a survey of actual miles of pipeline by 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 Metering and Regulating Stations

Source Category Description

M&R stations are used to transmit and distribute natural gas to measure gas flow 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 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 (MTCH4 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 2024b, 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 2024b), based on EPA/GRI (1996) data. 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 2011–2021, EPA/GRI (1996) for 1990–1992, and a linear extrapolation for 1993–2010.									

Activity Data

The activity data for M&R stations are the number of stations, classified by 10 categories based on inlet pressure category (e.g., 100–300, 40–100), 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. The team calculated CH_4 emissions as the number of stations multiplied by the EF and then converted the MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 factor of 84.

Geospatial Data and Allocation Methodology

The team used the national counts of M&R stations from the U.S. GHG Inventory (EPA 2024b) to estimate the number of M&R stations in New York State by applying a ratio of NYS pipeline miles to U.S. pipeline miles and a ratio of M&R stations by type to pipeline miles. They then distributed state-level M&R stations by type to counties using a county-to-state ratio of gas distribution employees from County Business Patterns (NAICS 2212).

Sample Calculations

Equation 36 **CH_4 emissions (MT CO_2e) = pipeline miles x AF_1 x AF_2 x EF x AR5 GWP20**

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})
- AR5 GWP20 = GWP = 84

For example, in 2020, the U.S. had 4,244 M&R stations with inlet pressure greater than 300 psi. For this year, the U.S. had 1,337,012 miles of pipeline mains, resulting in a ratio of 0.0032. Applying this ratio to the pipeline miles in the State (49,778) results in 158 M&R stations with inlet pressure greater than 300 psi. 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, resulting in emissions of 1,764 MT CO_2e as shown below:

Equation 37

$$\text{M\&R station } CH_4 \text{ emissions (MT } CO_2e) = 49{,}778 \times 0.0032 \times 0.061538 \times 2.1427 \times 84$$
$$\text{M\&R station } CH_4 \text{ emissions (MT } CO_2e) = 1764 \text{ MT } CO_2e$$

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 1993–2010 are based on an extrapolation, which could be inaccurate. In addition, EFs are based on studies of emissions from outside New York State, so they may 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 experts estimate that between 3,000 and 4,000 M&R stations exist 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 and 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 less than 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 2024b, 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 2024b), based on data from the Gas Technical Institute (GTI; 2009 for all; 2019 for commercial and industrial) and Clearstone Engineering (2011) for residential.			

In the first iteration of the Oil and Gas Methane Inventory, published in 2019 (NYSERDA 2019a), the methodology for service meters used an EF of 0.0097 for commercial and industrial meters derived by EPA in its 2018 U.S. GHG Inventory (EPA 2018a). In this version of the inventory, the EPA applied separate EFs for commercial and industrial meters by updates to the 2021 U.S. GHG Inventory (EPA 2024b).

Activity Data

The activity data for service meters is the number of service meters. State-level data on the distribution meter counts came from the PHMSA Pipeline Mileage and Facilities database (U.S. Department of Transportation 2023), U.S. Census Bureau reported household utility gas counts and County Business Patterns and the EIA-reported residential, commercial, and industrial customer counts.

The team calculated CH_4 emissions as the number of distribution meters times the EF and then converted the MTs of CH_4 to MT CO_2e by applying the AR5 GWP20 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. Analysts then geospatially allocated meter counts by census tract to the county and gas utility service areas based on the most recently available geospatial distribution of service areas (State of New York Open Data 2023). To address the undercounting of homes with utility gas in the one-year census data, they scaled census counts by the total residential meter count reported by EIA (EIA 2024a) Since census data for 1990–2006 were not readily available, the 2006 distribution of meters by census block was used as the baseline. The same methodology was applied to scale the total residential meter count using EIA-reported data for those years. The U.S. Census Bureau's American Community Survey reported the number of homes using utility gas as the primary heat source (U.S. Census Bureau 2022).

Commercial meters were allocated based on the count of businesses by ZIP Code, available from the Census County Business Patterns dataset geospatially allocated to county and gas service territories (U.S. Census Bureau 2023b). 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 (EIA 2024c).

Industrial meters were allocated based on the count of businesses with manufacturing North American Industry Classification System (NAICS) codes, available from the Census County Business Patterns dataset (U.S. Census Bureau 2023b), 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 (EIA 2024c).

Sample Calculations

Equation 38 CH_4 emissions (MT CO_2e) = service meters x AF1 x AF2 x EF x AR5 GWP20

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})
- AR5 GWP20 = GWP = 84

For example, according to the PHMSA data, in 2020, New York State had 3,241,702 service meters. The ratio of residential to total meters estimated from the allocation methodology is 4,150,738/4,559,150. Based on the allocation methodology, in 2020, Albany County had 101,851 homes with utility gas as the primary heat source, and New York State had 4,150,738. Applying the allocation factors to the PHMSA data, in 2020, Albany County had 72,419 residential service meters, resulting in 2,716 MT CO_2e, as shown:

Equation 39

Distribution meter CH_4 (MT CO_2e) = 3,241,702 x 4,150,738/4,559, 150 x 101,851/4,150,738 x 0.0015 x 84
Distribution meter CH_4 (MT CO_2e) = 9,124.8 MT CO_2e

Limitations and Uncertainties

The estimates for emissions from services and meters rely on values from the EPA's 2018 GHG emissions inventory (Annex 3.6, Table 3.6-2). These values stem from GRI's 1996 study, which used Indaco Air Quality Services' 1992 report, "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-yr^{-1}.

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

Potential Areas of Improvement

This estimate may be improved by using more updated estimates of leak rates from residential meters. The EPA/GRI (1996) study suggested potential regional variations in leak rates from residential meters, making New York State or Northeast-specific measurements, where available, more 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 CH_4 concentration spike compared to the low concentration of CH_4 in the exhaust during steady-state operation. The CH_4 emissions from residential appliances in this category reflect the appliance exhaust during ignition, extinguishment, and steady-state operation.

Emissions Factors

Source Category	Residential Appliances			
Default EF ($MTCH_4$ appliance-1 yr^{-1})	Furnace 0.00022 (0.00014–0.00051) Boiler 0.00032 (0.00015–0.00075) Storage Water Heater 0.000077 (0.00002–0.000084) Tankless Water Heater 0.0012 (0.00098–0.041) Stove 0.000056 (0.00004–0.000071) Oven 0.00013 (0.00011–0.00014)			
Source	Merrin and Francisco 2019			
EF Confidence	Geography: NYS	Recency: ≤ 5 Years	Methodology: Empirical Observation	Status: Peer-Reviewed
Source Description	Merrin and Francisco (2019) sampled CH_4 concentrations in exhaust from residential natural gas appliances at 72 sites in Boston, MA, and Indianapolis, IN, and 28 sites in Illinois and NYS. Testing used a Picarro G4301 cavity ringdown spectroscopy portable gas concentration analyzer. The authors studied furnaces, boilers, storage water heaters, tankless water heaters, stoves, and ovens. Merrin & Francisco 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: $appliance\ annual\ emissions\ (kg) = ignition\ emission\ (kg/activation) + extinguishment\ emission\ (kg/activation) * \frac{activations}{year} + steady\ state\ emission\ rate \left(\frac{kg}{hr}\right) * annual\ runtime \left(\frac{hr}{yr}\right)$ The CH_4 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. Merrin and Francisco report per-alliance annual emissions values and 97.5% confidence interval range to account for the uncertainty.			

Two recent studies reference Merrin and Francisco's work (2019). Lebel et al. (2020) developed emissions factors from natural gas water heaters in northern California and compared the emissions factors to those Merrin and Francisco developed. While the EFs Lebel et al. developed are higher than those by Merrin and Francisco for water heaters, Lebel et al. (2020) note that Merrin and Francisco did not measure pilot lights due to their sampling protocol. However, EF values were similar for both studies' components, indicating that EFs are comparable regardless of location/ climate. Saint-Vincent and Pekney (2020) compared the Merrin and Francisco EF for furnaces to EFs used in other countries. They use the EF for furnaces Merrin and Francisco developed and convert it to units of kilograms per terajoule (kg/TJ). Saint-Vincent and Pekney 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 Mid-Atlantic (New Jersey, New York State, and Pennsylvania; EIA 2024d) is estimated using information from the 2015 Residential Energy Consumption Survey (RECS; Tables HC3.7, HC6.7, and HC8.7; EIA 2018b). 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 Mid-Atlantic region. Table 8 shows the estimated number of appliances by appliance type in the Mid-Atlantic region in 2015.

Table 8. Number of Natural Gas Appliances in the Mid-Atlantic Region by Appliance Type, 2015

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

Table 9 shows the fraction of housing units with appliance type, calculated by dividing the total number of appliances by the total number of housing units in the Mid-Atlantic in 2015 from RECS (15.4 million).

Table 9. Fraction of Housing Units with Appliance Type by Appliance, 2015

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

The team used NYSERDA's "Single-Family Building Assessment" report (2019b) and the U.S. Census Bureau's "National, State, and County Housing Unit Totals: 2010–2023" (YEAR) to develop the fraction of housing units by housing unit type across the three climate zones in the State, which Table 10 details.

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 Climate Zone 5 Climate Zone 6	0.181274	0.146721	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 calculated by multiplying the county-level number of houses from U.S. Census Bureau data 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 is required for 2000–2020 because the number of county-level housing units was available from the U.S. Census. For 1990–1999, the ratio of county-to-State total housing units in 2000 was applied to distribute state-level numbers to the county level.

Sample Calculation

Equation 40 **CH_4 emissions (MT CO_2 e) = ∑Housing unitscounty x fraction of housing unitsappliance x housing unit type fractionclimate zone x CFng service x EFappliance x AR5 GWP20**

where:

- Housing $units_{county}$ = total number of housing units in county
- Fraction of housing $units_{appliance}$ = fraction of housing units with natural gas appliance
- Housing unit type $fraction_{climate}$ = fraction of housing unit type by climate zone
- $CF_{ng\ service}$ = correction factor to account for counties without natural gas service
- $EF_{appliance}$ = CH_4 emissions factor by appliance ($MTCH_4$ $appliance^{-1}$ yr^{-1})
- AR5 GWP20 = GWP = 84

For example, in 2020, Albany County had 7,737 natural gas furnaces in single-family homes in Albany, resulting in 143 MT CO_2e as shown below:

Equation 41 **Gas furnace CH_4 (MT CO_2 e) = 143,314 x 0.36129 x 0.146721 x 1.0185 x 0.00022 x 84**
Gas furnace CH_4 (MT CO_2 e) = 143 MT CO_2e

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 was 3,583.4 MT CO_2e.

Limitations and Uncertainties

Several limitations exist in the current draft emission estimates due to unavailable data. The inventory does not currently include emissions from natural gas clothes dryers because data on emissions from residential natural gas clothes dryers are not readily available. However, the impact of excluding natural gas clothes dryers is likely minimal. Research by Fisher et al. (2018) indicates that pilot lights are a primary source of end-use CH_4 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, implying that emissions from other appliances, such as natural gas dryers, are negligible.

Potential Areas of Improvement

The appliance estimates are based on Mid-Atlantic survey results from RECS. Conducting an NYS-specific survey could enhance the accuracy of the appliance count estimates. For example, NYSERDA's "Single-Family Building Assessment" report includes information on the penetration rates of some natural gas appliance types. These rates could refine the Mid-Atlantic survey results.

3.2.7.8 Residential Buildings

Source Category Description

In addition to appliance emissions, postmeter fugitive CH_4 emissions in residential buildings result from plumbing connections and pilot lights. This source category estimates CH_4 leakage from residential building pipes, pipe connections, and pilot lights associated with quiescent appliances (e.g., 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, 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 based on the number of housing units with natural gas service. State-level data on meter distribution was sourced from the PHMSA Pipeline Mileage and Facilities database (U.S. Department of Transportation 2023), U.S. Census Bureau 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, available at the census tract level for 2006–2020, were geospatially allocated by census tract to the county and gas utility service areas based on the most recent geospatial distribution of service areas.

Due to undercounting homes with utility gas in the one-year census data, census counts were scaled using the total residential meter count reported by the EIA (EIA 2024a). Census data were not readily available for 1990–2006, so the team used the 2006 distribution of meters by census block as the baseline. The same methodology was applied to scale the total residential meter count using EIA-reported data for those years. The U.S. Census Bureau's American Community Survey reported several homes with utility gas as the primary heat source (U.S. Census Bureau 2022).

Sample Calculations

Equation 42 CH_4 **emissions (MT** CO_2 **e) = housing units**$_{ng}$ **x EF x AR5 GWP20**

where:

Equation 43 **Housing units**$_{ng}$ **= number of housing units with natural gas service**

- EF = CH_4 EF (MTCH_4 housing unit^{-1} yr^{-1}) = 0.00181
- AR5 GWP20 = GWP = 84

For example, in 2020, Cattaraugus County had 13,176 housing units, resulting in 2,003 MT CO_2e, as shown below.

Equation 44 **Residential building** CH_4 **(MT** CO_2 **e) = 13,176 x 0.00181 x 84**
Residential building CH_4 **(MT** CO_2**e) = 2,003 MT** CO_2**e**

Limitations and Uncertainties

Fischer et al. (2018a) assumed that CH_4 emissions from multifamily housing could be estimated using results from single-family homes because they share similar characteristics for natural gas plumbing and appliances. The study found no significant relationship ($p < 0.1$) between whole-house leakage and house age.

Potential Areas of Improvement

Accurate emissions estimates for residential buildings from 1990 to 2005 require county-level housing unit data for New York State during that period.

3.2.7.9 Commercial Buildings

Source Category Description

Post-meter fugitive CH_4 leaks in commercial buildings result from gas appliance and pipeline leaks. Since gas appliance combustion emissions are addressed in other sections of the NYS GHG inventory, this source category focuses exclusively 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 food service 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 Sweeney et al. (p. 138) while restaurant emissions factors are derived from scenario 3.</td><td colspan="2">ICF (2020) analyzed field data to characterize CH_4 emissions from commercial buildings in California. Combining estimates of emissions from pipe joints and appliances, the team estimated total fugitive CH_4 emissions from commercial buildings across California to be between 540 and 620 MMcf per year as measured or 311 to 392 Mmcf per year for the alternative estimate designed to reduce the impact of outliers.</td></tr>
</table>

Activity Data

The activity data for commercial buildings consist of county-level counts of buildings by type. Data for each commercial building type were obtained from the U.S. Census Bureau's County Business Patterns datasets. For the period from 1998 to 2011, the dataset provided building counts by NAICS codes, such as 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 (hospitals), 722511 (full-service restaurants), 722513 (limited-service restaurants), and 722514 (cafeterias, grill buffets, and buffets). The individual restaurant counts were summed to a total count per county. Because county-level data for these NAICS codes are unavailable before 1998, data for 1990 to 1998 were held constant based on 1998 figures.

Geospatial Data and Allocation Methodology

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

Sample Calculations

Equation 45 CH_4 **emissions (MT** CO_2 **e) = ∑commercial buildings**$_{type}$ **x EF x AR5 GWP20**

where:

- commercial buildings$_{type}$ = number of commercial buildings by building type.
- EF_{type} = CH_4 EF by building type ($MTCH_4$ building^{-1} yr^{-1}).
- AR5 GWP20 = GWP = 84

For example, in 2020, Cattaraugus County had 126 restaurants, resulting in 508 MT CO_2e as shown below:

Equation 46 **Restaurant** CH_4 **(MT** CO_2 **e) = 126 x 0.0480325 x 84**
Restaurant CH_4 **(MT** CO_2e**) = 508 MT** CO_2e

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.

Due to the limited number of buildings and appliances analyzed and outliers in the ICF (2020) sample, the uncertainty of this analysis is significant. The range of emissions spans approximately 78.6 Mmcf to 1.1 billion cubic feet (Bcf) of CH_4 annually. In addition, EFs for all buildings are based on studies conducted in California, which may not accurately represent the current conditions and leak rates from commercial buildings in New York State.

Potential Areas of Improvement

- Obtain more accurate county-level data on commercial buildings before 1998 to replace the constant values used for 1990–1998.
- Develop emission factors and collect data for additional commercial building types to enhance the comprehensiveness of the analysis.

Accurate county-level data on commercial buildings prior to 1998 would improve the estimates for this category by replacing the constant values currently used for the period from 1990 to 1998. Furthermore, developing emissions factors and collecting data for additional commercial building types would enhance the comprehensiveness and accuracy of the analysis.

4 Results

This section analyzes the detailed, activity-driven CH_4 emissions inventory for the oil and natural gas sector in New York State. It draws on data from the section 3.1 and the methodology outlined in the section 3.2. Following IPCC guidelines and EPA best practices, the analysis identifies and describes CH_4 emissions by source category and provides a geospatially resolved breakdown of emissions by county. It also highlights trends in CH_4 emissions captured by the inventory from 1990 to 2022.

4.1 Inventory Updates

The inventory has improved with each iteration of the project. Appendix A details these enhancements. Table 12 compares emissions across key inventory years in all three inventories, including the first NYS GHG Inventory (1990–2015) and subsequent NYS Oil and Gas Sector Methane Emissions Inventory (1990–2017, 1990–2020, 1990–2022, and the current 1990–2022 iteration).

In the first iteration of the project, CH_4 emissions for 2015 totaled 112,870 MT CH_4 or approximately 2.82 MMT CO_2e (AR4 GWP100). These emissions were 27% higher than previous estimates for natural gas systems (2.22 MMT CO_2e, AR4, GWP100 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 MMT CO_2e (AR4 GWP100) or 8.951 MMT CO_2e (AR5 GWP20). The second iteration estimated 2017 emissions at 14.7 MMT CO_2e (AR5 GWP20), a 64% increase due to incorporating beyond-the-meter sources and updated emission factors for distribution and conventional production.

When emissions from the 2015 inventory are converted to AR5 GWP20, the second iteration shows a 113.5% increase from the original 2015. Using 2020 as the most recent common year, the third iteration estimated CH_4 emissions to be 6.2% higher than the second iteration. In 2021, CH_4 emissions from oil and natural gas activity in New York State totaled 176,051 MTCH_4, equivalent to 14.8 MMT CO_2e (AR5 GWP20).

Using 2021 as the common year, the fourth iteration estimates showed an 11.39% decrease in CH_4 emissions compared to the third iteration. By 2022, CH_4 emissions from oil and natural gas activity in the State totaled 157,699 MTCH_4, equivalent to 13.2 MMT CO_2e (AR5 GWP20).

Table 12. Comparison of Total Emissions across Key Inventory Years

Emissions reported in MMT CO_2e; calculated using AR4 and AR5 GWP100 and GWP20 values.

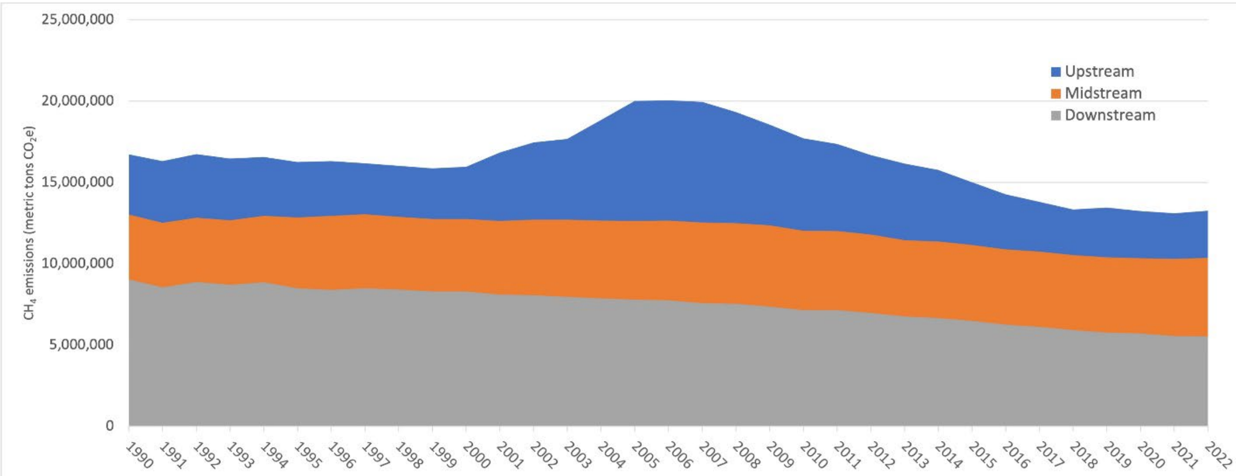
Inventory	AR4 GWP100	AR4 GWP20	AR5 GWP100	AR5 GWP20
1990				
NYS GHG Inventory, 1990–2015	2.8	8.06	3.14	9.41
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	2.74	7.88	3.07	9.21
NYS Oil and Gas Methane Emissions Inventory, 1990–2020	5.17	14.89	5.80	17.40
NYS Oil and Gas Methane Emissions Inventory, 1990–2021	5.42	15.60	6.07	18.20
NYS Oil and Gas Methane Emissions Inventory, 1990–2022	4.97	14.33	5.57	16.71
2005				
NYS GHG Inventory, 1990–2015	3.5	10.07	3.93	11.76
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	3.52	10.12	3.95	11.83
NYS Oil and Gas Methane Emissions Inventory, 1990–2020	6.15	17.72	6.93	20.73
NYS Oil and Gas Methane Emissions Inventory, 1990–2021	6.42	18.48	7.19	21.56
NYS Oil and Gas Methane Emissions Inventory, 1990–2022	5.96	17.15	6.67	20.01
2015				
NYS GHG Inventory, 1990–2015	2.22	6.39	2.49	7.46
NYS Oil and Gas Methane Emissions Inventory, 1990– 2017	2.82	8.12	3.16	9.48
NYS Oil and Gas Methane Emissions Inventory, 1990– 2020	4.74	13.65	5.31	15.92
NYS Oil and Gas Methane Emissions Inventory, 1990–2021	4.98	14.34	5.58	16.73
NYS Oil and Gas Methane Emissions Inventory, 1990–2022	4.46	12.85	5.00	15.00

4.2 Emissions Time Series

Figure 12 shows the total CH_4 emissions in New York State from 1990 to 2022. Retrospective emissions are calculated by applying current methodologies and EFs to past activity data. Figure 12 shows an overall increase in CH_4 emissions from 1990, peaking at 20.038 MMT CO_2e in 2006. Since 2005, CH_4 emissions have declined annually, except for a slight increase in 2019. Overall, CH_4 emissions have decreased 33.89% from their 2006 peak, as discussed in greater detail in the following section.

Figure 12. Total Methane Emissions in New York State, 1990–2022

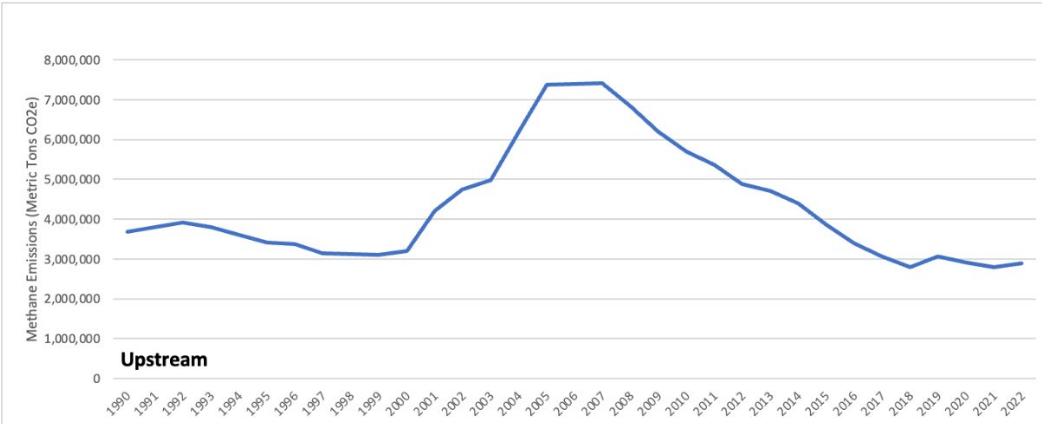
Calculated using AR5 GWP20 values.



Total emissions are the sum of upstream (Figure 13), midstream (Figure 14), and downstream (Figure 15) emissions. While upstream emissions are smaller than midstream and downstream emissions, they have shown greater variability over time, reflecting the cyclical nature of oil and gas exploration and well completions in New York State. Upstream CH_4 emissions peaked at 7.416 MMT CO_2e in 2007, aligning with the observed peak in natural gas production (Figure 4) and well completions (Figure 2), both driven by peak natural gas prices. Since 2007, well completions have fallen to zero, and natural gas production has decreased to roughly one-fifth of its 2007 peak production, leading to a substantial decline in emissions from upstream source categories. Overall, upstream emissions decreased 22% from 1990 to 2022 and 61.0% from 2007 to 2022.

Figure 13. Upstream Methane Emissions in New York State, 1990–2022

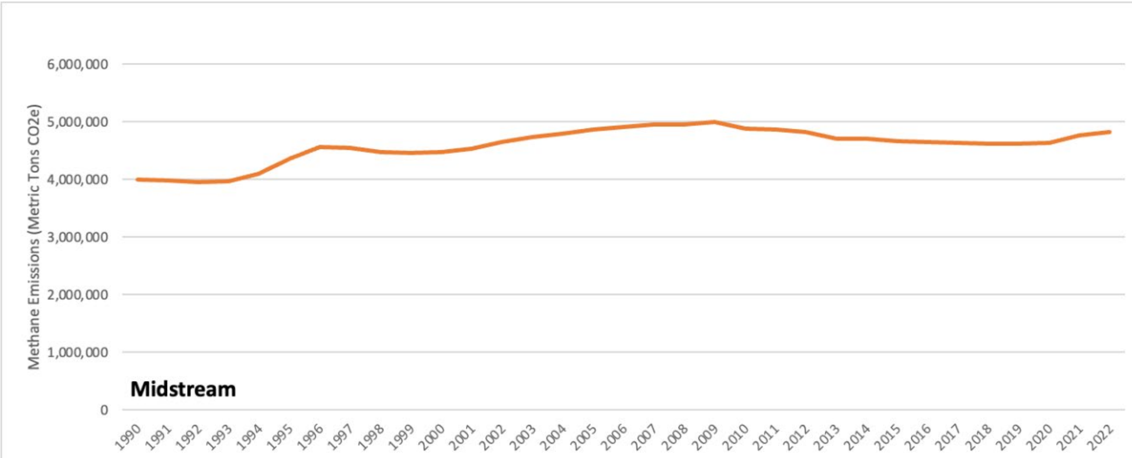
Calculated using AR5 GWP20 values.



Midstream CH_4 emissions (Figure 14) increased by 20.4% from 1990–2022. However, since 2009, these emissions have decreased by 3.7%, primarily due to reduced natural gas production and subsequent declines in natural gas gathering. As shown in Figure 17, midstream CH_4 emissions are largely driven by transmission and storage compressor stations and transmission pipelines. DEC data show that increasing compressor counts and transmission pipeline miles in New York State generally contributed to higher midstream CH_4 emissions. Despite declining gas production since 2006, natural gas consumption in the State has grown by 22%, increasing from 1,080,215 MMcf in 2005 to 1,361,023 MMcf in 2022 (EIA 2024). Correspondingly, emissions peaked in 2009, coinciding with the addition of new compressor stations and transmission pipelines required to maintain natural gas pressure along the transmission system in New York State.

Figure 14. Midstream Methane Emissions in New York State, 1990–2022

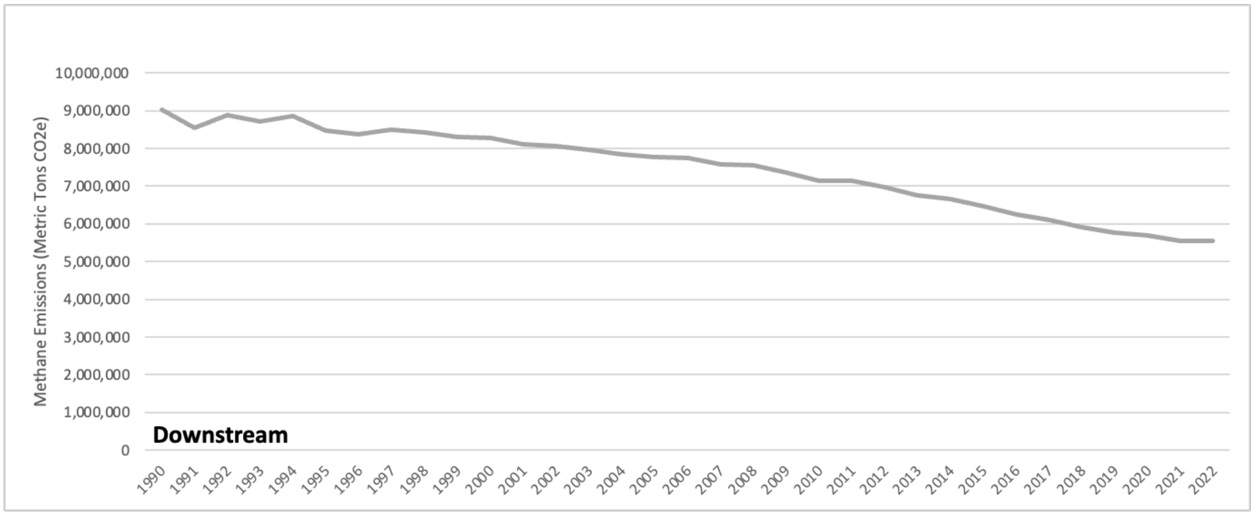
Calculated using AR5 GWP20 values.



Downstream CH_4 emissions (Figure 15) decreased 36.8% from 1990 to 2022. The two largest source categories to downstream emissions—cast-iron and unprotected steel distribution main pipelines—have decreased significantly since 1990 and have largely been replaced with plastic distribution mains. Because plastic mains have much lower leak rates and lower EFs, this transition has driven the downward trend observed in Figure 15. Although natural gas consumption in New York State has increased, seen in the increasing number of residential services and meters, the overall emissions have declined. This reduction results from the widespread replacement of cast-iron and unprotected steel distribution lines with plastic, which has offset the growth in the number of meters and services.

Figure 15. Downstream Methane Emissions in New York State, 1990–2022

Calculated using AR5 GWP20 values.



4.3 Total Emissions

Oil and natural gas activities in New York State in 2022 emitted 157,699 MT CH_4 in 2022, equivalent to 13,246,755 MT CO_2e (values given in AR5 GWP20 unless otherwise noted). Using 2015 as the most recent common year, this study estimates CH_4 emissions to be 109.53% higher than the previous estimate of CH_4 emissions from the oil and natural gas sector in the 2015 NYS GHG inventory (16.73 MMT CO_2e, AR5 GW20). Using 2021 as the most recent common year, this study estimates CH_4 emissions to be 11.38% lower than the previous iteration of the NYS Oil and Gas Methane Emissions Inventory. This reduction reflects updates to transmission station activity data in the midstream sector, using the best available data (see Section 3.2.11.6).

4.4 Emissions by Upstream, Midstream, and Downstream Stages, in 2022

Figure 16 shows upstream, midstream, and downstream emissions as percentages of total CH_4 emissions, and Figure 17 breaks down emissions by upstream, midstream, and downstream source categories using AR5 GWP20 units. Tables 13, 14, and 15 also present these data over time. Downstream emissions totaled 5.539 MMT CO_2e, accounting for 41.82% of total CH_4 emissions. Similar to the previous inventory, cast-iron steel mains are the largest downstream single-source category, followed by unprotected steel mains and services. Midstream emissions totaled 4.817 MMT CO_2e, accounting for 36.36% of emissions, with compressors (storage and transmission) comprising the largest source categories in the inventory. Storage and transmission compressor stations are the largest single-source categories identified in New York State, surpassed only by conventional gas wells, the dominating single-source category of upstream emissions. Upstream emissions totaled 2.890 MMT CO_2e, accounting for 21.82% of total CH_4 emissions. These totals highlight that, as a major consumer of natural gas, the State's midstream and downstream source categories drive the majority of CH_4 emissions.

Figure 16. Methane Emissions by Stage as Percentages of Total Emissions, 2022

Calculated using AR5 GWP20 values; grouped by downstream, midstream, and upstream stages.

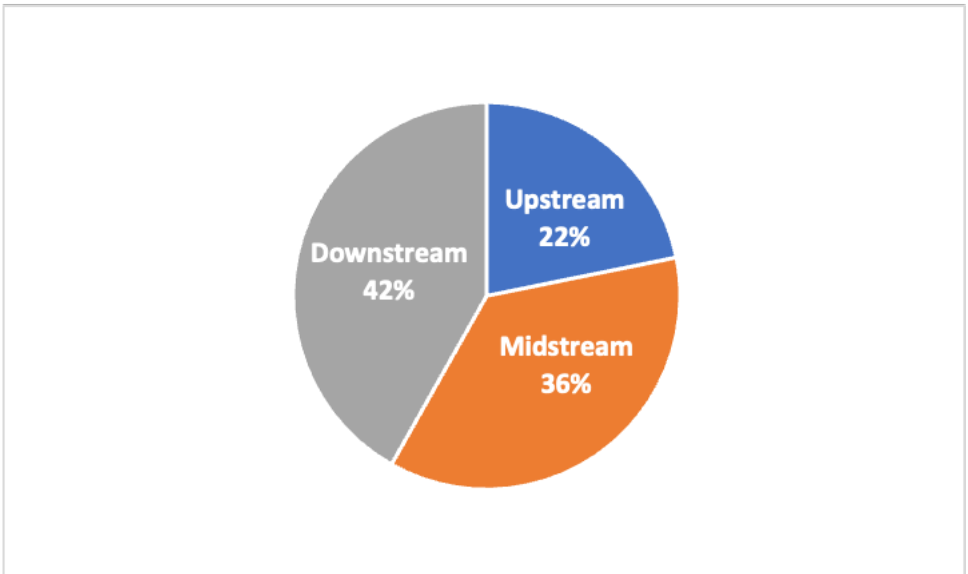
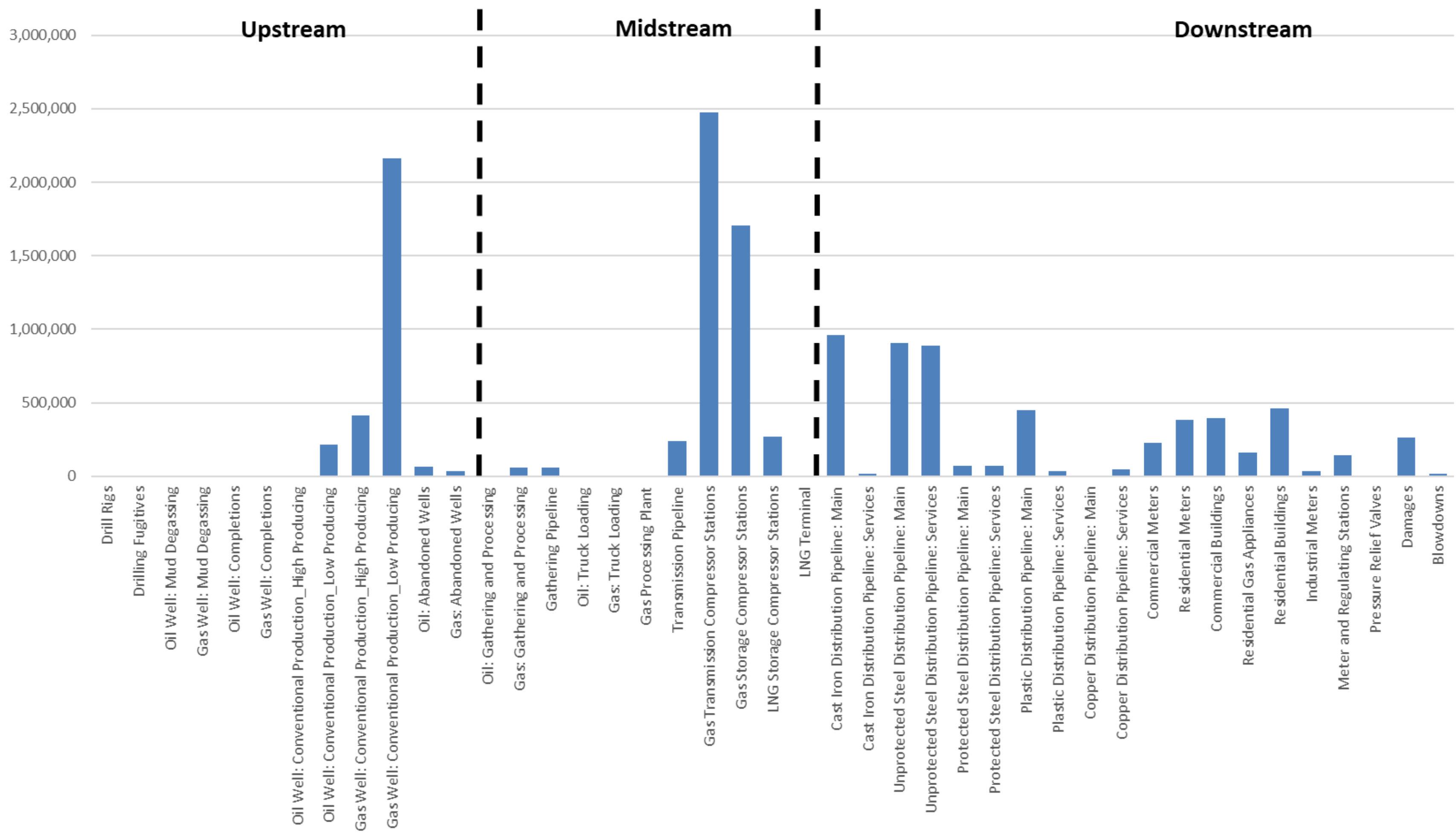


Figure 17. Methane Emissions by Source Category and Stage in New York State, 2022

Calculated using AR5 GWP20 values; grouped by downstream, midstream, and upstream stages.

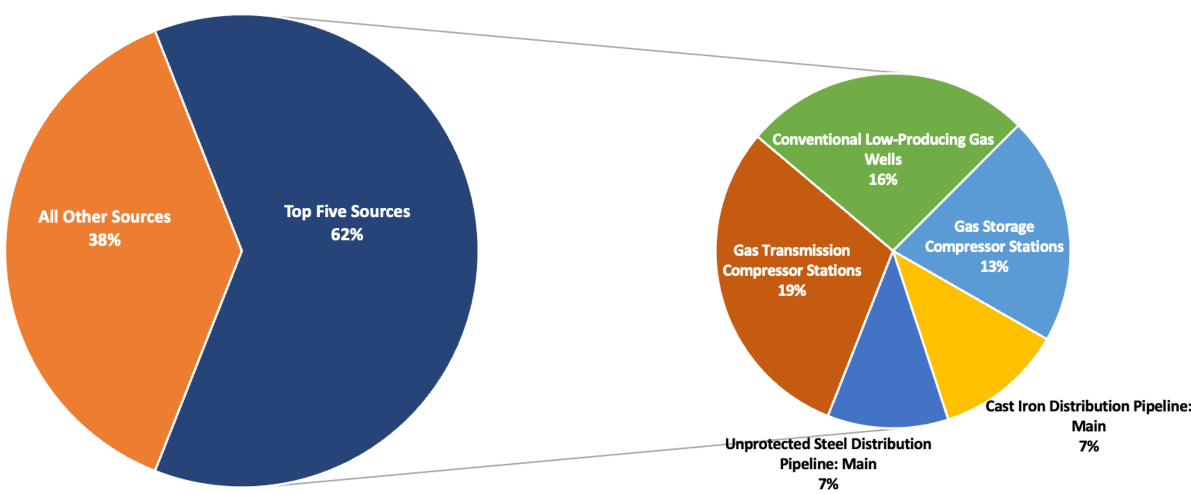


4.5 Emissions by Equipment Source Category, 2022

Figures 17 and 18 show that New York State's 64 natural gas transmission compressor stations are the largest single source category, accounting for 2.476 MMT CO_2e or 18.7% of total CH_4 emissions. Low-producing conventional gas wells follow closely, accounting for 2.162 MMT CO_2 or 16.3% of total CH_4 emissions. Combined, the top five emitting source categories—gas transmission compressor stations (18.70%), conventional low-producing gas wells (16.32%), gas storage compressor stations (12.89%), cast-iron mains (7.23%), and unprotected steel distribution mains (6.83%)—account for 62% of total CH_4 emissions, highlighting the significant contributions of compressor stations, gas wells, and cast-iron and unprotected steel mains to New York State's CH_4 inventory.

For gas pipelines, emissions from gathering pipelines account for 0.64% of total emissions, transmission pipelines for 1.81%, distribution mains (including cast-iron, unprotected steel, protected steel, plastic, and copper mains) for 18.00%, and distribution service lines for 8.02%. Cast-iron and unprotected steel mains comprise the majority (78.11%) of emissions from distribution pipeline mains, accounting for 14.06% of total emissions.

Figure 18. Top Five Methane Emitting Source Categories, 2022



The inventory also estimates zero CH_4 emissions in 2022 from several source categories, primarily related to oil and gas exploration and well-completion activities. Additional source categories with zero emissions include: (1) gas truck loading, assumed to emit zero CH_4, as evaporative emissions from oil stored in atmospheric tanks are incorporated into site-level EFs, (2) gas processing because the State has no processing plants, (3) LNG terminals because New York State has no LNG terminals, and (4) copper distribution mains because none exist in the State. The 2015 inventory approach erroneously included these categories by scaling the national inventory to New York State, whereas the current methodology corrects this by excluding them.

Table 13. Methane Emissions by Source Category in New York State, 1990–2000

Emission values reported in MT CO_2e; calculated using AR5 GWP20 values.

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

Table 13. (continued)

Category	Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Upstream	Gas Well: Unconventional Production—High Producing	0	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	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	2,138,640	2,138,640	2,138,640	2,138,640	2,138,640	2,194,920	2,194,920	2,194,920	2,194,920	2,194,920	2,194,920
	Gas Storage Compressor Stations	1,138,368	1,138,368	1,138,368	1,138,368	1,138,368	1,351,812	1,422,960	1,494,108	1,494,108	1,494,108	1,494,108
	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

Table 13. (continued)

Category	Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Midstream	LNG Storage Compressor Stations	0	0	0	0	0	0	0	0	0	0	0
	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
	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

Table 13. (continued)

Category	Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Downstream	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	306,919	277,190	320,852	321,911	331,701	327,477	329,558	335,920	338,724	339,849	353,557
	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	370,296	334,429	387,107	388,384	400,197	395,100	397,610	405,287	408,669	410,026	426,565

Table 14. Methane Emissions by Source Category in New York State, 2001–2011

Values in MT CO2e calculated using AR5 GWP20.

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
Downstream	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
	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
	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	211,109	218,169	215,060	221,143	225,350	232,251	150,020	155,422	151,834	151,929	158,353
	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	192,608	196,994	210,485	203,696	207,626	215,899	213,792	207,865	207,806	205,889	213,806
	Residential Meters	341,088	349,868	352,319	356,837	357,218	358,851	360,760	363,305	362,337	359,857	374,464
	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	411,521	422,114	425,071	430,523	430,983	432,953	435,256	438,327	437,158	434,166	451,789

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	2,194,920	2,251,200	2,251,200	2,251,200	2,251,200	2,307,480	2,307,480	2,307,480	2,307,480	2,307,480	2,307,480
	Gas Storage Compressor Stations	1,565,256	1,565,256	1,636,404	1,636,404	1,636,404	1,636,404	1,636,404	1,636,404	1,707,552	1,707,552	1,707,552
	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

Table 15. Methane Emissions by Source Category in New York State, 2012–2022

Values in MT CO2e calculated using AR5 GWP20.

Category	Source	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Upstream	Drill Rigs	13	11	13	3	2	1	0	11	4	0	0
	Drilling Fugitives	687	600	705	188	131	83	4	600	214	0	0
	Oil Well: Mud Degassing	81,138	68,622	86,084	14,070	13,676	13,151	35,799	70,416	23,217	0	0
	Gas Well: Mud Degassing	8,512	5,777	3,917	481	0	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	0
	Gas Well: Completions	1,428	1,714	714	143	0	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	471
	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	217,151
	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	412,348
	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	2,161,767
	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
	Gas Well: Unconventional Production—Low Producing	0	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	62,881
	Gas: Abandoned Wells	1,991	3,384	4,372	5,648	6,275	7,653	9,032	20,659	25,504	30,783	35,796

Table 15. (continued)

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	3,446
	Gas: Gathering and Processing	147,697	133,331	117,402	102,020	81,829	69,839	61,559	66,135	69,069	59,239	56,952
	Gathering Pipeline	143,942	37,139	52,058	37,318	32,928	36,422	32,941	30,231	36,176	59,210	61,459
	Oil: Truck Loading	162	165	160	129	101	83	84	84	76	74	72
	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	236,912	238,631	238,631	238,631	238,631	238,631	236,599	236,860	236,235	237,537	239,656
	Gas Transmission Compressor Stations	2,307,480	2,307,480	2,307,480	2,307,480	2,307,480	2,307,480	2,307,480	2,307,480	2,307,480	2,420,040	2,476,320
Downstream	Gas Storage Compressor Stations	1,707,552	1,707,552	1,707,552	1,707,552	1,707,552	1,707,552	1,707,552	1,707,552	1,707,552	1,707,552	1,707,552
	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
	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	957,947
	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	18,896
	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	904,874
	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	891,545
	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	70,642
	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	69,045
	Plastic Distribution Pipeline: Main	338,655	350,521	360,817	371,089	384,186	395,580	407,698	419,415	429,437	440,630	451,154
	Plastic Distribution Pipeline: Services	28,332	29,239	30,337	31,040	31,624	31,527	33,136	33,702	38,318	35,117	34,616
	Copper Distribution Pipeline: Main	0	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	48,893

Table 15. (continued)

Downstream	Meter and Regulating Stations	159,323	161,411	156,992	147,396	150,740	153,527	155,119	155,088	157,879	158,759	141,565
	Pressure Relief Valves	3,862	3,874	3,904	3,925	3,942	3,960	3,966	3,978	3,989	4,014	4,030
	Damages	226,751	227,094	230,786	229,662	229,753	231,346	253,406	254,944	277,849	268,548	264,972
	Blowdowns	14,514	14,536	14,773	14,701	14,707	14,809	16,221	16,319	17,785	17,190	16,961
	Commercial Meters	210,505	210,175	215,002	217,913	218,012	219,678	221,183	230,656	229,576	226,765	225,933
	Residential Meters	368,927	368,246	370,067	370,868	370,477	374,484	375,947	375,881	377,929	379,723	382,863
	Industrial Meters	33,875	35,914	35,951	34,162	36,222	37,587	38,698	39,638	37,583	34,068	35,338
	Commercial Buildings	235,109	239,678	241,982	244,416	247,234	253,284	253,560	252,344	244,960	244,092	396,211
	Residential Gas Appliances	196,319	196,837	197,510	198,073	198,951	199,934	200,932	163,422	161,209	160,347	161,950
	Residential Buildings	445,109	444,288	446,485	447,451	446,979	451,813	453,579	453,499	455,970	458,134	461,923

4.6 Emissions by County and Economic Region, 2022

Figure 19 shows the distribution of CH4 emissions by county in New York State. Counties with the highest emissions align with regions of high oil and natural gas exploration and production areas in the western part of the State and areas with high population density and extensive gas services around New York City and Long Island. Downstream emissions in counties associated with New York City and Long Island (New York, Kings, Bronx, Richmond, Queens, Nassau, and Suffolk) total 3.43 MMT CO_2e, approximately 61.91% of total downstream emissions.

As shown in Figure 20, Chautauqua County had the highest total CH_4 emissions, accounting for 11.11% of statewide CH_4 emissions from the oil and natural gas sector, followed by Erie County (10.6%). Chautauqua County had the highest conventional gas production from low-producing wells in New York State and the highest gas gathering and processing volume, resulting in high upstream and midstream emissions. Erie County ranked highest in the number of miles of gas transmission pipelines and compressor stations, resulting in high midstream emissions.

The top five counties (Chautauqua, Erie, Steuben, Kings, and Cattaraugus) accounted for 42.83% of statewide CH_4 emissions in 2022. Figure 20 shows data for each county, and Tables 16 through 18 provide annual total emissions by county.

Figure 19. Map of Methane Emissions by County in New York State, 2022

Calculated using AR5 GWP20 values.

Source: Mapbox 2024; OpenStreetMap 2024.

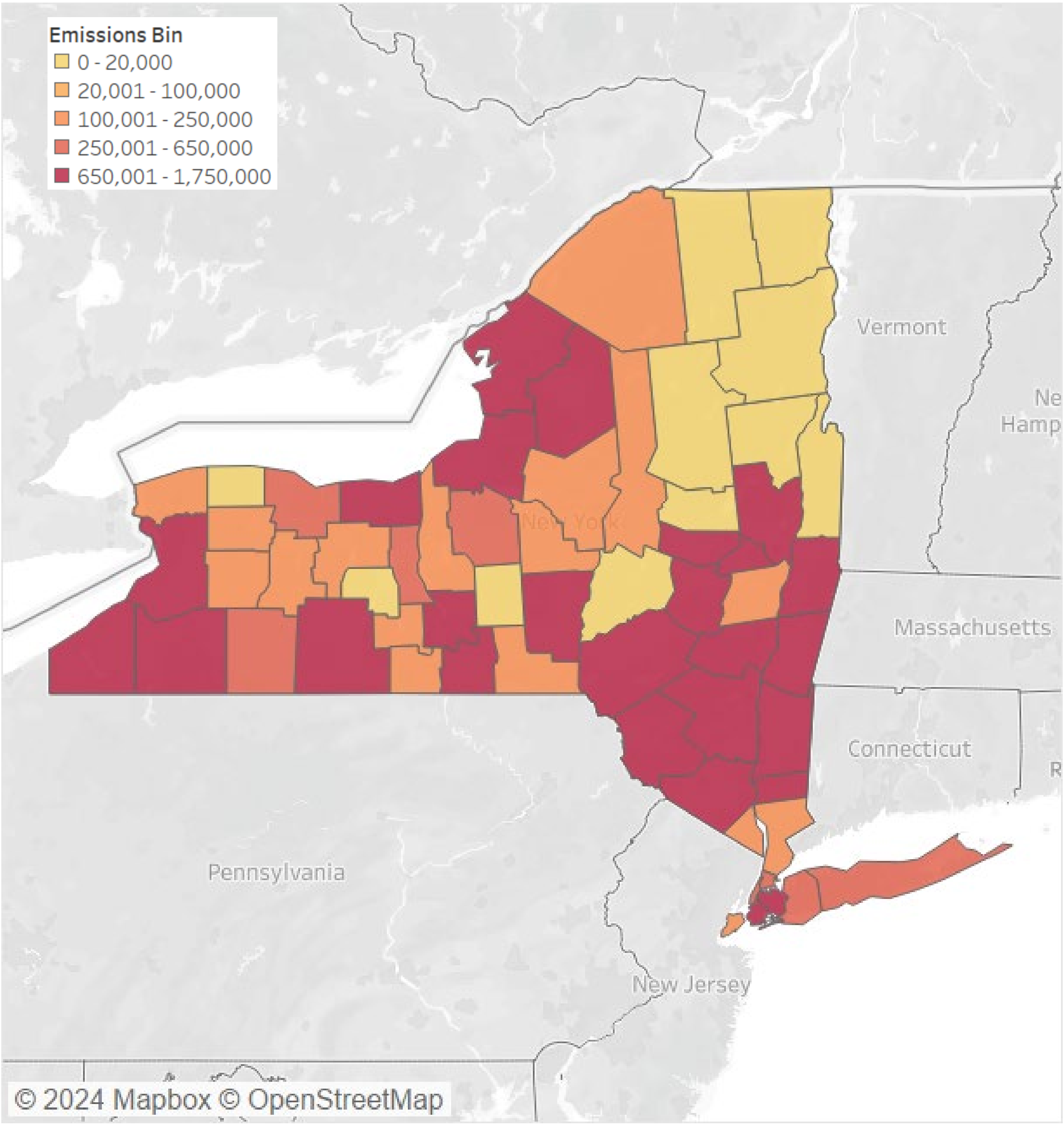


Figure 20. Methane Emissions by County in New York State, 2022

Calculated using AR5 GWP20 values.

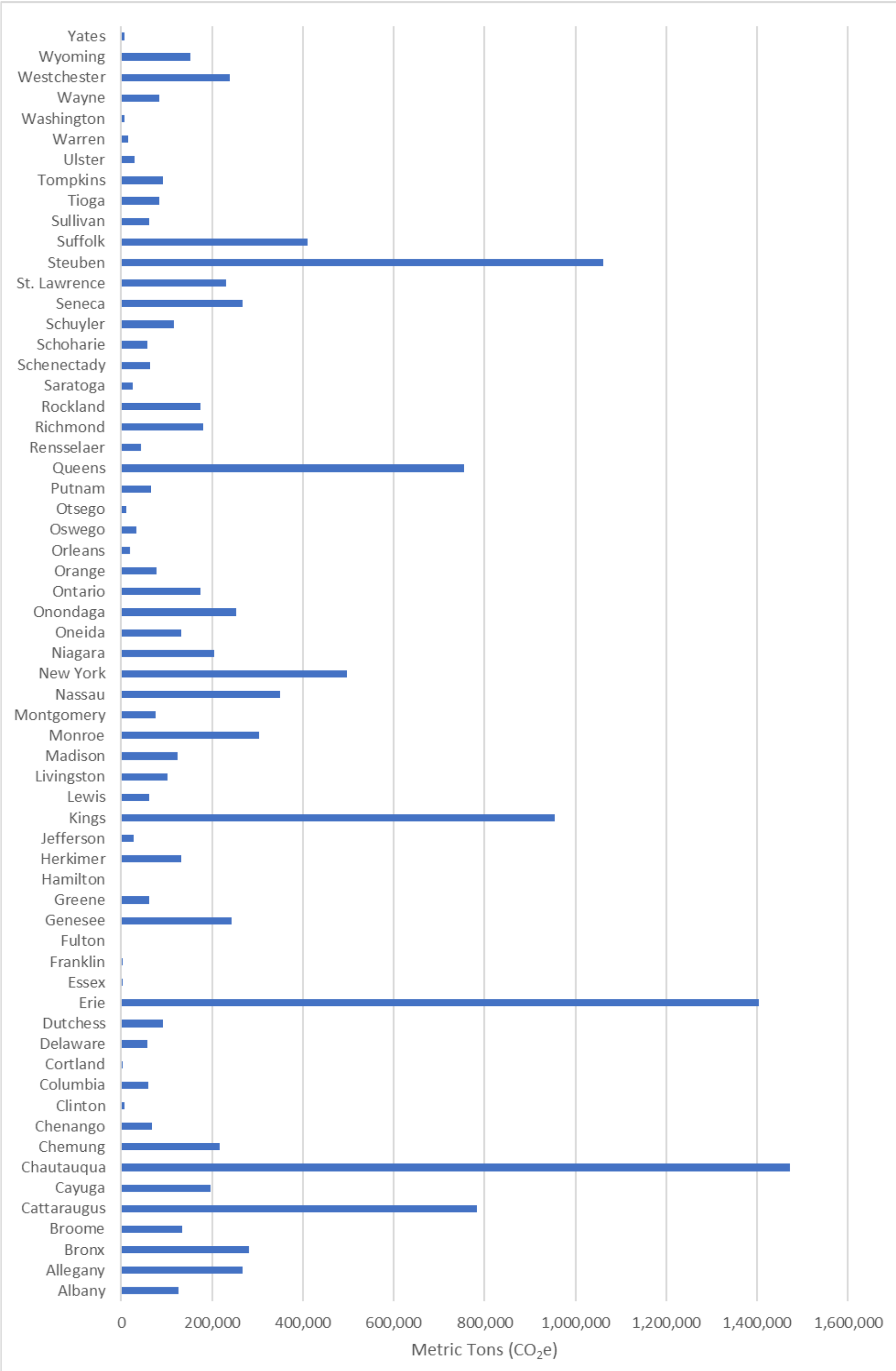


Table 16. Methane Emissions by County in New York State, 1990–2000

Values in MT CO2e calculated using AR5 GWP20.

County	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Albany	274,054	262,474	270,816	266,150	269,526	260,553	258,431	260,434	257,641	255,956	255,192
Allegany	312,054	309,071	330,472	306,029	320,315	311,245	306,318	317,951	306,325	303,733	303,555
Bronx	372,036	355,638	367,165	360,895	365,572	352,880	350,982	353,699	350,658	348,219	347,819
Broome	195,656	188,444	193,797	190,447	192,629	186,584	185,164	186,482	184,412	184,054	182,926
Cattaraugus	514,644	509,967	640,701	627,044	583,673	629,151	594,663	591,371	615,879	616,248	622,621
Cayuga	369,292	348,581	303,593	285,381	287,423	285,895	305,093	302,411	292,945	283,488	274,206
Chautauqua	2,471,927	2,606,318	2,581,085	2,547,384	2,592,745	2,423,525	2,537,376	2,336,164	2,235,960	2,186,581	2,103,091
Chemung	125,637	122,222	124,942	123,251	124,296	122,589	121,720	123,073	121,388	130,643	134,832
Chenango	301	288	277	264	270	262	247	248	252	256	266
Clinton	11,575	10,709	11,126	11,229	11,313	10,937	10,569	10,886	10,238	10,211	10,241
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	97,174	94,410	95,598	95,699	96,097	94,992	94,158	95,227	93,838	93,864	94,401
Erie	1,667,944	1,630,874	1,688,912	1,719,603	1,646,223	1,678,775	1,645,343	1,633,275	1,625,817	1,579,366	1,580,647
Essex	4,056	3,912	3,978	3,869	3,904	3,797	3,676	3,763	3,584	3,600	3,701
Franklin	4,448	4,164	4,271	4,262	4,309	4,177	4,072	4,127	4,041	4,061	4,107
Fulton	62	54	52	57	59	58	55	56	57	58	61
Genesee	324,713	311,884	297,654	297,560	296,894	297,525	291,129	289,155	284,046	276,359	267,631
Greene	6,975	6,640	6,783	6,839	6,881	6,771	6,657	6,809	6,648	6,703	6,781
Hamilton	549	535	545	537	540	529	523	530	513	515	526
Herkimer	84,811	83,565	84,525	84,021	84,377	83,374	83,053	83,420	82,833	82,689	82,688
Jefferson	101,521	99,253	100,922	100,013	100,665	98,906	98,514	98,992	98,349	98,059	97,975
Kings	1,500,526	1,428,932	1,484,582	1,449,401	1,473,260	1,412,445	1,401,232	1,415,768	1,399,427	1,386,986	1,383,493
Lewis	64,604	64,310	64,423	64,370	64,452	64,274	64,154	64,261	64,173	64,184	64,274
Livingston	101,962	99,142	107,763	99,430	101,034	94,843	94,167	84,069	83,871	79,259	84,319
Madison	93,490	92,108	93,904	88,375	93,763	94,622	92,637	95,164	102,817	115,757	112,023
Monroe	591,783	563,388	585,039	571,975	580,200	557,139	551,258	557,516	547,458	543,223	541,591
Montgomery	83,845	82,520	83,498	82,993	83,361	82,365	82,071	82,442	81,899	81,729	81,639
Nassau	602,997	569,567	590,297	584,045	593,008	571,766	565,364	571,597	564,512	560,251	560,689
New York	729,504	678,654	705,574	704,299	715,373	690,822	683,191	695,216	688,254	682,616	688,743
Niagara	217,751	209,438	215,807	211,991	214,409	207,676	205,780	207,724	204,459	203,031	202,353
Oneida	185,905	179,057	184,071	181,186	183,121	177,744	176,146	177,617	175,141	174,088	173,787
Onondaga	459,686	441,483	455,172	447,175	452,529	437,697	434,162	437,586	432,234	429,418	428,579
Ontario	191,224	188,438	193,181	189,499	189,625	188,593	186,583	188,813	187,079	185,126	186,781

Table 16. (continued)

County	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Orange	171,813	165,209	169,713	167,797	169,349	164,867	163,476	165,404	162,651	161,880	162,107
Orleans	38,025	36,333	35,937	34,501	35,253	34,041	32,570	32,842	32,796	33,030	33,772
Oswego	49,332	66,767	48,809	47,552	48,303	46,208	45,690	46,261	95,044	44,943	44,843
Otsego	1,566	1,573	1,580	1,586	1,593	1,600	1,607	1,613	1,620	1,627	1,634
Putnam	11,819	10,926	11,332	11,483	11,573	11,425	11,247	11,714	11,265	11,337	11,551
Queens	1,163,629	1,107,923	1,149,921	1,124,955	1,143,146	1,097,810	1,089,240	1,099,592	1,087,912	1,078,622	1,076,357
Rensselaer	74,458	70,608	73,516	71,806	72,931	69,830	69,123	69,883	68,681	68,162	67,899
Richmond	300,941	286,139	297,659	290,369	295,894	282,830	280,962	283,312	281,430	278,635	277,999
Rockland	242,579	232,410	239,800	235,756	238,659	230,836	229,079	231,141	228,954	227,379	227,105
St. Lawrence	87,421	84,166	85,202	87,442	88,098	87,371	87,295	87,931	87,557	87,558	87,944
Saratoga	95,917	90,770	94,569	92,414	93,878	89,948	89,106	90,221	88,765	88,107	88,003
Schenectady	101,201	96,065	100,035	97,561	99,140	151,165	150,275	151,088	149,550	148,638	148,206
Schoharie	59,842	59,857	59,873	59,888	59,903	59,919	59,934	59,949	59,965	59,980	59,995
Schuyler	207,343	207,091	207,302	207,236	207,297	207,140	207,669	207,201	207,448	207,741	209,221
Seneca	216,670	201,783	179,413	158,217	163,714	148,371	163,660	165,851	140,672	144,717	148,455
Steuben	319,318	303,986	326,925	322,214	319,204	396,654	496,367	467,379	504,252	552,979	739,085
Suffolk	632,738	603,455	621,283	617,966	626,403	609,079	600,787	612,580	599,140	596,660	599,331
Sullivan	6,414	6,257	6,405	6,330	6,345	6,259	6,110	6,290	5,922	5,996	6,045
Tioga	76,792	75,337	75,989	75,026	75,262	74,654	74,495	74,757	75,332	74,407	75,344
Tompkins	114,611	111,808	113,909	112,797	113,603	111,454	110,831	111,495	110,991	111,118	110,078
Ulster	42,241	39,639	41,248	40,863	41,320	39,651	38,768	39,804	38,328	38,269	38,381
Warren	23,795	22,353	23,290	22,945	23,254	22,313	21,907	22,270	21,610	21,565	21,516
Washington	14,480	13,665	14,283	13,962	14,111	13,540	13,166	13,636	12,760	12,721	12,733
Wayne	100,533	98,311	100,318	99,132	99,681	98,486	97,397	98,560	96,870	96,965	96,936
Westchester	440,476	417,114	432,143	426,419	432,190	416,944	413,070	417,301	412,847	410,304	410,430
Wyoming	287,521	297,162	290,658	275,455	278,215	279,811	260,164	266,935	258,363	254,314	249,209
Yates	5,833	3,612	5,129	5,374	4,937	5,756	5,389	4,669	3,609	6,787	5,868

Table 17. Methane Emissions by County in New York State, 2001–2010

Values in MT CO2e calculated using AR5 GWP20.

County	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Albany	250,409	249,580	247,216	244,488	242,609	241,669	239,269	238,713	233,239	229,149
Allegany	322,413	326,354	336,406	345,321	361,263	385,292	393,398	408,724	399,306	400,805
Bronx	341,388	341,509	338,685	334,521	331,890	330,253	327,121	326,557	320,043	314,968
Broome	180,368	180,721	210,406	188,068	179,335	174,337	172,502	172,158	168,205	165,387
Cattaraugus	625,158	613,331	578,960	581,951	649,054	825,934	876,750	826,576	775,907	872,512
Cayuga	265,884	272,995	261,612	249,388	197,807	259,344	253,652	252,340	286,516	294,772
Chautauqua	2,124,582	2,052,060	2,035,115	2,022,042	2,048,671	2,111,406	2,218,898	2,258,468	2,196,332	2,052,363
Chemung	804,668	1,482,527	1,440,451	1,361,810	2,313,459	2,190,938	1,971,641	1,482,118	1,133,098	1,008,298
Chenango	249	258	261	1,226	2,158	1,935	16,989	66,085	210,531	232,419
Clinton	10,032	9,903	9,982	9,703	9,689	9,782	9,864	9,816	9,538	9,339
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	93,601	93,680	94,115	93,658	93,679	93,760	93,808	93,457	92,626	91,866
Erie	1,545,113	1,610,610	1,607,032	1,596,557	1,621,389	1,659,894	1,665,141	1,712,244	1,741,952	1,806,745
Essex	3,582	3,602	3,581	3,589	3,538	3,499	3,515	3,504	3,379	3,355
Franklin	3,983	3,958	3,953	3,859	3,826	3,867	3,802	3,800	3,691	3,594
Fulton	57	60	60	59	59	57	56	57	54	52
Genesee	257,510	264,126	246,911	256,191	241,610	239,952	269,942	258,838	245,415	247,099
Greene	6,691	6,742	6,750	6,697	6,693	6,739	6,776	6,792	6,651	6,595
Hamilton	529	537	538	525	524	526	542	543	521	517
Herkimer	82,217	82,087	81,798	81,501	81,201	81,083	80,917	80,997	80,466	80,051
Jefferson	97,020	96,941	96,433	95,810	95,489	95,298	95,112	94,959	93,886	93,165
Kings	1,354,626	1,349,799	1,332,630	1,317,112	1,303,911	1,295,639	1,272,993	1,271,784	1,239,187	1,214,914
Lewis	64,146	64,189	64,126	64,006	64,003	63,973	64,003	64,008	63,887	63,783
Livingston	77,336	71,857	70,439	77,174	74,408	71,158	77,873	72,831	67,571	62,679
Madison	118,562	120,467	119,423	120,099	117,875	123,585	140,683	172,883	213,500	184,457
Monroe	529,960	526,305	519,729	512,731	507,138	503,847	498,792	497,072	483,221	472,972
Montgomery	81,120	81,017	80,733	80,431	80,715	80,205	79,971	79,959	79,339	78,910
Nassau	549,386	545,080	541,357	534,436	531,022	529,634	517,076	513,778	499,987	489,863
New York	673,347	661,754	660,858	649,636	643,264	644,672	629,489	625,046	608,298	595,243
Niagara	198,941	197,892	195,303	193,230	191,492	190,370	189,032	188,657	184,618	181,671
Oneida	170,892	170,227	168,859	167,114	166,267	164,933	163,681	163,334	160,078	157,681
Onondaga	420,896	419,702	414,758	411,228	407,371	407,309	403,228	400,283	391,240	384,691
Ontario	183,908	183,760	184,531	184,857	181,599	182,639	181,694	186,563	183,585	179,907

Table 17. (continued)

County	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Orange	159,866	159,519	158,883	157,575	156,941	156,686	156,126	155,521	152,739	150,586
Orleans	32,134	32,633	32,130	31,394	30,888	30,417	29,749	29,343	28,093	26,889
Oswego	43,739	43,493	42,927	43,840	41,789	41,471	41,053	40,949	75,136	38,571
Otsego	1,640	1,660	1,660	1,660	1,660	1,668	2,837	1,727	2,355	1,727
Putnam	11,290	11,327	11,538	11,316	11,384	11,453	11,543	11,426	11,099	10,879
Queens	1,054,968	1,052,080	1,039,931	1,027,494	1,018,003	1,012,096	993,618	991,284	965,434	946,099
Rensselaer	66,182	65,938	65,156	64,353	63,708	63,312	62,698	62,526	60,635	59,257
Richmond	271,975	271,130	267,135	263,981	261,378	259,810	252,570	251,986	244,214	238,700
Rockland	223,186	222,106	220,325	217,971	216,396	215,435	213,551	212,879	208,002	204,453
St. Lawrence	87,324	87,447	87,721	87,644	87,600	87,418	87,282	87,992	87,377	86,979
Saratoga	86,235	85,802	84,944	83,859	83,143	82,878	82,053	81,600	79,223	77,428
Schenectady	146,022	145,458	144,228	143,047	142,196	141,606	140,525	140,328	137,799	135,897
Schoharie	60,011	60,056	60,056	60,056	60,056	60,073	60,073	60,207	60,207	60,207
Schuyler	208,062	209,117	206,832	326,951	533,480	539,260	419,806	322,311	305,947	266,672
Seneca	148,299	154,060	148,447	152,039	149,017	159,631	200,959	283,257	261,125	235,162
Steuben	1,065,754	1,045,797	1,430,395	2,659,251	2,695,215	2,417,654	2,518,579	2,325,508	1,981,827	1,510,257
Suffolk	590,555	589,878	587,935	582,091	581,002	581,499	563,296	561,013	548,627	540,172
Sullivan	6,037	6,064	6,030	6,062	6,101	6,109	6,206	6,287	6,210	6,193
Tioga	147,587	150,285	145,554	145,912	144,592	147,683	146,781	145,641	144,124	145,310
Tompkins	109,259	108,834	108,877	108,078	107,804	106,850	107,356	106,970	105,239	104,325
Ulster	37,519	37,508	37,535	37,037	36,877	93,161	92,959	92,763	91,755	91,040
Warren	21,020	20,801	20,561	20,306	20,080	20,005	19,963	19,809	19,350	18,907
Washington	12,467	12,349	12,156	12,004	11,898	11,851	11,897	11,771	11,447	11,182
Wayne	96,089	95,805	96,550	95,308	95,987	109,637	100,880	97,135	96,883	93,174
Westchester	401,725	399,832	397,519	392,005	388,798	387,573	383,440	381,172	371,285	363,711
Wyoming	247,180	245,735	244,148	249,672	246,593	253,192	254,879	245,559	242,776	239,546
Yates	4,726	3,666	3,550	3,084	3,483	2,547	3,662	7,762	3,593	3,752

Table 18. Methane Emissions by County in New York State, 2011–2022

Values in MT CO2e calculated using AR5 GWP20.

County	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Albany	228,492	224,274	218,722	216,422	212,143	206,461	202,988	197,790	190,615	188,532	184,732	126,801
Allegany	404,413	430,866	408,014	413,525	377,370	358,511	363,100	349,329	361,233	320,983	336,812	268,267
Bronx	314,220	309,272	301,554	299,071	293,415	285,775	280,924	273,786	282,694	283,040	279,552	282,142
Broome	164,940	162,239	158,577	156,990	154,067	150,283	147,981	144,637	138,428	137,366	134,880	133,925
Cattaraugus	823,044	783,475	802,633	818,382	682,759	680,119	710,367	686,747	777,366	649,697	653,805	782,531
Cayuga	287,765	261,896	245,590	240,654	226,456	217,685	197,593	187,565	184,177	210,278	183,920	195,995
Chautauqua	2,049,277	2,038,851	2,051,560	1,956,204	1,819,607	1,679,899	1,486,148	1,399,504	1,583,660	1,431,769	1,506,166	1,471,877
Chemung	932,323	708,569	637,884	505,580	423,532	284,020	228,192	193,498	201,728	182,964	165,934	217,769
Chenango	220,700	182,989	154,361	133,002	116,399	101,884	86,169	85,182	81,239	79,560	71,003	68,391
Clinton	9,367	9,113	8,900	8,822	8,664	8,417	8,334	8,152	8,109	7,932	7,826	7,921
Columbia	1,693	1,691	1,694	1,693	1,688	1,683	1,680	1,664	1,665	1,662	1,668	59,049
Cortland	60,461	60,461	60,499	60,499	60,499	60,499	60,499	60,463	60,467	60,456	60,479	4,326
Delaware	1,372	1,372	1,380	1,380	1,379	1,378	1,378	1,366	1,375	1,371	1,378	57,616
Dutchess	91,895	91,279	90,364	90,147	89,511	88,769	88,351	87,619	90,453	90,043	89,676	91,008
Erie	1,796,588	1,745,076	1,671,749	1,629,242	1,572,776	1,526,259	1,491,637	1,376,341	1,426,003	1,473,434	1,416,839	1,404,137
Essex	3,353	3,298	3,203	3,185	3,102	3,032	2,952	2,891	2,638	2,587	2,578	2,939
Franklin	3,605	3,504	3,376	3,339	3,262	3,172	3,097	3,027	2,900	2,887	2,796	3,060
Fulton	52	52	47	47	43	41	39	38	37	38	36	200
Genesee	247,026	242,122	230,853	231,190	203,291	195,514	190,983	207,384	168,880	193,082	200,679	243,590
Greene	6,596	6,526	6,454	6,395	6,284	6,198	6,202	6,106	6,076	6,071	6,037	62,404
Hamilton	510	517	510	501	499	500	493	489	419	393	397	499
Herkimer	79,944	79,479	78,942	78,680	78,176	77,566	77,231	76,642	76,001	75,735	75,268	131,417
Jefferson	93,023	92,273	91,143	90,700	89,804	88,674	87,972	86,950	85,437	85,091	84,496	28,131

Table 18. (continued)

County	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Kings	1,214,139	1,189,578	1,153,793	1,140,410	1,112,775	1,075,601	1,053,237	1,018,894	999,083	985,345	958,184	954,220
Lewis	63,786	63,708	63,562	63,513	63,410	63,301	63,197	63,071	63,090	63,029	62,949	62,553
Livingston	60,350	58,044	53,724	56,062	49,729	50,683	50,873	45,846	37,892	93,952	43,945	101,299
Madison	211,010	177,856	165,251	155,497	148,664	140,154	129,243	125,688	124,452	125,163	120,302	123,777
Monroe	471,566	461,627	447,473	441,783	430,787	416,407	407,612	394,570	379,305	373,928	364,567	303,197
Montgomery	78,800	78,382	77,718	77,462	76,945	76,320	75,878	75,273	74,415	74,103	73,673	74,989
Nassau	489,037	479,158	466,030	460,948	449,920	436,566	429,003	416,965	412,923	408,824	400,725	349,374
New York	595,380	583,011	565,898	560,399	545,782	526,766	516,742	501,083	500,050	494,800	482,963	497,602
Niagara	181,267	178,227	173,862	172,294	169,098	164,866	162,340	158,526	153,928	152,648	149,674	203,879
Oneida	157,255	154,929	151,454	150,266	147,676	144,203	142,270	139,228	135,426	135,131	132,018	131,927
Onondaga	383,641	377,300	368,267	364,780	358,009	348,582	342,942	334,595	321,161	317,902	312,094	252,512
Ontario	180,614	179,619	178,507	176,759	176,156	172,718	174,359	172,899	173,539	175,525	285,415	175,473
Orange	150,232	148,087	145,285	144,302	142,399	139,655	137,920	135,324	135,827	134,482	132,697	77,730
Orleans	26,770	26,163	24,300	24,043	22,740	21,583	20,827	20,043	19,894	19,919	19,086	18,544
Oswego	38,524	37,620	36,249	35,813	34,917	33,600	33,171	32,020	30,411	30,161	29,197	33,816
Otsego	1,727	1,727	1,739	1,739	1,739	1,739	1,739	1,724	1,726	13,389	12,910	12,324
Putnam	10,781	10,512	10,349	10,364	10,238	9,992	9,788	9,580	9,403	9,337	9,182	65,847
Queens	944,676	926,248	899,482	889,593	867,949	840,174	823,264	797,323	789,849	778,499	760,580	755,160
Rensselaer	59,108	57,700	55,770	54,927	53,507	51,517	50,329	48,555	46,256	45,521	44,471	43,985
Richmond	238,241	232,782	224,958	221,738	215,242	207,216	202,368	199,462	193,150	190,165	184,689	180,906
Rockland	204,033	200,426	195,670	193,877	190,542	185,672	182,676	185,397	181,116	179,376	175,819	174,927
St. Lawrence	87,088	87,215	86,282	86,253	85,455	84,620	84,438	83,548	83,108	82,731	82,198	25,135
Saratoga	77,278	75,539	72,968	72,190	70,315	67,779	66,248	67,581	67,002	66,332	64,557	64,389
Schenectady	135,539	133,736	131,039	129,980	127,865	125,223	123,509	121,784	117,807	117,237	115,796	58,476

Table 18. (continued)

County	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Schoharie	60,207	60,207	60,236	60,236	60,236	60,236	60,236	61,182	61,189	61,193	61,173	116,956
Schuyler	266,738	256,247	246,807	247,771	243,228	209,828	206,460	211,330	211,174	211,187	210,999	266,775
Seneca	207,686	195,038	187,602	184,851	175,175	174,350	166,681	168,840	155,313	157,421	161,836	231,935
Steuben	1,338,672	1,217,921	1,126,236	1,104,714	1,028,428	934,446	888,028	852,693	837,296	829,174	776,111	1,060,848
Suffolk	540,840	532,814	522,473	517,887	507,134	496,727	490,887	481,240	475,113	471,465	464,339	410,118
Sullivan	6,191	6,083	6,064	6,045	6,016	5,943	5,902	5,841	5,543	5,500	5,500	62,098
Tioga	143,815	145,814	143,141	142,988	143,374	142,312	142,067	141,662	141,098	140,958	140,699	84,807
Tompkins	104,166	103,229	101,884	101,333	100,370	98,950	98,320	97,026	94,971	94,318	93,698	92,502
Ulster	90,998	90,275	89,328	89,120	88,349	87,465	86,944	86,092	84,941	84,527	83,955	28,538
Warren	18,816	18,382	17,772	17,503	17,046	16,466	16,108	15,583	15,523	15,274	14,915	15,333
Washington	11,168	10,921	10,531	10,342	10,028	9,724	9,517	9,216	8,557	8,483	8,241	8,306
Wayne	94,239	92,958	91,504	90,850	89,978	89,551	88,855	87,980	86,997	86,284	85,733	83,904
Westchester	362,881	355,397	345,405	341,901	334,317	324,307	318,214	309,204	302,714	299,915	294,209	239,914
Wyoming	238,175	235,115	226,188	219,802	213,724	207,277	206,343	208,620	188,772	213,340	212,289	152,070
Yates	3,589	2,531	4,466	4,474	3,222	4,908	4,540	6,129	5,745	7,050	6,885	6,615

Figure 21 shows New York State's 10 distinct economic regions, defined by Empire State Development, and Table 19 presents CH_4 emissions for these regions. In 2022, CH_4 emissions were highest in Western New York (31.2% of total emissions) and New York City (20.2%).

As discussed in Section 2.2, 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. Although the New York City region lacks oil or natural gas development, it has a high concentration of distribution lines, natural gas services, and meters Supplying commercial and residential gas services to end users.

Figure 21. Map of Economic Regions in New York State

Source: As identified by Empire State Development (ESD 2024).

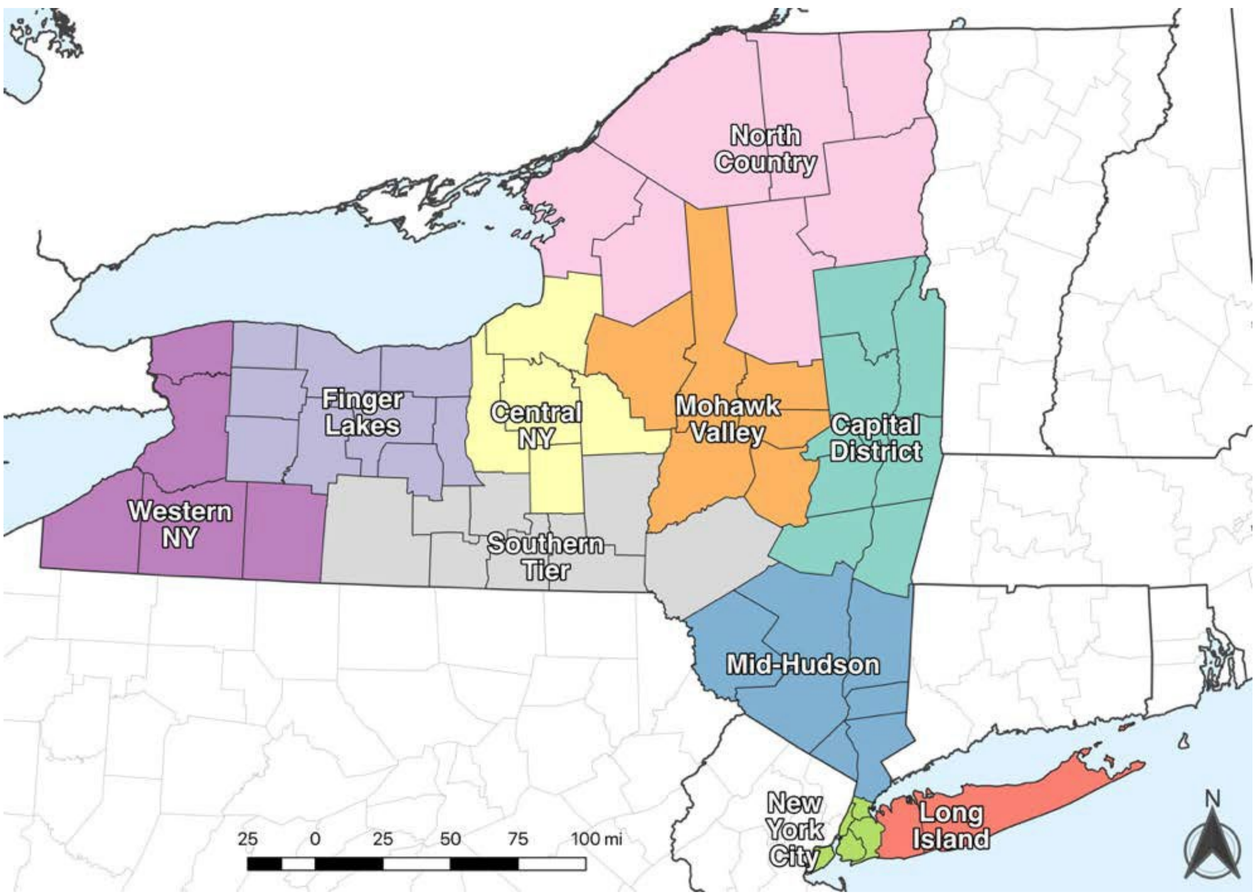


Figure 22. Map of Methane Emissions by Economic Region in New York State, 2022

Calculated using AR5 GWP20 values.

Source: Mapbox 2024; OpenStreetMap 2024.

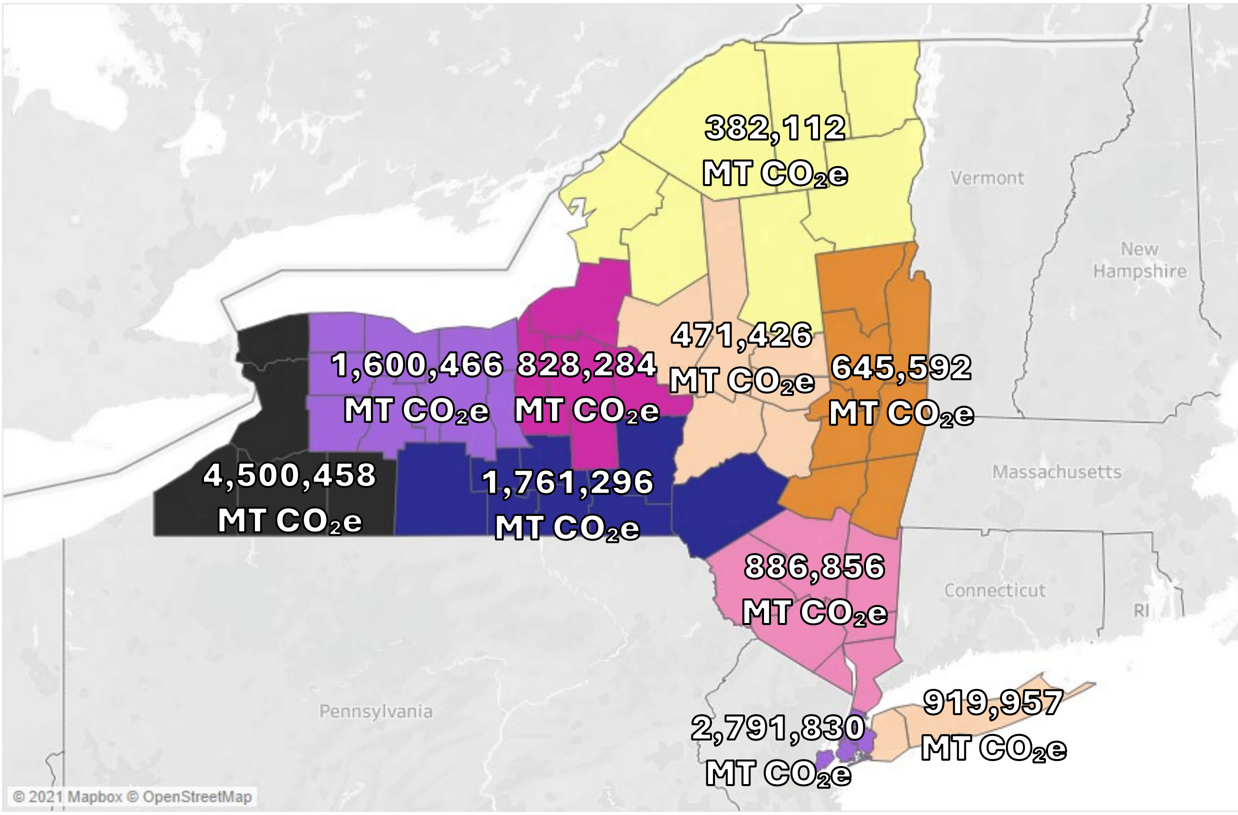


Table 19. Methane Emissions by Economic Region in New York State, 2022

Upstate/Downstate	Region	% of CH_4 Emissions
Upstate	Western New York	31.2%
Upstate	Finger Lakes	10.2%
Upstate	Southern Tier	13.8%
Upstate	Central New York	4.6%
Upstate	North Country	2.5%
Upstate	Mohawk Valley	3.1%
Upstate	Capital District	3.1%
Downstate	Hudson Valley	5.6%
Downstate	New York City	20.2%
Downstate	Long Island	5.7%

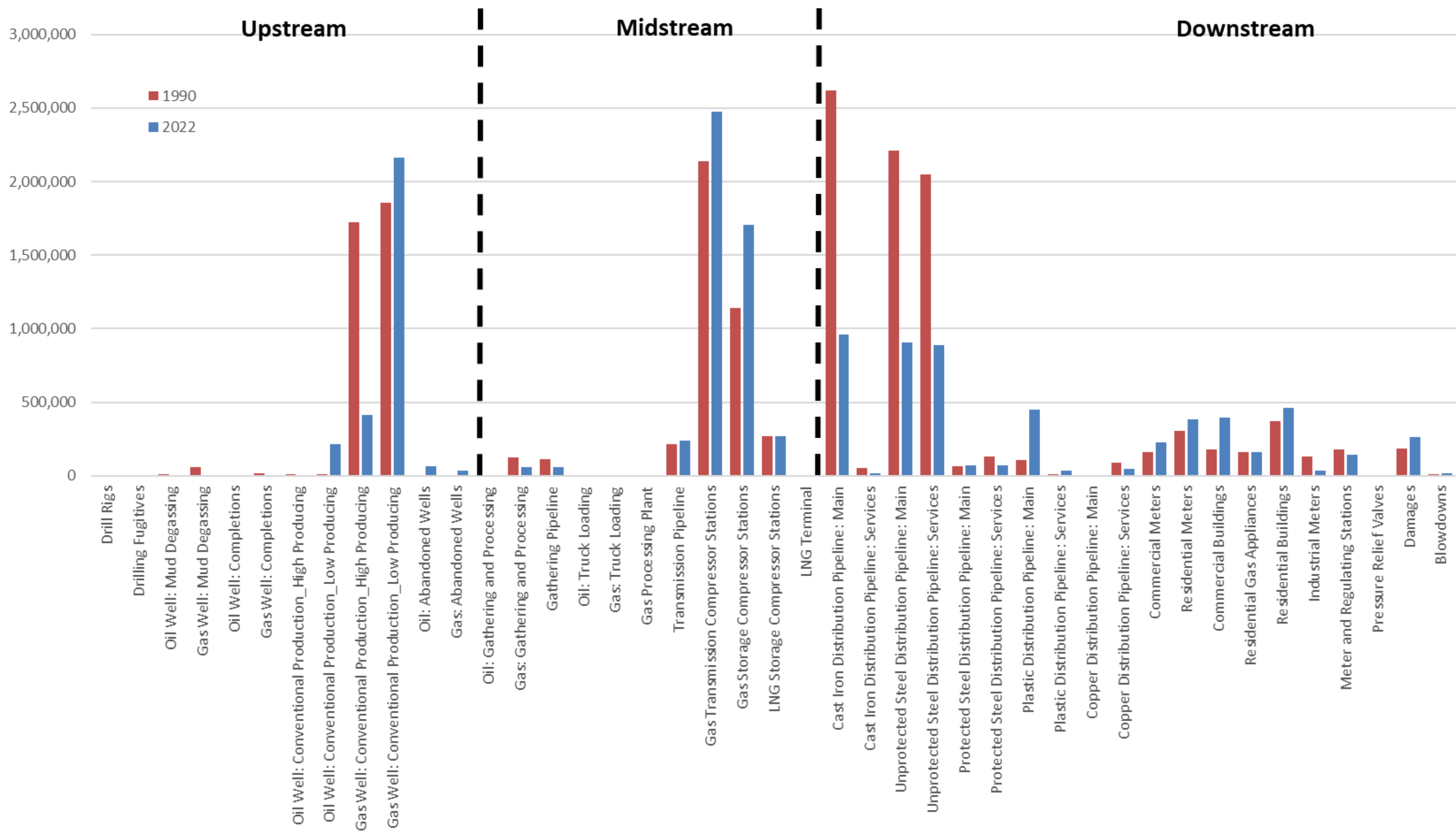
4.7 Summary of Source Category Comparison, 1990–2022

The largest upstream decrease in emissions was from conventional oil production from high-producing wells (-95.27%), aligning with the decreasing completion and production patterns shown in Figures 2 and 4 and discussed in section 2. In the midstream source category, emissions from transmission pipelines increased by 11.54%, driven by expanded pipeline mileages in New York State during that period. Similarly, CH_4 emissions from transmission compressors rose by 15.79%, and emissions from gas storage compressor stations increased by 50%. Both were attributed to adding compressor stations required to support increased pipeline capacity. These increases in pipeline and storage capacity and associated compressors reflect growing natural gas consumption trends as identified by the EIA (2024b).

In the downstream source category, a significant shift from cast-iron and unprotected steel distribution mains to lower-emitting plastic pipes led to a net decrease in emissions. Emissions from cast-iron and unprotected steel distribution mains decreased by 63.42% and 59.04%, respectively, while plastic pipeline mains increased by 311.81%. Although emissions from plastic distribution mains and services, along with residential and commercial meters, have risen, these increases were offset by greater reductions achieved through replacing cast-iron and unprotected steel pipelines (Figure 23).

Figure 23. Comparison of Methane Emissions by Source Category in New York State, 1990 and 2022

Calculated using AR5 GWP20 conversion factors.



4.8 Emissions Inventory Validation

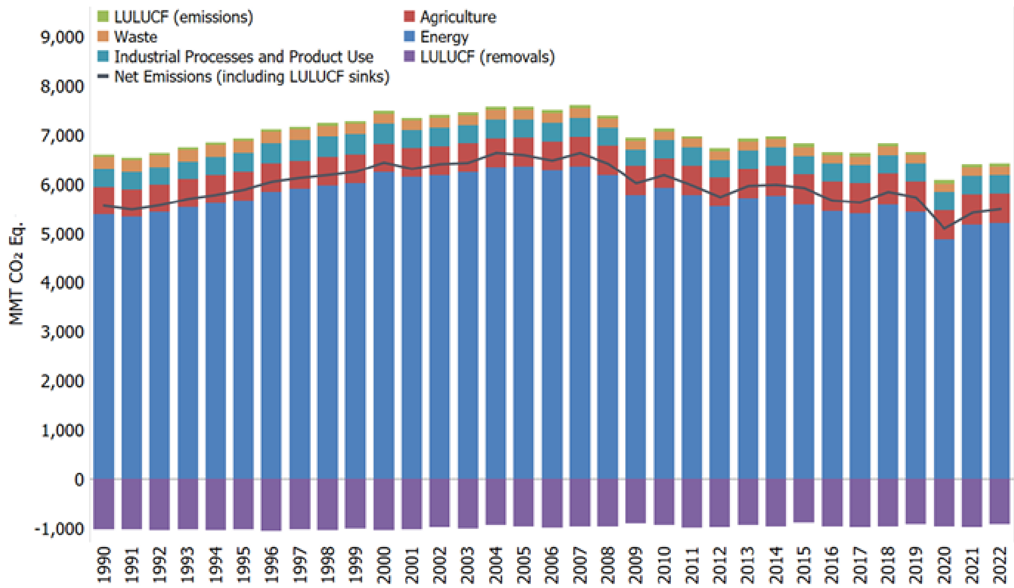
4.8.1 Comparison to the 2022 Environmental Protection Agency's U.S. Greenhouse Gas Inventory

Previous NYS oil and natural gas sector CH_4 emissions inventories (pre-2015) used a national scaling approach, estimating State emissions based on the national-to-state natural gas consumption ratio. The current inventory applies a BU, activity-driven methodology to estimate emissions more accurately. The updated and improved methodology allows direct comparison with other activity-based BU inventories, including the 2022 EPA U.S. GHG Inventory (EPA 2024b).

The 2022 EPA U.S. GHG Inventory (EPA 2024b) estimated total CH_4 emissions from oil and natural gas systems at 212.7 MMT CO_2e in 2022. The NYS inventory finds total CH_4 emissions at 13.2 MMT CO_2e (AR5 GWP20), equivalent to 6.21% of the national total. Nationwide, the EPA data show a 26.1% decrease in emissions since 1990 and a 17.7% decrease from 258.3 from 2005 to 2022. Similarly, the State's emissions decreased by 20.7% since 1990 and 33.78% from 2005 to 2022. Despite some discrepancies, when viewing nationwide energy emissions trends described in the 2022 EPA GHG Inventory, the NYS time series CH_4 emissions mirror the energy-sector emissions in the national inventory (Figure 24). These data show a similar pattern to that shown in Figure 12, peaking in 2005 and declining. As such, patterns in CH_4 emissions in New York State described here follow trends in large-scale nationwide energy shifts.

Figure 24. Time Series Trends in Emissions from Energy and Other Sectors

Source: EPA 2024b, Figure ES-11.



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

The database reported that Subpart W CH4 emissions in New York State totaled 1.059 MMT CO_2e in 2022, while this inventory estimated a greater amount for 2022 CH_4 emissions at 13.2 MMT CO_2e. This discrepancy arises partly because Subpart W reporting requires reporting only from facilities emitting more than 25,000 MT CO_2e annually. In contrast, New York State has several smaller facilities emitting CH_4 below this threshold.

Most notably, Subpart W data exclude emissions from meters, pipelines, and buildings, which are significant contributors. More specifically, Subpart W data for 2022 show 0.992 MMT CO_2e emitted by local distribution companies, 0.010 MMT CO_2e from transmission/compression, and 0.057 MMT CO_2e from underground natural gas storage. This inventory estimated emissions from natural gas distribution to be 4.52 MMT CO_2e or 427% 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, with estimated emissions of 2.476 MMT CO_2e in 2022, indicating that Subpart W underestimated total transmission compression emissions. The inventory estimates emissions from underground natural gas storage to be 1.71 MMT CO_2e in 2022, an order of magnitude greater than reported under Subpart W.

Subtracting downstream emissions from the total inventory estimates upstream and midstream emissions at 7.71 MMT CO_2e, 115 times higher than emissions reported for these segments under Subpart W in New York State. The discrepancy exceeds the findings of Alvarez et al. (2018), who estimate CH_4 emissions from the oil and natural gas supply chain to be ~ 60% higher than EPA estimates. These discrepancies result from Subpart W's facility reporting thresholds and the omission of certain CH_4 emission sources. This highlights the critical need for detailed BU inventories that include all sources and for validating these BU inventories using TD flight or satellite measurements.

4.8.3 Comparison to Other State Inventories

New York State shares borders with Pennsylvania, New Jersey, Connecticut, Massachusetts, and Vermont. The following section summarizes each adjacent state's most recent inventory year.

Pennsylvania primarily uses the default EPA SIT to estimate emissions from the residential, commercial, industrial, transportation, electricity production, agriculture, waste management, forestry, and land use sectors. It reports CO_2 equivalents using AR4 GWP100 values. Pennsylvania estimates total natural gas and oil system emissions at 15.67 MMT CO_2e in 2021, driven mainly by natural gas production (8.40 MMT CO_2e), natural gas transmission (2.35 MMT CO_2e), and natural gas distribution (2.36 MMT CO_2e; Pennsylvania Department of Environmental Protection 2024). As expected, Pennsylvania's estimated emissions from the oil and natural gas sector are much higher than those of New York State when converted to AR5 GWP20 estimates. Pennsylvania is the second-largest natural gas producer in the U.S. (after Texas), producing about 7.41 MMcf of natural gas in 2021, compared with 9,734 Mcf in New York State (EIA 2024e).

New Jersey derives 45.8% of electricity generation from natural gas. A total of 36 exploration wells were drilled, none after 1982, due to a lack of natural gas resources and regulatory limitations. As a result, New Jersey is primarily a natural gas consumer, as identified in the 2024 U.S. GHG Inventory (EPA 2024b), which estimates emissions of 2.49 MMT CO_2e (AR5, GWP100) from the natural gas transmission and distribution segments. New Jersey uses the EPA SIT to estimate emissions from these segments (New Jersey Department of Environmental Protection 2024).

Connecticut relies heavily on the EPA SIT to calculate GHG emissions by sector. As a primarily a natural gas–consuming state with minimal oil and natural gas resources, 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. In

2021, total emissions in Connecticut were estimated at 34.7 MMT CO_2e, depending on whether emission estimates were based on electric consumption or generation. The aggregated nature of Connecticut's GHG inventory makes drawing direct comparisons to the NYS inventory challenging (Connecticut DEEP 2023).

Massachusetts identifies only the transmission and distribution segments of the oil and natural gas sector as relevant to the state. Using the EPA SIT, Massachusetts estimates emissions from leaks in pipelines and services, customer meters, metering/regulating stations, and venting. In 2021, the most recent year of complete data, estimated emissions from natural gas transmission and distribution systems were 0.7 MMT CO_2e. (Massachusetts Department of Environmental Protection 2024).

Vermont's GHG inventory uses the EPA SIT and 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. Midstream and downstream emissions estimates are very small, reflecting the state's low natural gas consumption of 13,481 MMcf in 2021 compared with New York State's 1,361,023 MMcf in 2022. Vermont estimates total emissions from the midstream and downstream segments of the oil and natural gas sector at 0.031 MMT CO_2e (Vermont Department of Environmental Conservation 2024).

Table 20 presents a comparison of the NYS inventory with the inventories of these states. The estimated emissions-to-consumption ratio is consistent for most states, except Pennsylvania and Vermont, which have significantly different natural gas profiles. Pennsylvania's high upstream natural gas production results in a much higher ratio of emissions to consumption, as production-related emissions increase the ratio. Vermont, with minimal natural gas infrastructure and very low consumption, has an emissions-to-consumption ratio 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	2022	2021	2021	2021	2021	2021
Oil and Gas CH_4 (MMT CO_2e)	13.2	15.67	2.49	N/A[a]	0.7	0.031
Consumption (MMcf)[b]	1,361,023	1,801,483	671,501	296,584	392,539	13,481
Production (MMcf)[b]	9,734	7,413,118	0	0	0	0
Emissions/ consumption	9.71×10^{-04}	8.70×10^{-06}	3.71×10^{-06}	N/A	1.79×10^{-06}	2.30×10^{-06}

[a] Connecticut data are not separately reported for the oil and natural gas sector.

[b] Consumption and production figures are derived from EIA data for the year corresponding to the inventory.

4.8.4 Comparison to Top-Down and Bottom-Up Studies

Validation of an emission inventory using alternative methodologies is critical in assessing its robustness. The NYS inventory uses a BU methodology to estimate emissions using site-level activity data and EFs. Recent studies have highlighted discrepancies between BU and TD methodology (e.g., Marchese et al. 2015; Mitchell et al. 2015; Subramanian et al. 2015; Omara et al. 2016; Alvarez et al. 2018). One challenge in validating BU emission inventories with TD studies is the limited availability of TD study data. As discussed in section 3.1.2.6, TD studies require detailed atmospheric measurements and modeling to estimate emission flux. A thorough review of the available literature and consultations with the PAC and other experts during the initial iteration revealed a lack of TD data specific to New York State.

As emphasized in the discussion of EFs in section 3, the State should validate that the applied EFs accurately reflect local conditions, and TD studies can validate local conditions at the site and regional level. Therefore, New York State should consider TD validation for the higher-emitting segments of the inventory because such validation could reduce inventory uncertainty.

4.9 Uncertainty

Uncertainty is extensively addressed in section 3 about the limitations of the EFs used. Although the inventory adheres to best practices and uses EFs from various EPA tools, several sources of uncertainty warrant discussion.

1. **Pipeline Emissions:**
   Emissions from gathering, transmission, and distribution pipelines comprise a significant portion of the total estimated emissions. The literature on pipeline emission rates is limited, with most studies focusing on specific cities. Therefore, the applied EFs, based on the EPA Oil and Gas Tool and EPA SIT guidance, are often derived from older studies conducted in other states. A pressing need exists for new empirical data on per-mile leak rates to better reflect present conditions in New York State.

2. **Compressor Station Emissions:**
   Transmission and storage compressor stations are significant CH_4 sources in the State. The emission estimation methodology uses EFs based on peer-reviewed literature, employing best practices for measuring and estimating compressor emissions. However, these studies and others identify a potentially wide range of emission rates under normal operating conditions, often exhibiting nonnormal distribution. Applying a central estimate introduces inherent uncertainty into emission estimates.

3. **Activity Data and EFs:**
   This inventory relies on the best available activity data and EFs but is limited to site-level estimates due to the lack of component counts for NYS facilities. Facilities may have different component compositions compared to those used in this inventory, potentially resulting in the application of less tailored EFs.

4. **High-Emitting Sources:**
   The inventory does not explicitly estimate high-emitting sources, which have been widely observed and described in the literature along all stages of the upstream, midstream, and downstream processes. A few sites or facilities often contribute most of the regional emissions. However, the unknown distribution of high-emitting sources in the State makes applying statistical methods to estimate their likelihood challenging.

4.9.1 Emission Inventory Uncertainty

Using the uncertainty bounds identified in Table 6, the following figures illustrate total time series emissions, including upper and lower confidence bounds. Comparing Figures 25 and 27, midstream emissions drive the lower bound of the uncertainty estimate. Analysts determined that the lower-bound value was the most applicable value to New York State, aligning the best and lower-bound estimates for upstream and downstream EFs.

The team determined the upper-bound emissions estimates by selecting the upper-bound EF provided by the sources chosen for the best estimate EFs. These upper-bound estimates represent the potential maximum emissions for the State, incorporating EFs from other states where high-emitting techniques are prevalent in the oil and natural gas sector. They also reflect literature-based EFs for 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. The upper-bound emission estimates are four and two times the best estimate values in these categories, respectively. This reflects the wide uncertainty range introduced by high-emitting sources in the sample population, which is particularly notable in these source categories.

Figure 25. Total Emissions with Upper and Lower Bounds

Calculated using AR5 GWP20 conversion factors.

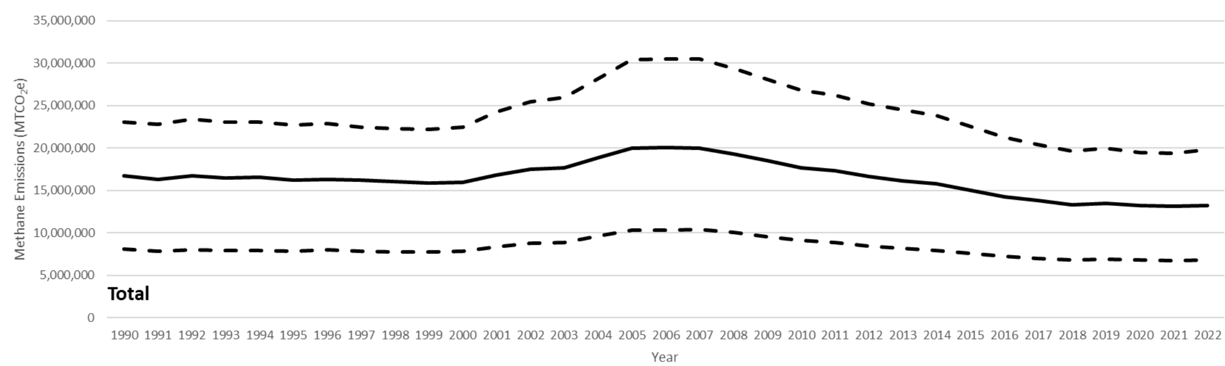


Figure 26. Upstream Emissions with Upper and Lower Bounds

Calculated using AR5 GWP20 conversion factors.

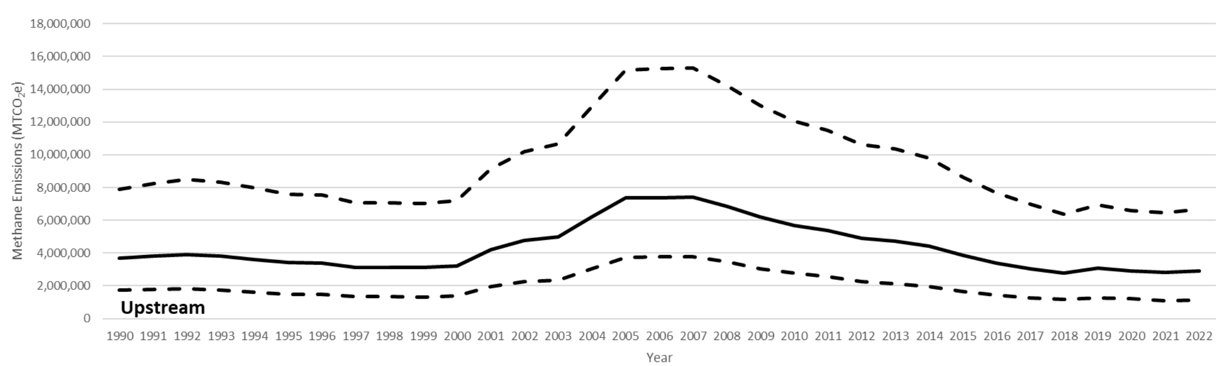


Figure 27. Midstream Emissions with Upper and Lower Bounds

Calculated using AR5 GWP20 conversion factors.

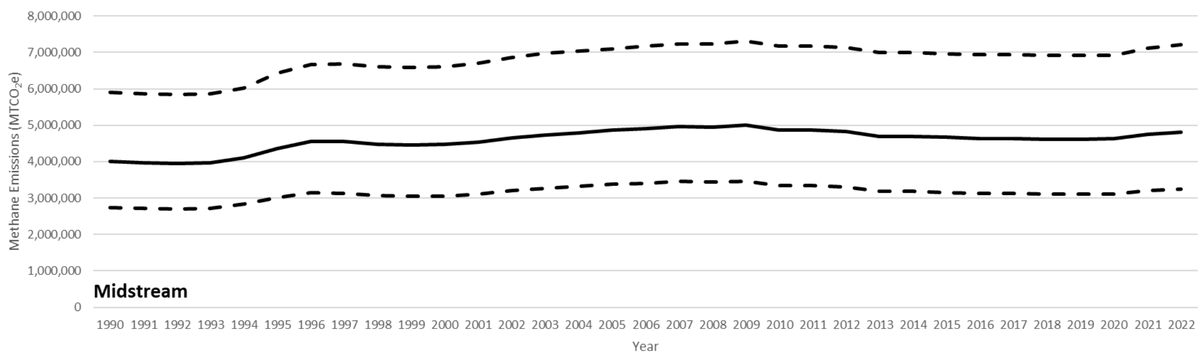
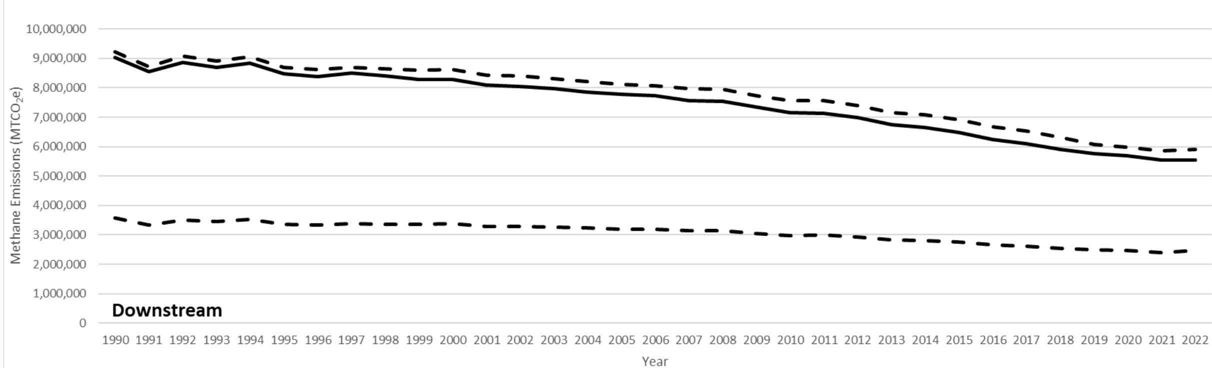


Figure 28. Downstream Emissions with Upper and Lower Bounds

Calculated using AR5 GWP20 conversion factors.



4.10 Comparing AR4 and AR5 Emission Estimates

CH_4, a short-lived climate pollutant, lasts approximately 12 years. To capture the near-term climate impacts of CH_4 emissions most effectively, results are reported in terms of AR5 GWP20. However, as discussed in Appendix A.5, reporting emissions using a range of GWPs, including AR4, AR5, and both short- and long-term climate effects, provides a more comprehensive illustration of climate impact. Selecting alternate GWPs, whether AR4 or AR5, and short- or long-term effects can yield markedly different results. Recent literature underscores the importance of considering the short-lived effects of CH_4, represented by GWP20. The CH_4 emissions estimates throughout this report use AR5 GWP20 values.

Under AR4, GWP100 for CH_4 is 25, and GWP20 is 72. 2014 IPCC's AR5 updated these values, increasing GWP100 to 28 and GWP20 to 84. AR6 further revised these figures in 2021, decreasing GWP20 to 82.5 for fossil-origin CH_4 and 80.8 for non–fossil-origin CH_4, while GWP100 changed to 29.8 for fossil-origin CH_4 and 27.2 for non–fossil-origin CH_4 (IPCC 2021). The following section describes the 2020 emissions estimated in the context of AR4 and AR5 GWPs and the NYS inventory.

As shown in Table 21, changing the GWP from AR4 GWP100 to GWP20 for the original 2015 NYS inventory increases CH_4 emissions from 2.22 MMT CO_2e to 6.39 MMT CO_2e for the oil and natural gas sector. Under AR5 GWP100, this inventory finds CO_2e emissions are 12.2% higher than estimates under AR4 GWP100. Under AR5 GWP20, emissions estimates are 16.6% higher than estimates under AR4 GWP20.

Table 21. Comparison of Global Warming Potential Values for Oil and Gas Methane Emissions in New York State

Values in MMT CO2e calculated using GWP20 from AR4 and AR5.

Source/Category	AR4 GWP100	AR4 GWP20	AR5 GWP100	AR5 GWP20
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 (MMT CO_2e)	2.22	6.39	2.49	7.46
Current Inventory				
2017 Oil and Gas CH_4 (MMT CO_2e)	2.66	7.67	2.98	8.95
2020 Oil and Gas CH_4 (MMT CO_2e)	4.20	12.09	4.70	14.10
2021 Oil and Gas CH_4 (MMT CO_2e)	4.40	12.67	4.93	14.78

5 Future Improvements

Developing an emissions inventory is a continuous process that requires incorporating improvements as better data on EFs and emission source activity become available. In addition, measurements of atmospheric CH_4 concentrations can help assess the completeness and accuracy of the emissions inventory. Following is a list of actions New York State is currently taking to improve future inventories:

- Continuously reviewing literature to identify new data on EFs and emission source activity
- Identifying additional sources of CH_4 emissions to include in the NYS oil and natural gas sector CH_4 emissions inventory, such as:
  - Residential refrigeration and clothes dryers
  - Additional commercial buildings, including grocery stores, religious buildings, and services (e.g., vehicle repair, dry cleaning/laundromat, post office, hair salon)
  - Industrial buildings
- Investigating the impact of cast-iron pipeline reconditioning on emissions estimates from existing infrastructure
- Comparing TD measurements of CH_4 emissions with BU inventory values as data become available to verify inventory and improve inventory estimates

6 Conclusions

With the passage of the Climate Act in 2019, New York State committed to reducing economywide GHG emissions 40% by 2030 and no less than 85% by 2050 from 1990 levels. While efforts have primarily focused on reducing CO_2 emissions—the dominant driver of the rise in global average temperatures—New York State is prioritizing CH_4 due to its significant short-term impacts on climate change. This project aims to support CH_4 emission reduction efforts in New York State and achieve Climate Act goals by improving the State's understanding of CH_4 emissions from the oil and natural gas sector.

This inventory shows a marked improvement over prior iterations of the New York State oil and natural gas sector methane emission inventories, based on the four identified areas of best practices and recommendations identified in the first iteration of the project (described in Appendix A and presented in the following table and discussion). Developing the emissions inventory is a continuous process that requires ongoing improvements as better data on emissions factors and emission source activity become available. With each iteration, the inventory improves as up-to-date data on activity and emissions factors are identified. New York State is taking additional steps to improve future inventories. Table 22 summarizes best practice recommendations, their implementation in the current inventory, and areas for future inventory improvement.

Table 22. Best Practice Recommendations and Future Inventory Improvements

Recommendation	Implementation in Current Inventory	Areas for Future Improvement
Recommendation 1 Develop a more detailed set of activity data, including site- and component-level data, to capture the impacts of CH_4 mitigation strategies targeted at the site or component level.	Applied best available activity data using public inputs and NYS agency data	• Collect data on transmission and storage CSs, including those with electric compressors. • Collect county-level data on distribution pipeline miles by pipeline material. • Collect county-level data on residential, commercial, and industrial gas meters. • Identify additional CH_4 emissions sources and compile county-level data.

Table 22 (continued)

Recommendation	Implementation in Current Inventory	Areas for Future Improvement
Recommendation 2 Estimate and apply EFs for upstream and downstream oil and gas activities in the State using: • Best available data • Validation by both BU and TD studies • Specific geographic location	• Applied best available EFs from the published literature	• Develop NYS-specific EFs for: ○ Well pads during production ○ Transmission and storage CSs ○ Fugitive emissions from storage reservoirs • Identify EFs for: ○ Various types of commercial buildings ○ Industrial buildings ○ Additional residential appliances
Recommendation 3 Align available geospatial data with inventory data to create a geospatial emissions inventory to: • Enhance ability to identify hot spots and air quality concerns • Allow verification of emission inventories with empirical data	• Collect and use air-quality data: • Measure ambient CH_4 concentrations throughout NYS • Verify emission estimates using observed concentrations • Compare TD measurements: • Gather data as it becomes available • Analyze CH_4 emissions in comparison to the inventory • Verify inventory and identify areas for potential improvement	• Collect and use air-quality data: ○ Measure ambient CH_4 concentrations throughout NYS ○ Verify emission estimates using observed concentrations • Compare TD measurements: ○ Gather data as it becomes available ○ Analyze CH_4 emissions in comparison to the inventory ○ Verify inventory and identify areas for potential improvement
Recommendation 4 • Conduct uncertainty analysis when calculating and reporting its CH_4 inventory: ○ Account for uncertainties in published EFs ○ Could include assessment of high-emitting sources across the State • Develop and apply models to account for high-emitting sources: • For known emission releases (e.g., reported leakage) • For estimated releases (e.g., leakage based on pipeline age or material).	• Assessed uncertainty in applied EFs • Identified most likely range of CH_4 emission from the oil and natural gas sector • Applied inventory methodology to potentially include high-emitting sources • Recognized need for better information on statistical distribution of such sources	• Develop better understanding of high-emitting sources • Distribution across the State • Frequency of operation in the high-emitting state

In the current inventory, total CH_4 emissions in 2022 reached an estimated 13.2 MMT CO_2e (AR5, GWP20), accounting for 6.21% of the total nationwide emissions estimated by the EPA. Decreased high-producing well activity and transitioning from leak-prone cast-iron and unprotected steel pipelines to plastic largely drove these results. Despite increased natural gas consumption, total CH_4 emissions have declined since 2005, with an average annual decrease of 2.8%. This decrease aligns with observed large-scale nationwide energy shifts.

The largest methane emission source categories identified in the State inventory 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 builds off the methodology developed for the 2017 inventory and incorporates findings from the latest empirical research. By consistently applying established best practices grounded in a thorough literature review and expert consultation, this inventory improves the methane emissions baseline in New York State.

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8 Glossary

Abandoned wells

Unplugged wells (primarily oil or gas) that have not been operated or maintained by prevailing statutes and regulations. Many abandoned wells have deteriorated significantly.

Associated gas

Gas produced as a byproduct of crude oil production.

Conventional reservoir

A reservoir where buoyant forces retain hydrocarbons beneath a sealing caprock. The reservoir and fluid characteristics typically allow oil or natural gas to flow readily into wellbores. This term distinguishes conventional reservoirs from shale and other unconventional reservoirs, where gas may be distributed throughout the reservoir on a basin scale, and buoyant forces or water column influence are insignificant.

Global warming potential

The index translates emissions levels of various gases into a common measure to compare their relative radiative forcing without directly calculating changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing caused by the emission of 1 kg of a GHG to that of 1 kg of CO_2 over a specified time (usually 100 years).

Green completions

Reduced emissions that capture flowback and collect natural gas instead of venting it into the atmosphere.

Orphan wells

A subset of abandoned wells for which no owner can be identified. Many of these wells were drilled before a regulatory framework was established in New York State. Due to their age and lack of comprehensive data, orphan wells may pose significant public health and environmental risks.

Plugged wells

A well that has been permanently closed, usually after either logs indicate insufficient hydrocarbon potential to complete the well or after production operations have drained the reservoir. Regulatory bodies have varying requirements for plugging operations. Most require that cement plugs be placed and tested across all open hydrocarbon-bearing formations, casing shoes, freshwater aquifers, and possibly other areas near the surface, including the top 20 to 50 feet (6 to 15 meters) of the wellbore. The well designer may set bridge plugs with cement slurries to prevent higher-density cement from falling into the wellbore. In this case, the bridge plug is set first, followed by cement pumped on top of the plug through a drillpipe. The drillpipe is then withdrawn before the slurry thickens.

Super-emitters

Super-emitters are sources with much higher emission rates than the average for their source type. Definitions vary, such as the top 5% of highest-emitting sources responsible for most emissions (Brandt et al. 2016) or sites with the highest proportional loss rates (Zavala-Araiza et al. 2015). Super-emitters may include chronic, episodic, routine, or malfunctioning sources. Due to the various uses of this term in the literature and its ambiguity, recent reports (e.g., ITRC and the recent National Academies of Science report on CH_4; National Academies of Sciences, Engineering and Medicine 2018) prefer the term “high-emitting sources” to describe these emission sources.

Unconventional resource

An umbrella term for oil and natural gas produced through methods that do not meet the criteria for conventional production. The classification depends on resource characteristics, exploration and production technologies, economic factors, and production scale and duration. Perceptions of these factors evolve. Currently, the term refers to resources such as coalbed methane, gas hydrates, shale gas, fractured reservoirs, and tight gas sands, which differ in porosity, permeability, fluid trapping mechanism, or other characteristics from conventional sandstone and carbonate reservoirs.

Well completions

A general term for assembling downhole tubulars and equipment to enable safe and efficient oil or gas production. The start of the completion process depends on the well type and design. Many options or actions during the well’s construction phase significantly impact its productivity.

Appendix A. Inventory Improvement

Appendix A provides detailed descriptions of previous iterations of the inventories and improvements.

A.1 2015 versus 2022 Inventories

The original 2015 inventory used straightforward calculations and a transparent approach but had several drawbacks (see Appendix A.3.4). By scaling national emissions by consumption, New York State's (NYS's) simplified approach failed to account for the unique aspects of the State's oil and natural gas sector. This highly aggregated approach, lacking both component-level and geographic resolution, limited the State's ability to effectively target its CH_4 reduction policies and programs. Additionally, it did not address the inherent uncertainty in emission factors (EFs) and activity data.

Significant improvements were made for the 2017 inventory, developed during the first iteration of this project, drawing on the best practices identified in the literature. These improvements focused on:

1. Using appropriately scaled activity data
2. Including of state-of-the-art EFs
3. Geospatially resolving activities and emissions
4. Applying and reporting uncertainty factors, including high-emitting sources

These best practices were maintained during the project's current iteration as the inventory was updated with activity data through 2022 for all source categories, emissions factors were improved, and new source categories were added to reconcile the inventory with top-down emissions estimates.

A.2. Updates for 2022 Inventory

To improve the 2022 inventory, the team conducted a literature review to identify updated EFs and new source categories from recent publications and industry datasets. The review identified and updated the New York State Department of Environmental Conservation (DEC) permit data, which used different activity data for transmission compressor stations compared to the 2021 inventory. These data included geolocation information, enabling accurate mapping to the appropriate counties. The 2022 inventory was updated to align with the DEC data. As a result of this update, the number of transmission compressor stations decreased from 64 to 44, and emissions declined from 3.66 million metric tons of carbon dioxide equivalent (MMT CO_2e) in 2021 to 2.42 MMT CO_2e in 2022. Similarly, storage compressor stations decreased from 26 to 24, and emissions decreased from 1.85 MMT CO_2e in 2021 to 1.71 MMT CO_2e in 2022.

A.3. Previous Updates for 2021 Inventory

Building on the best practices (Appendix A.6) and previous updates for the 2020 inventory (Appendix A.4), the 2021 inventory included updates to activity data and emissions calculations through 2021. Key differences in the 2021 inventory include:

- Updates to abandoned well counts (Appendix A.2.1)
- Addition of downstream sources, including industrial meters, metering and regulating (M&R) stations, pressure relief valves, damages, blowdowns, and various commercial building types, such as education, lodging, office buildings, warehouses, and retail buildings (Appendix A.2.2)
- Update to the commercial meter EF to align with the U.S. Environmental Protection Agency's (EPA's) U.S. Greenhouse Gas (GHG) Inventory (Appendix A.2.3)

A.3.1 Abandoned Well Counts

An analysis of the NYS Orphaned Wells Map (DEC 2024b) DEC's grant application to plug abandoned wells revealed discrepancies between the inventory and the map. The inventory was updated to include additional well types and statuses from ESOGIS, expanding the definition of "abandoned." This update added nearly 5,000 abandoned wells in New York State to the inventory, increasing estimated emissions from this source.

A.3.2 Additional Downstream Sources

A literature review for additional sources and updated emissions factors identified several new studies and reports published since the New York State Oil and Gas Sector Methane Emissions Inventory: 1990-2020. A review of the EPA's U.S. GHG Inventory, prompted by the Joint Utilities' Supplemental Proposal for an Annual Greenhouse Gas Emissions Inventory Report, led to the addition of several new downstream sources, which increased downstream emissions:

- M&R stations
- Industrial meters
- Pressure relief valves
- Damages
- Blowdowns

ICF (2020) data on fugitive emissions from commercial building types in California (e.g., offices, lodging, education, retail, warehouse, and food service) informed EFs for these categories, enhancing completeness and increasing EFs from commercial buildings.

A.3.3 Updated Commercial Meter Emissions Factor

The inclusion of industrial meters in the EPA's U.S. GHG Inventory prompted an update to the commercial meter EF, increasing it from 9.7 kilograms per meter (kg/meter) to 23.4 kg/meter. This change is reflected in the NYS Oil and Gas Sector Methane Emissions Inventory: 1990–2021 and increased commercial meter emissions.

A.3.4 Results of 2021 Updates

Table A-6 compares emissions for 2015 (the common year across all four inventories) with emissions from 1990 and 2005 in the first NYS GHG Inventory (1990–2015) and subsequent iterations of the NYS Oil and Gas Sector Methane Emissions Inventory (1990–2017, 1990–2020, 1990–2021).

Table A-1. Emissions Comparison in Key Inventory Years

Includes with AR4 and AR5 GWP100 and GWP20 values applied from the four inventories.

Inventory	AR4 GWP100	AR4 GWP20	AR5 GWP100	AR5 GWP20
1990				
NYS GHG Inventory, 1990–2015	2.8	8.06	3.14	9.41
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	2.74	7.88	3.07	9.21
NYS Oil and Gas Methane Emissions Inventory, 1990–2020	5.17	14.89	5.80	17.40
NYS Oil and Gas Methane Emissions Inventory, 1990–2021	5.42	15.60	6.07	18.20
2005				
NYS GHG Inventory, 1990–2015	3.5	10.07	3.93	11.76
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	3.52	10.12	3.95	11.83
NYS Oil and Gas Methane Emissions Inventory, 1990–2020	6.15	17.72	6.93	20.73
NYS Oil and Gas Methane Emissions Inventory, 1990–2021	6.42	18.48	7.19	21.56
2015				
NYS GHG Inventory, 1990–2015	2.22	6.39	2.49	7.46
NYS Oil and Gas Methane Emissions Inventory, 1990– 2017	2.82	8.12	3.16	9.48
NYS Oil and Gas Methane Emissions Inventory, 1990– 2020	4.74	13.65	5.31	15.92
NYS 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, emissions in 202 totaled 14,104,891 MT CO_2e (AR5 GWP20). The current iteration of the inventory estimates that total emissions reached 14,982,220 MT CO_2e in 2020. Thus, the improvements made between the second and current iteration increased emissions by 6.2%.

A.4 Previous Updates for 2020 Inventory

During the project's second iteration, researchers assessed the 2017 NYS Oil and Gas Sector Methane Emissions Inventory (NYSERDA 2019a) and made several updates. In addition to incorporating activity data and emissions for 2018–2020 into the 2017 inventory, they introduced four key differences between the 2017 inventory and the 2018–2020 inventories, as discussed in the following section:

- Updated distribution emissions factors based on utility-reported data (appendix A.2.1)
- Added beyond-the-meter sources, including residential appliances and residential and commercial buildings, covering 1990 to 2020 (Appendix A.2.2)
- Expressed CH_4 emissions in terms of CO_2e using the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) global warming potential 20-year (GWP20; Appendix A.2.3)
- Updated conventional production emissions factors based on Omara et al. (2016) (Appendix A.2.4)

Table A-2. 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 GWP100	AR5 GWP20
Conventional Production Emissions Factors	Low emissions factors from Omara et al. (2016)	Mid-emissions factors from Omara et al. (2016)

A.4.1 Updates to Distribution Emissions Factors

A comparison of utility-reported distribution pipeline emissions under the Environmental Protection Agency's (EPA's) GHG Reporting Program (the Facility Level Information on GreenHouse Gases Tool, or FLIGHT, database) and the estimated distribution pipeline emissions in New York State's 2017 oil and natural gas sector inventory revealed discrepancies between utility-reported emissions and the New

York State estimated emissions for pipeline mains and services. To ensure that the NYS CH_4 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 kilograms per mile (kg/mile) for consistency.

Table A-2 compares emissions factors used in the 2017 NYS inventory (2017 low, yellow shading) to the updated emissions factors used in the 2020 inventory (2017 high, green shading). These updates resulted in a 330% increase in distribution pipeline emissions (868,826 to 3,736,804 MMT CO_2e AR5 GWP20 in 2020) and a 26% increase in overall emissions from the oil and natural gas sector (11,236,913 to 14,104,891 MMT CO_2e AR5 GWP20 in 2020).

Table A-3. Comparison of Distribution Pipeline Methane Emission Factors

Based on utility-reported emissions versus EFs used in the NYS 2017 Oil and Natural Gas Sector Inventory.

Material & Type	2017 EF Units	Calculated from Utility-Reported Data to GHGRP	2017 NYS Inventory EFs		Updated EFs Units	Calculated from Utility-Reported Data to GHGRP	Updated NYS Inventory EFs	
		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.4.2 Addition of Beyond-the-Meter Sources

New York State's 2017 CH4 emissions inventory estimated CH4 emissions from the oil and natural gas sector up to and including emissions from the meter but did not account for end-use emission estimates beyond the meter. Since completing the 2017 inventory, researchers have published more studies on beyond-the-meter missions, enabling the inclusion of these emissions estimates. Including CH4 emissions from beyond-the-meter end-use processes may help to further reconcile discrepancies in emission estimates from top-down (TD) versus top-up (BU) approaches, as discussed in Section 3.1.2.6.

For example, a recent TD measurement study by Plant et al. (2019) conducted a recent TD measurement study indicating that downstream emissions in the Northeastern U.S. are around 0.8% of consumption. In comparison, the 2019 NYS inventory estimated BU downstream emissions at about 0.2% of consumption, aligning closely with natural gas utility data on delivery and losses reported by to the EPA's FLIGHT database. Thus, in addition to inherent methodological differences, missing end-use sources could partially explain the discrepancy between TD studies such as Plant et al. and the NYS inventory.

The following section presents the results of a literature review on beyond-the-meter end-use CH_4 emissions. The review aimed to identify the range of appliances and buildings contributing to end-use CH_4 emissions and to determine the leak rates from those appliances and building plumbing.

To conduct the literature review, researchers searched the U.S. Energy Information Administration (EIA) to identify natural gas end uses in the residential and commercial sectors (EIA 2024f). They then identified the following key terms to guide the search:

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
    - Clothes drying

The results of the literature review, presented in Tables A-3 and A-4, informed the development of beyond-the-meter CH_4 emission estimation methods for residential appliances (Section 3.2.12.7), residential buildings (Section 3.2.12.8), and commercial buildings (hospitals and restaurants; Section 3.2.12.9). Due to limited available data, researchers did not estimate emissions for residential refrigeration, clothes driers, or many commercial building types. Researchers have identified adding these appliances and building types as an area for future improvement. Adding these beyond the meter sources increased the overall emissions in the oil and natural gas sector inventory by 9% compared to the 2017 inventory estimate. This increase includes 5% from residential buildings, 2.2% from residential appliances, and 1.8% from commercial buildings.

Table A-4. Literature Review of Beyond-the-Meter Emissions: Results Containing Emissions Factors

Author	Year	Title	Summary	Appliance(s) Covered	Emissions	Geography
Hong and Howarth	2016	GHG emissions from domestic hot water: heat pumps compared to most commonly used systems	EFs for residential natural gas tankless and storage water heaters are estimated at 0.82 to 4.02 kg/GJ water heated. The EF is a life-cycle 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.	2018a	An estimate of natural gas CH_4 emissions from California homes	Postmeter CH_4 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 CH_4 emissions from residential natural gas are 35.7 Gg/yr.	Postmeter	<1 g CH_4/day/housing unit	California
Merrin and Francisco	2019	Unburned CH_4 emissions from residential natural gas appliances	EF equals 0.38 g/kg of natural gas consumed for U.S. residential appliances. Calculates total CH_4 emissions and CH_4 emissions per year for each appliance (e.g., 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, MA, and Indianapolis, IN, and 28 sites in Illinois and NYS
Lebel	2020	Quantifying CH_4 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 and Pekney	2020	Beyond the meter: Unaccounted sources of CH_4 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 U.S. based on Merrin and Francisco (2019). EFs from other countries: • UK: 4.3 kg CH_4/TJ consumed (heating units or furnaces) • Germany: 2.3 kg CH_4/TJ consumed (furnaces) • Japan: 4.5 kg CH_4/TJ consumed (furnaces) • Switzerland: 1 kg CH_4/TJ consumed Type of furnace, efficiency, furnace technology, and age may affect EFs. Mentions that Hong and Howarth (2016; summarized above) calculated an EF for residential natural gas tankless and storage water heaters to be between 0.60 and 4.02 kg/GJ.	Furnaces	4.1 kg/TJ natural gas consumed	U.S.

Table A-4. (continued)

Author	Year	Title	Summary	Activity Data	Geography
EIA	2018b	2015 RECS Survey Data	Survey data identifies the appliances households use, including stoves, ovens, water heaters, furnaces, and boilers. It also includes data on end-use fuel consumption in the U.S. and in Northeast for space heating, water heating, air conditioning, refrigerators, and other uses. More detailed consumption data specifies the site energy consumption of natural gas space heating, water heating, clothes drying, cooking, pool heaters, and hot tub heaters in the Northeast. Additionally, the survey includes 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 describes building characteristics and consumption and expenditures in the U.S.	NG 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	Survey data identifies specific end uses, such as using natural gas for heating buildings and water, drying clothes, operating refrigeration and cooling equipment, and outdoor lighting.	N/A	U.S.
NYSERDA	2019	RBSA Single-Family Building Assessment	Survey data provides a profile of new and existing homes in NYS based on data from a representative sample. It reports changes in building and equipment stock since the 2015 RSBS, including changes in the saturation of energy-consuming equipment (e.g., 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	NYS
U.S. Census Bureau	2018	Annual estimates of county housing units for states, 2010–2018	Survey data provides total number of housing units by county.	Counts of housing units by county	NYS

A.4.3 Global Warming Potential

The current inventory calculates emissions using AR5 GWP20, as required by the Climate Act, while the previous iteration used AR4 GWP100.

A.4.4 Updates to Conventional Production Emissions Factors

The 2017 NYS Oil and Gas Sector Methane Emissions Inventory (NYSERDA 2019a) used the 25th percentile emissions factors from Omara et al. (2016). To align with the out-of-state oil and gas CH_4 inventory (NYSERDA 2021), the 2020 inventory updated these factors to the median emissions values. Table A-5 summarizes these EF changes. These updates increased emissions from the oil and gas sector by 13%, rising from 12,482,204 to 14,104,891 MMT CO_2e.

Table A-5. Comparison of Emissions Factors Used in the 2017 Inventory and 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.4.5 Results of 2020 Updates

Table A-6 compares emissions for 2015, the common year across all three inventories, from the first NYS GHG Inventory (1990–2015) to the first and second iterations of the NYS Oil and Gas Sector Methane Emissions Inventory (1990–2017 and 1990–2020).

Table A-6. Emissions Comparison with Fourth and Fifth Assessment Report Global Warming Potential Values

This table compares emissions in key inventory years with AR4 and AR5 GWP100 and GWP20 values applied from the three inventories.

Inventory	AR4 GWP100	AR4 GWP20	AR5 GWP100	AR5 GWP20
1990				
NYS GHG Inventory, 1990–2015	2.8	8.06	3.14	9.41
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	2.74	7.88	3.07	9.21
NYS Oil and Gas Methane Emissions Inventory, 1990–2020	5.17	14.89	5.80	17.40
2005				
NYS GHG Inventory, 1990–2015	3.5	10.07	3.93	11.76
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	3.52	10.12	3.95	11.83
NYS Oil and Gas Methane Emissions Inventory, 1990–2020	6.15	17.72	6.93	20.73
2015				
NYS GHG Inventory, 1990–2015	2.22	6.39	2.49	7.46
NYS Oil and Gas Methane Emissions Inventory, 1990–2017	2.82	8.12	3.16	9.48
NYS 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 MT CO_2e (AR4 GWP100) or 8,951,651 MT CO_2e (AR5 GWP20). The second iteration of the inventory estimates total emissions in 2017 at 14,701,916 MT CO_2e. Thus, the improvements made between the first and second iterations increased emissions 64%.

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