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# New York State Greenhouse Gas Inventory: 1990 – 2014

## Final Report

December 2016

Revised February 2017

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# NYSERDA Record of Revision

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# New York State Greenhouse Gas Inventory: 1990–2014

***Final Report***


Prepared by:

**New York State Research and Development Authority**

Albany, NY



December 2016
Revised February 2017

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# Acronyms and Abbreviations

| | |
|---|---|
| AEO | Annual Energy Outlook, published by the EIA |
| Btu | British thermal units |
| CAFE | Corporate average fuel economy |
| $CH_4$ | Methane |
| CNG | Compressed natural gas |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | Carbon dioxide equivalent |
| $CO_2FFC$ | Carbon dioxide from fossil fuel combustion |
| DOT | New York State Department of Transportation |
| EIA | Energy Information Administration |
| EPA | Environmental Protection Agency |
| FHWA | Federal Highways Administration |
| GSP | Gross State Product |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| Gwh | Gigawatt hours |
| HFC | Hydrofluorocarbons |
| HCFC | Hydrofluorochlorocarbons |
| LPG | Liquid petroleum gas |
| MMt | Million metric tons |
| MSW | municipal solid waste |
| $N_2O$ | Nitrous oxide |
| NYISO | New York Independent System Operator |
| ODS | Ozone depleting substance |
| ORNL | Oak Ridge National Laboratory |
| PFC | Perfluorinated Chemicals |
| RCI | Residential, Commercial, Industrial |
| SEDS | State Energy Data System |
| $SF_6$ | Sulfur Hexafluoride |
| SIT | State Inventory Tool |
| T&D | Transmission and Distribution |
| VMT | Vehicle miles traveled |

# Summary

## S.1 Introduction

Unequivocal warming of the Earth over the past century is documented by observations that include increases in global average temperatures, rapid melting of mountain glaciers and land ice sheets, and higher global average sea levels. In North America, extreme heat and drought events are becoming more frequent and prolonged. Although total precipitation is increasing only slightly, intense and damaging storms like Sandy and Irene are occurring more often. A changing climate affects human health, society, and the economy both directly and indirectly, through its effects on agriculture, sea level, fisheries, and other natural resources. The rate and extent of climate change depend on the amount of greenhouse gases (GHGs) present in, and delivered to, the atmosphere.

This report provides a detailed accounting of emissions in New York State from 1990–2014. The report identifies the emissions associated with different sectors and describes sector-specific calculation methodologies to provide greater detail and context on what sectors and sources are driving emissions. Accordingly, the chapters correspond to the different sectors, and are organized as follows:

- Chapter 1: Residential, Commercial/Institutional, and Industrial Fuel Combustion.[1]
- Chapter 2: Industrial Non-Fuel Combustion Processes.[2]
- Chapter 3: Transportation Energy Use.
- Chapter 4: Power Supply and Delivery.
- Chapter 5: Agriculture.
- Chapter 6: Waste Management.

1 Chapter 1 focuses on emissions in the Residential, Commercial, and Industrial sector, but also includes associated emissions from electricity generation that meets the demand for this sector. These electricity generation emissions are included in Chapter 1 for informational purposes only, as Chapter 4 separately identifies emissions from the electricity generation sector. While emissions from electricity generation appear in both chapters, they are not double counted.

2 Chapter 2 provides estimates of emissions associated with natural gas T&D.

The report systematically looks at six primary GHG's: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$).

Emissions of these six GHGs are converted to and presented using a common metric, the $CO_2$ equivalent ($CO_2e$), so that the global warming potential of each of these different GHGs can be presented in equivalent terms.

## S.2 New York State GHG Emissions: Sources and Trends

Table S-1 provides a summary of GHG emissions estimated for New York State by sector and gas in 2014, the most recent year for which historical data are available.

### Table S-1. 2014 New York State Greenhouse Gas Inventory (MMtCO$_2$e)[a]

| | $CO_2$ | $CH_4$ | $N_2O$ | PFC | HFC | $SF_6$ | Total | % of Total |
|---|---|---|---|---|---|---|---|---|
| **Fuel Combustion[b]** **(inc. Net Imports of Electricity)** | **179.69** | **0.41** | **0.88** | **-** | **-** | **-** | **180.98** | **83.12%** |
| Electricity Generation | 30.36 | 0.01 | 0.04 | - | - | - | 30.41 | 13.97% |
| Transportation | 73.28 | 0.05 | 0.69 | - | - | - | 74.01 | 33.99% |
| Residential | 35.19 | 0.25 | 0.06 | - | - | - | 35.50 | 16.31% |
| Commercial | 21.93 | 0.07 | 0.02 | - | - | - | 22.03 | 10.12% |
| Industrial | 10.98 | 0.02 | 0.04 | - | - | - | 11.04 | 5.07% |
| Net Imports of Electricity | 7.96 | 0.01 | 0.03 | - | - | - | 7.99 | 3.67% |
| **Fuel Combustion** **(exc. Net Imports of Electricity)** | **171.73** | **0.41** | **0.85** | **-** | **-** | **-** | **172.99** | **79.45%** |
| **Other Sources** | **3.94** | **19.74** | **2.44** | **0.38** | **10.03** | **0.22** | **36.74** | **16.88%** |
| ***Power Supply & Delivery*** | *2.69* | - | *0.05* | - | - | *0.22* | *2.96* | *1.36%* |
| Electricity Transmission and Distribution | - | - | - | - | - | 0.22 | 0.22 | 0.10% |
| Municipal Waste Combustion | 2.69 | - | 0.05 | - | - | - | 2.74 | 1.26% |
| ***Agriculture, Forestry & Waste*** | - | *17.56* | *2.39* | - | - | - | *19.95* | *9.16%* |
| Agricultural Animals | - | 3.56 | - | - | - | - | 3.56 | 1.63% |
| Agricultural Soil Management | - | - | 1.46 | - | - | - | 1.46 | 0.67% |
| Landfills | - | 11.63 | - | - | - | - | 11.63 | 5.34% |
| Manure Management | - | 0.79 | 0.37 | - | - | - | 1.16 | 0.53% |
| Municipal Wastewater | - | 1.58 | 0.55 | - | - | - | 2.13 | 0.98% |
| ***Industrial Processes & Manufacturing*** | *1.24* | *2.18* | - | *0.38* | *10.03* | - | *13.83* | *6.35%* |
| Aluminum Production | - | - | - | 0.25 | - | - | 0.25 | 0.11% |
| Cement Production | 0.38 | - | - | - | - | - | 0.38 | 0.18% |
| Iron & Steel Production | 0.14 | - | - | - | - | - | 0.14 | 0.07% |
| Limestone Use | 0.58 | - | - | - | - | - | 0.58 | 0.27% |
| Natural Gas Leakage[b] | - | 2.18 | - | - | - | - | 2.18 | 1.00% |
| ODS Substitutes | - | - | - | - | 10.03 | - | 10.03 | 4.61% |
| Semiconductor Manufacturing | - | - | - | 0.13 | - | - | 0.13 | 0.06% |
| Soda Ash Use | 0.13 | - | - | - | - | - | 0.13 | 0.06% |
| **Total** (inc. Net Imports of Electricity) | **183.63** | **20.15** | **3.31** | **0.38** | **10.03** | **0.22** | **217.73** | **100%** |
| % of Total (inc. Net Imports of Electricity) | 84.34% | 9.26% | 1.52% | 0.17% | 4.61% | 0.10% | 100% | - |
| **Total** (exc. Net Imports of Electricity) | **175.67** | **20.15** | **3.29** | **0.38** | **10.03** | **0.22** | **209.73** | **-** |

[a] MMtCO$_2$e = million metric tons of carbon dioxide equivalent; $CO_2$ = carbon dioxide; $CH_4$ = methane; $N_2O$ = nitrous oxide; PFC = perfluorocarbons; HFC = hydrofluorocarbons; $SF_6$ = sulfur hexafluoride

[b] 2014 energy-related emissions, a category calculated as part of New York's State Energy Plan (SEP) that includes fuel combustion, net electricity imports, power supply & delivery, and natural gas leakage, totals 186.12 MMtCO$_2$e, or 85 percent of total emissions.

[c] A recent study found that measured emissions of methane from natural gas systems are approximately 1.5 times greater than those published in the U.S. Environmental Protection Agency national GHG inventory. A commensurate scaling of this analysis would increase the emissions from natural gas leakage to 3.3 MMTonsCO$_2$e or one percent of total emissions. See Brandt, et al., 2014. "Methane Leaks from North American Natural Gas Systems." *Science* 343, February.

## S.3 Emissions

### S.3.1 Overview

The *New York State Greenhouse Gas Inventory: 1990–2014* is based on the U.S. Environmental Protection Agency (EPA) production-based methodology and tailored to estimate current emissions produced within the State's boundaries. The inventory adopts the EPA protocols for identified emissions, as well as categorization for sources of emissions. Additionally, the inventory reflects emissions associated with the electricity sources used to meet all of New York State's demands, corresponding to a consumption-based approach for the power supply and delivery sector (i.e., emissions associated with imported electricity).

This report illustrates the historical development of GHG emissions. Table S-2 shows the trend in New York State's historical GHG emissions from 1990–2014. Emissions gradually increased from 1990, peaked in 2005, and then began to decline. In 2014 emissions were approximately eight percent lower than in 1990. This reduction stands in contrast to the seven percent national increase in total GHG emissions over the same time period. Energy-related emissions were thirteen percent lower in 2014 relative to 1990 levels.[3]

[3] Energy-related emissions is a category calculated as part of New York's State Energy Plan (SEP) that includes fuel combustion, net electricity imports, power supply & delivery, and natural gas leakage.

**Table S-2. New York State GHG Emissions, 1990–2014 ($MMtCO_2e$)**

Values for 1990–2014 are based on historical data. GHG = greenhouse gas; MMTCO2e = million metric tons of carbon dioxide equivalent. Totals may not equal exact sum of subtotals shown in this table due to independent rounding.

| Gas and Category | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| **Carbon Dioxide** | **204.72** | **203.62** | **225.58** | **229.11** | **189.66** | **183.63** |
| *Fuel Combustion* | *201.57* | *199.66* | *221.63* | *223.65* | *186.02* | *179.69* |
| Electricity Generation | 62.76 | 51.10 | 55.47 | 53.38 | 37.20 | 30.36 |
| Net Imports of Electricity | 1.63 | 4.24 | 5.66 | 6.52 | 9.55 | 7.96 |
| Transportation | 57.18 | 60.72 | 71.77 | 81.14 | 73.58 | 73.28 |
| Residential | 33.76 | 34.37 | 39.40 | 39.22 | 31.42 | 35.19 |
| Commercial | 26.37 | 26.84 | 31.97 | 28.45 | 24.06 | 21.93 |
| Industrial | 19.86 | 22.40 | 17.37 | 14.94 | 10.22 | 10.98 |
| *Other Sources* | *3.16* | *3.96* | *3.95* | *5.46* | *3.64* | *3.94* |
| Municipal Waste Combustion | 1.23 | 1.90 | 2.00 | 3.52 | 2.30 | 2.69 |
| Cement Production | 0.67 | 0.76 | 0.80 | 0.79 | 0.51 | 0.38 |
| Iron and Steel Production | 0.83 | 0.83 | 0.75 | 0.60 | 0.24 | 0.14 |
| Limestone Use | 0.24 | 0.29 | 0.22 | 0.37 | 0.45 | 0.58 |
| Soda Ash Use | 0.20 | 0.19 | 0.18 | 0.17 | 0.14 | 0.13 |
| **Methane** | **23.52** | **24.57** | **23.95** | **22.29** | **20.22** | **20.15** |
| *Fuel Combustion* | 0.68 | 0.75 | 1.04 | 0.73 | 0.39 | 0.41 |
| Electricity Generation | 0.04 | 0.02 | 0.03 | 0.03 | 0.01 | 0.01 |
| Net Imports of Electricity | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| Transportation | 0.11 | 0.10 | 0.09 | 0.07 | 0.06 | 0.05 |
| Residential | 0.37 | 0.47 | 0.70 | 0.47 | 0.20 | 0.25 |
| Commercial | 0.11 | 0.13 | 0.18 | 0.14 | 0.08 | 0.07 |
| Industrial | 0.05 | 0.03 | 0.04 | 0.03 | 0.02 | 0.02 |
| *Other Sources* | *22.84* | *23.82* | *22.91* | *21.55* | *19.83* | *19.74* |
| Agricultural Animals | 3.37 | 3.20 | 3.30 | 3.17 | 3.36 | 3.56 |
| Landfills | 12.89 | 13.43 | 13.52 | 13.49 | 12.17 | 11.63 |
| Manure Management | 0.50 | 0.56 | 0.68 | 0.75 | 0.77 | 0.79 |
| Municipal Wastewater | 1.44 | 1.45 | 1.52 | 1.55 | 1.55 | 1.58 |
| Natural Gas Leakage | 4.63 | 5.17 | 3.88 | 2.59 | 1.99 | 2.18 |

### Table S-2 continued

| Gas and Category | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| **Nitrous Oxide** | **5.93** | **6.26** | **6.37** | **5.10** | **3.89** | **3.31** |
| *Fuel Combustion* | *3.51* | *4.11* | *4.26* | *2.89* | *1.49* | *0.88* |
| Electricity Generation | 0.18 | 0.13 | 0.15 | 0.14 | 0.08 | 0.04 |
| Net Imports of Electricity | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 |
| Transportation | 3.10 | 3.76 | 3.82 | 2.51 | 1.27 | 0.69 |
| Residential | 0.09 | 0.10 | 0.15 | 0.11 | 0.06 | 0.06 |
| Commercial | 0.05 | 0.05 | 0.06 | 0.05 | 0.03 | 0.02 |
| Industrial | 0.08 | 0.05 | 0.07 | 0.05 | 0.03 | 0.04 |
| *Other Sources* | *2.41* | *2.15* | *2.11* | *2.21* | *2.39* | *2.44* |
| Agricultural Soil Management | 1.59 | 1.32 | 1.26 | 1.30 | 1.51 | 1.46 |
| Manure Management | 0.31 | 0.29 | 0.27 | 0.30 | 0.30 | 0.37 |
| Municipal Waste Combustion | 0.04 | 0.06 | 0.05 | 0.08 | 0.04 | 0.05 |
| Municipal Wastewater | 0.47 | 0.49 | 0.52 | 0.52 | 0.54 | 0.55 |
| **Perfluorocarbons** | **0.44** | **0.41** | **0.47** | **0.37** | **0.42** | **0.38** |
| Aluminum Production | 0.38 | 0.31 | 0.33 | 0.27 | 0.32 | 0.25 |
| Semiconductor Manufacturing | 0.05 | 0.09 | 0.14 | 0.10 | 0.11 | 0.13 |
| **Hydrofluorocarbons** | | | | | | |
| ODS Substitutes | 0.02 | 2.42 | 5.95 | 7.27 | 9.05 | 10.03 |
| **Sulfur Hexafluoride** | | | | | | |
| Electricity Transmission and Distribution | 1.21 | 0.88 | 0.58 | 0.43 | 0.27 | 0.22 |
| **TOTAL** | **235.84** | **238.16** | **262.90** | **264.57** | **223.52** | **217.73** |
| **Totals** | **1990** | **1995** | **2000** | **2005** | **2010** | **2014** |
| **Fuel Combustion** | **205.76** | **204.52** | **226.93** | **227.27** | **187.90** | **180.98** |
| Electricity Generation | 62.99 | 51.25 | 55.65 | 53.55 | 37.29 | 30.41 |
| Net Imported Electricity | 1.63 | 4.26 | 5.69 | 6.55 | 9.59 | 7.99 |
| Transportation | 60.40 | 64.57 | 75.68 | 83.73 | 74.91 | 74.01 |
| Residential | 34.22 | 34.94 | 40.25 | 39.79 | 31.67 | 35.50 |
| Commercial | 26.53 | 27.01 | 32.21 | 28.64 | 24.17 | 22.03 |
| Industrial | 19.99 | 22.48 | 17.47 | 15.01 | 10.27 | 11.04 |
| **Other Sources** | **30.08** | **33.64** | **35.97** | **37.30** | **35.61** | **36.74** |
| **TOTAL** | **235.84** | **238.16** | **262.90** | **264.57** | **223.52** | **217.73** |
| ***Energy-Related Emissions [a]*** | ***212.87*** | ***212.53*** | ***233.45*** | ***233.90*** | ***192.51*** | ***186.12*** |

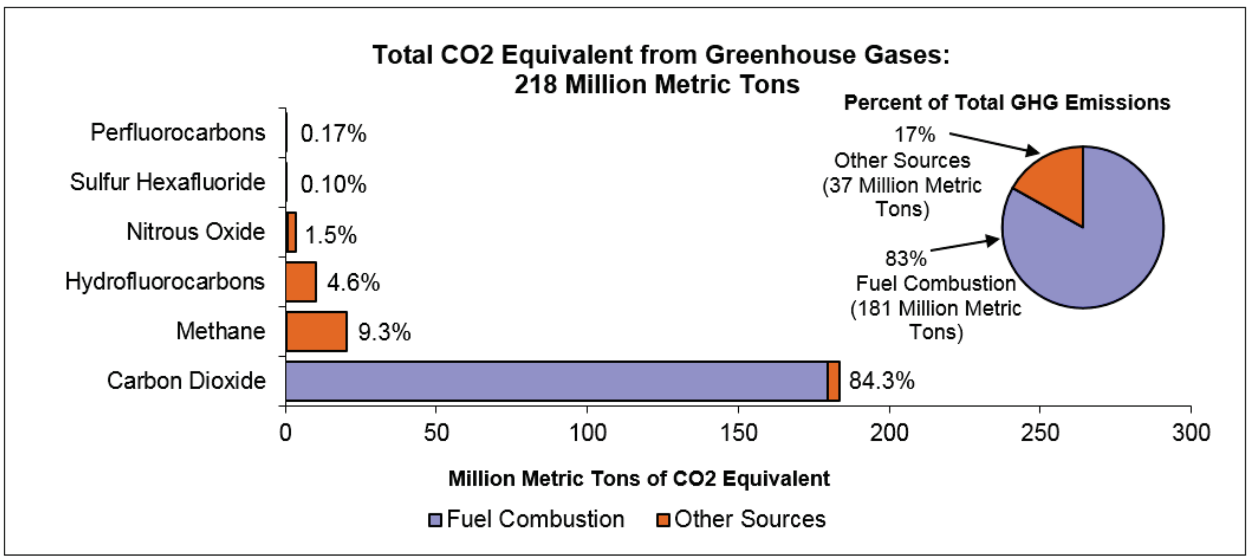
[a] Energy-related emissions is a category calculated as part of New York's State Energy Plan (SEP) that includes fuel combustion, net electricity imports, power supply & delivery, and natural gas leakage.

## S.3.2. Emissions Inventory

As shown in Table S-1, New York State accounted for approximately 218 million metric tons of carbon dioxide equivalent ($MMtCO_2e$) emissions in 2014, an average of 11 $MtCO_2e$ for each State resident.[4] At these levels, New York State's per capita GHG emissions were approximately half the U.S. average. The majority of the State's GHG emissions came from fuel combustion, which primarily represents the burning of fossil fuels (e.g., coal, natural gas, petroleum products) as an energy source to support various economic activities, including transportation, electric power generation, and heating and hot water needs for homes and businesses. Figure S-1 provides a breakdown of New York State's 2014 GHG emissions by gas. Even when considering the contributions of the six primary GHG emissions on a $CO_2e$ basis, this figure shows that $CO_2$ contributes the majority (84 percent) of all GHG emissions in the State.

**Figure S-1. 2014 Percentage of GHG Emissions by Gas and Source (Includes Net Imports of Electricity)**

CO2 = carbon dioxide; GHG = greenhouse gas.




[4] Historic U.S. and New York State population data is drawn from the American Community Survey.

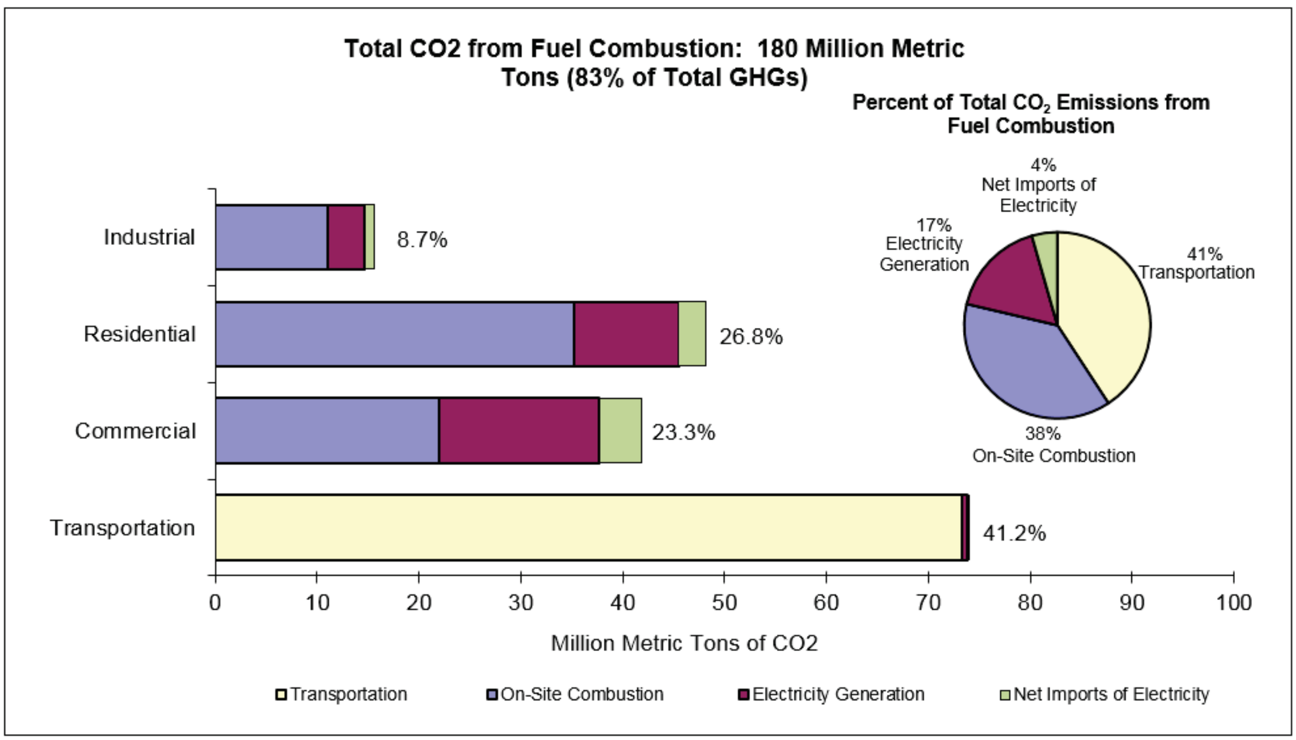
## S.3.3 Fuel Combustion

### *S.3.3.1 Emissions by Economic Sector*

The transportation sector accounted for approximately 41 percent of $CO_2$ emissions from fuel combustion in 2014 (shown in Figure S-2). The residential and commercial sectors were responsible for roughly 27 and 23 percent, respectively, after including an allocation of emissions from electricity generation. For both the residential and commercial sectors, emissions from on-site fuel combustion (including heating and hot water) were greater than the combined emissions associated with in-State and imported electricity generation. On-site fuel combustion from the industrial sector contributed approximately nine percent of the $CO_2$ fuel combustion emissions in the State.

**Figure S-2. 2014 $CO_2$ Emissions from Fuel Combustion by End Use Sector (Includes Net Imports of Electricity)**

$CO_2$ = carbon dioxide; GHG = greenhouse gas.

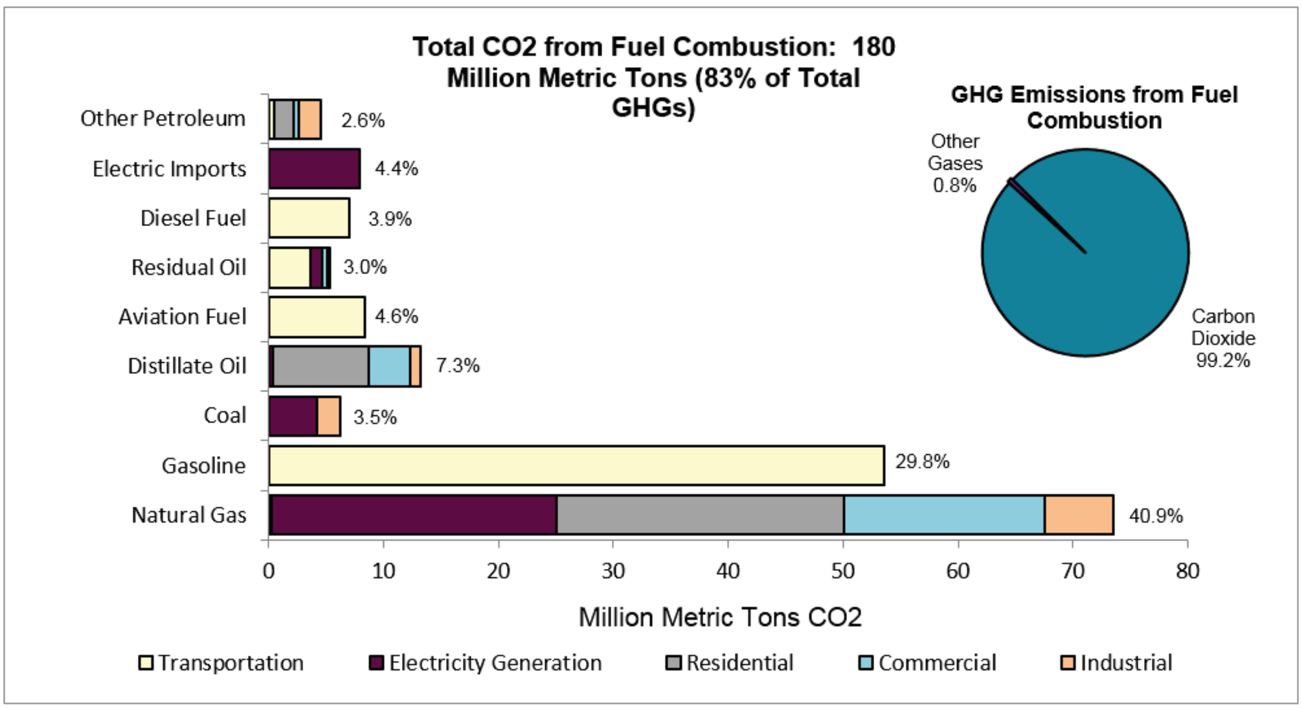


### *S.3.3.2 Emissions by Fuel*

Total $CO_2$ emissions from fuel combustion were allocated to specific fuels, and then further distributed to the economic sector (transportation, electricity generation, residential, commercial, and industrial), providing a more detailed profile. Figure S-3 shows the fuels that contribute to the 2014 New York State $CO_2$ fuel combustion emissions. In 2014, natural gas accounted for 41 percent of $CO_2$ emissions. These emissions result primarily from natural gas combustion for electricity generation and on-site residential, commercial, and industrial use. An additional 30 percent of the $CO_2$ fuel combustion emissions result from the burning of gasoline by the transportation sector. Emissions contributions also remain across fossil fuels, due primarily to the burning of coal, distillate oil, aviation fuel, residual oil, diesel, and other petroleum sources, as well as imported electricity.

**Figure S-3. 2014 $CO_2$ Emissions from Fuel Combustion by Fuel Type (Includes Net Imports of Electricity)**

$CO_2$ = carbon dioxide; GHG = greenhouse gas.

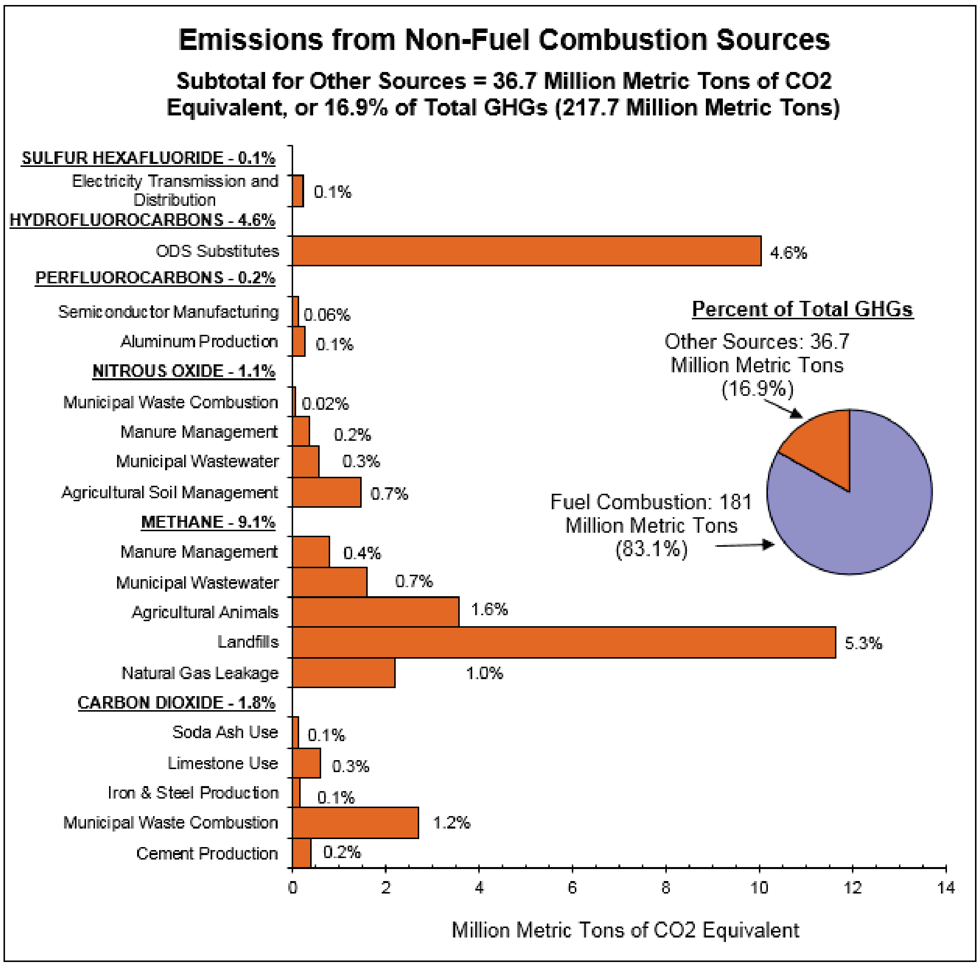


### *S.3.3.3 Non-Fuel Combustion Emissions*

Figure S-4 shows the sources of emissions from the non-fuel combustion category. In 2014, methane (which has a global warming potential 25 times greater than $CO_2$) accounted for the greatest portion of non-carbon dioxide $CO_2e$ emissions. The majority of methane emissions are the result of activities other than fuel combustion, representing 9.1 percent of total statewide $CO_2e$ emissions. The major sources of these methane emissions included landfills, natural gas system leakage, agricultural animals, and municipal wastewater facilities. Hydrofluorocarbon (HFC) emissions, resulting from use of substitutes for ozone-depleting substances (ODS), also represent a significant portion of non-fuel combustion emissions, at 4.6 percent of total statewide $CO_2e$ emissions.

**Figure S-4. 2014 Emissions from Non-Fuel Combustion Sources (Total Emissions Include Net Imports of Electricity)**

$CO_2$ = carbon dioxide; GHG = greenhouse gas; ODS = ozone-depleting substance.

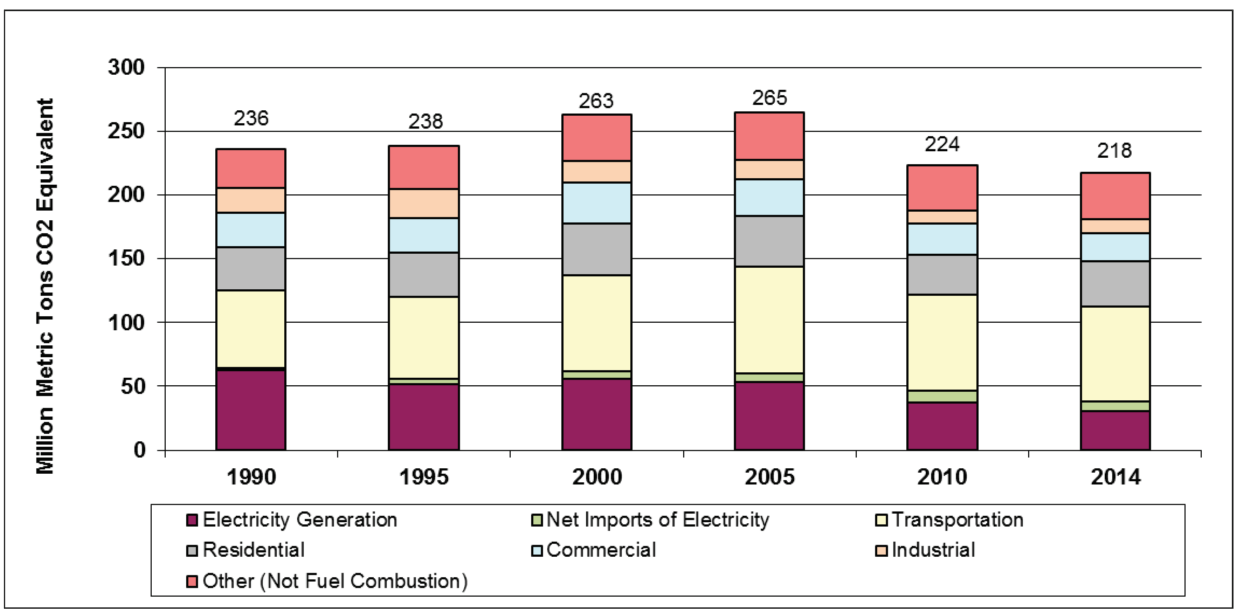


### S.3.3.4 Emission Trends

Figure S-5 below illustrates several trends in New York State GHG emissions from 1990–2014. Of all in-State energy-related sources of emissions, the transportation sector emissions showed by far the greatest growth in New York State, with emissions increasing by nearly 23 percent. This is due to an increase in the consumption of gasoline and diesel fuels, as a result of an increase in vehicle miles traveled (VMT) in the State, and an increase in the consumption of jet fuel resulting from an increase in domestic air travel. Emissions from non-fuel combustion sources also increased, growing roughly 22 percent. This is primarily due to an increase in the use of HFCs as ODS substitutes.

In contrast, emissions from electricity generated in-State dropped 52 percent during this same period, acting as a major driver of the State's decreasing GHG emissions. This drop is largely due to the significant decrease in the burning of coal and petroleum products in the electricity generation sector. Emissions from residential, commercial, and industrial buildings also decreased, showing a reduction of approximately 15 percent from 1990–2014. This reduction in emissions was primarily the result of a decrease in the use of coal and petroleum and an increase in the use of natural gas.

**Figure S-5. GHG Emissions by Source Category, 1990–2014**



### *S.3.3.5 GHG Emissions Intensity*

New York State emits approximately 11 metric tons of $CO_2e$ per capita (shown in Figure S-6), and its energy-related per capita emissions of 8.8 tons is the lowest of the 50 states. New York State also leads the nation in having the lowest GHG emissions per unit of economic output, averaging 0.17 kilograms (kg) of $CO_2e$ of emissions per dollar gross state product (GSP), while the U.S. averaged 0.46 kg of $CO_2e$ emissions per dollar gross domestic product (illustrated in Figure S-7).

**Figure S-6. New York State and U.S. GHG Emissions Per Capita, 1990–2014**

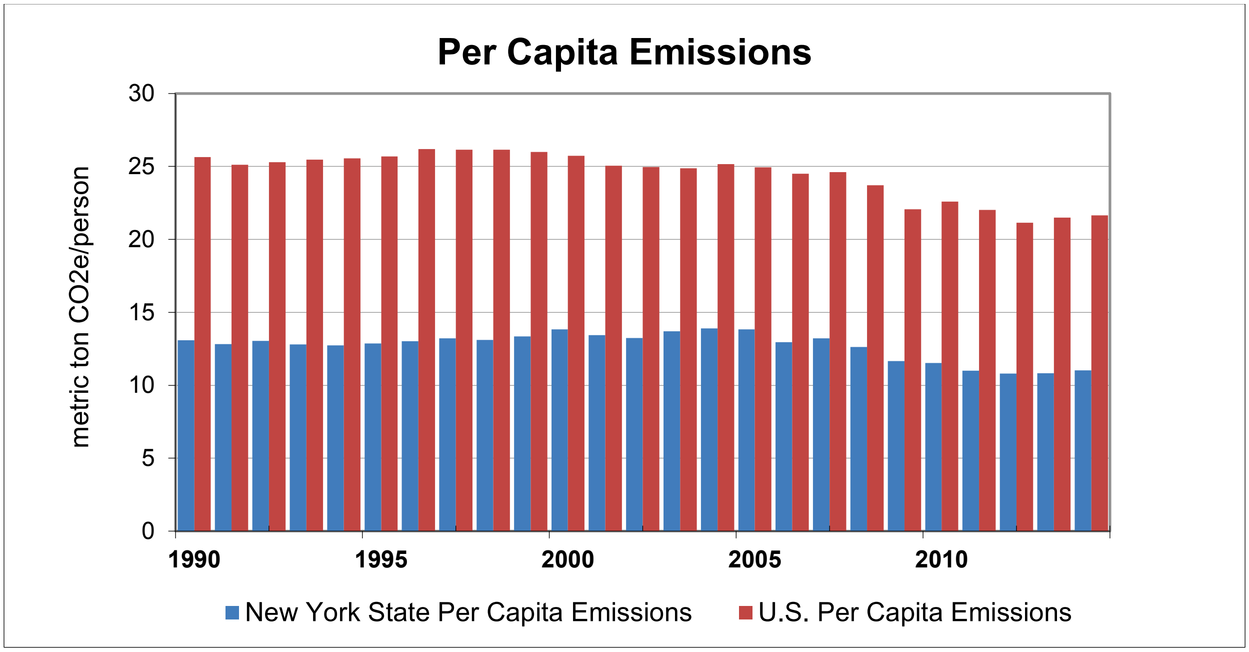
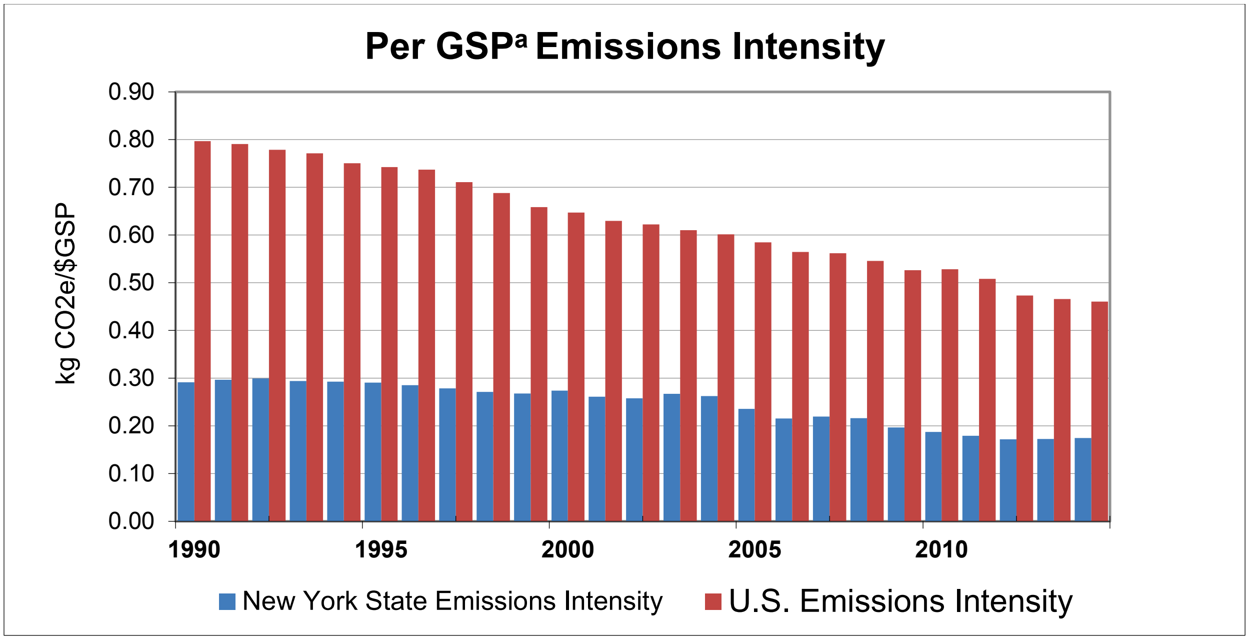


**Figure S-7. New York State and U.S. Emissions Intensity**




[a] Gross state product (GSP) is the measure of state economic output, which is the sum of all value added by businesses in a state.

## S.4 New York and U.S. Emission Comparisons

**Figure S-8. 2014 GHG Emissions by Sector: New York State and U.S.**

RCI = Residential, commercial/institutional, and industrial sector.

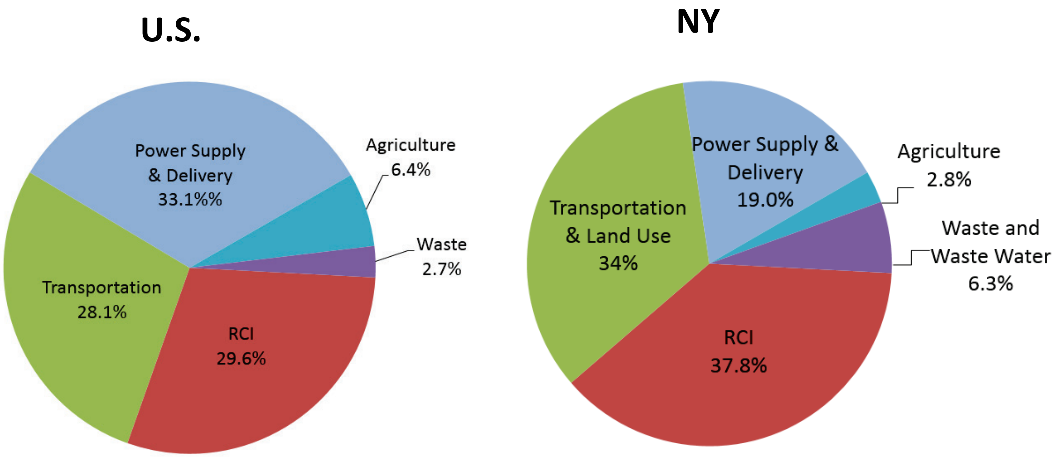


Figure S-8 shows the breakdown of emissions by major sector in New York State as compared to the United States. The principal sources of the State's GHG emissions in 2014 are the residential, commercial/institutional, and industrial sector; the transportation sector; and the power supply and delivery sector. Emissions for the residential, commercial, and industrial fuel use sectors are associated with the direct use of fuels (natural gas, petroleum, coal, and wood) to provide space heating, water heating, process heating, cooking, and other energy end-uses in the residential, commercial/institutional, and industrial sectors. This sector also accounts for GHG emissions from non-fuel sources in the industrial sector, such as $CO_2$ emissions from cement production, as well as emissions from the fossil fuel industry (e.g., natural gas leakage).

The transportation sector accounts for emissions associated with fuel consumption by all on-road and non-highway vehicles. Non-highway vehicles include jet aircraft, gasoline-fueled piston aircraft, railway locomotives, boats, and ships. The RCI sector includes emissions from non-highway agricultural and construction equipment. The power supply and delivery sector includes emissions associated with electricity generated within the State, imported electricity, emissions associated with municipal waste combustion (waste-to-energy facilities), and electricity transmission and distribution. The waste category includes emissions from landfills and wastewater. The U.S. agriculture emissions also include $CH_4$ and $N_2O$ emissions from forest fires.

The residential, commercial, and industrial sector, the transportation sector, and the power supply and delivery sector account for 38, 34, and 19 percent of the State's GHG emissions, respectively. These sectors are also the three largest emitters in the U.S., but in a different order, with the power supply and delivery sector at 33 percent, the transportation sector at 30 percent, and the RCI sector at 28 percent. In New York State, emissions from waste and agriculture combine to account for the remaining nine percent of GHG emissions in 2014, while these two sectors account for nine percent of GHG emissions in the U.S. Overall, in 2014 New York State emissions accounted for three percent of U.S. total emissions.

## S.5 A Closer Look at the Major Source of Emissions

The majority of the State's GHG emissions are associated with fuel combustion. The transportation sector accounts for the largest share of GHG emissions across the State, at 34 percent in 2014. Motor gasoline accounts for the majority of transportation GHG emissions; jet fuel contributes the second highest transportation GHG emissions; and diesel fuel ranks third among sources of transportation emissions. Residual fuel, liquefied petroleum gas, and other transportation fuels account for the remaining transportation GHG emissions in 2014. Despite transportation emissions increasing from 1990–2014, emissions were highest in 2006 and have fallen by 13 percent from 2006 through 2014. The main drivers of both the 2006 peak and subsequent decline are consumption of motor gasoline, diesel fuel, and jet fuel.

Activities in the RCI[5] fuel combustion sector produce GHG emissions when fuels are combusted to provide space heating, process heating, and other applications. Fuel combustion within the RCI sector accounts for 31 percent of the State's GHG emissions in 2014, with a decrease in total emissions from 1990–2014. In 2014, the residential sector's contribution toward the total RCI emissions from direct fuel use was 52 percent, while the commercial/institutional sector accounted for 32 percent and the industrial sector accounted for 16 percent.

In 2014, emissions from fuel combustion associated with the State's electricity consumption are eight $MMtCO_2e$ higher than those associated with in-State electricity production. The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity.[6] Electricity generation is dominated by natural gas and nuclear-powered units, with coal, oil, and hydro also important sources of historical generation in the State.

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5 The industrial sector includes emissions associated with agricultural energy use and fuel used by the fossil fuel production industry.

6 Estimating the emissions associated with electricity use requires an understanding of the electricity sources (both in-State and out-of-State) used by utilities to meet consumer demand. For further details, see Chapter 4.

# 1 Residential, Commercial/Institutional, and Industrial Fuel Combustion

## 1.1 Overview

Activities in the Residential, Commercial/Institutional, and Industrial (RCI)[7] sectors produce carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. Carbon dioxide accounts for 99 percent of these emissions on a million metric tons (MMt) of $CO_2$ equivalent ($CO_2e$) basis in New York. In addition, since these sectors consume electricity, one can also attribute emissions associated with electricity generation to these sectors in proportion to their electricity use.[8]

## 1.2 Emissions Inventory Data and Methodology

Historical emissions estimations from direct fuel use were estimated using the EPA State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for RCI fuel combustion.[9] The default historical fuel consumption data in SIT for New York, which came from the United States Department of Energy (DOE) Energy Information Administration's (EIA) *State Energy Data System* (SEDS), were updated with fuel consumption data for the Residential, Commercial/Institutional, and Industrial sectors from NYSERDA's *Patterns and Trends* report.[10]

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7 The industrial sector includes emissions associated with agricultural energy use and fuel used by natural gas transmission and distribution (T&D) and oil and gas production industries.

8 Emissions associated with the electricity supply sector (presented in Chapter 4) have been allocated to each of the RCI sectors for comparison of those emissions to the fuel-consumption-based emissions presented in Chapter 1. Note that this comparison is provided for informational purposes and that emissions estimated for the electricity supply sector are not double-counted in the total emissions for the state. One could similarly allocate GHG emissions from natural gas T&D, other fuels production, and transport-related GHG sources to the RCI sectors based on their direct use of gas and other fuels, but we have not done so here due to the difficulty of ascribing these emissions to particular end-users. Estimates of emissions associated with the transportation sector are provided in Chapter 3, and estimates of emissions associated with natural gas T&D are provided in Chapter 2.

9 GHG emissions were calculated using the EPA's State Inventory Tool (SIT), with reference to:

Emission Inventory Improvement Program (EIIP). 2006. "Chapter 1: Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels." and "Chapter 2: Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion." Volume VIII.

10 NYSERDA. 2016. "Patterns and Trends, New York State Energy Profiles: 2000-2014," (https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Patterns-and-Trends)

Note that the EIIP methods for the Industrial sector exclude the amount of stored carbon in products produced from fuels for non-energy uses from $CO_2$ emissions estimates. For example, the methods account for carbon stored in petrochemical feedstocks and in liquefied petroleum gases (LPG) and natural gas used as feedstocks by chemical manufacturing plants (i.e., not used as fuel), as well as carbon stored in asphalt and road oil produced from petroleum. The EIIP guidance document[11] explains the carbon storage assumptions for these products in detail. The primary tool to determine RCI combustion emissions is the Carbon Dioxide from Fossil Fuel State Inventory Tool Module ($CO_2$FFC SIT Module). In this module, fuel types are given carbon content values, combustion efficiencies,[12] and storage percentages. Table 1-1 shows fuel types for which the EIIP methods are applied in the SIT software to account for the Industrial Sector.

**Table 1-1. 2014 Fuel Types for the Industrial Sector**

| Fuel Type |
|---|
| Coking Coal |
| Other Coal |
| Asphalt & Road Oil |
| Distillate Fuel |
| Feedstocks, Naphtha less than 401°F |
| Feedstocks, Other Oils greater than 401°F |
| Kerosene |
| Liquefied Petroleum Gas |
| Lubricants |
| Miscellaneous Petroleum Products |
| Petroleum Coke |
| Pentanes Plus |
| Residual Fuel |
| Special Naphthas |
| Waxes |
| Natural Gas |

[11] Emissions Inventory Improvement Program. 2006. “Chapter 1: Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels.” Volume VIII.

[12] Combustion efficiency is defined as fuel specific percentage of carbon oxidized during combustion.

In addition to the fuel consumed directly by each of the RCI sectors, the proportion of each RCI sector's electricity sales to total electricity sales was used to allocate emissions associated with the electricity supply sector to each of the RCI sectors. Electricity sales associated with the RCI sectors were estimated based on information from the *Patterns and Trends* report[13]

## 1.3 Results

### 1.3.1 Residential Sector

The emissions inventory for the Residential sector presented in Figure 1-1 was developed from the emissions data in Table 1-2. Table 1-3 shows the relative contributions of emissions associated with each fuel type to total Residential sector emissions. For the Residential sector, emissions from direct fuel use (including heating and hot water) and electricity consumption decrease by 11 percent, from approximately 54 $MMtCO_2e$ in 1990 to 48 $MMtCO_2e$ in 2014. Emissions associated with natural gas consumption were the greatest source of emissions in 2014, accounting for approximately 52 percent. Emissions associated with electricity use were the second largest source, with 27 percent of the total in this sector. Petroleum use accounted for the next largest portion of Residential sector emissions at 21 percent of emissions. Coal and wood emissions account for one percent or less of Residential sector emissions throughout the analysis period. The Residential sector's share of total RCI emissions from direct fuel use and electricity increased from 37 percent in 1990 to 46 percent in 2014.

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13 NYSERDA. 2016. "Patterns and Trends, New York State Energy Profiles: 2000-2014," (https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Patterns-and-Trends)

**Figure 1-1. Residential Sector GHG Emissions from Fuel Combustion and Electricity, 1990–2014**

The Other category includes emissions associated with coal and wood combustion. Wood is considered a biomass fuel, and carbon dioxide emissions from biomass fuels grown sustainably are not counted (i.e., the $CO_2$ emissions are zero), as per EPA guidance. Consequently, the GHG emissions associated with this category include methane and nitrous oxide. In general, GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

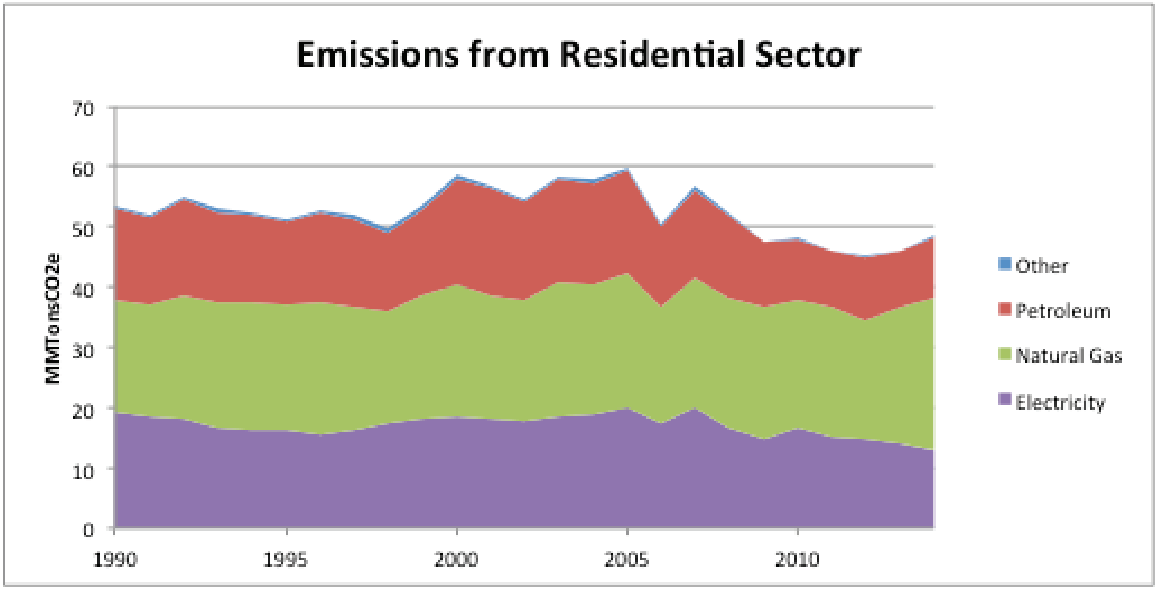



**Table 1-2. Residential Sector Emissions Inventory, 1990–2014 ($MMtCO_2e$)**

The Other category includes emissions associated with coal and wood combustion. Wood is considered a biomass fuel, and carbon dioxide emissions from biomass fuels grown sustainably are not counted (i.e., the $CO_2$ emissions are zero), as per EPA guidance. Consequently, the GHG emissions associated with this category include methane and nitrous oxide. In general, GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

| Fuel Type | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Other | 0.5 | 0.5 | 0.7 | 0.4 | 0.1 | 0.2 |
| Petroleum | 15.3 | 13.9 | 17.6 | 17.2 | 10.3 | 10.2 |
| Natural Gas | 18.5 | 20.6 | 22.0 | 22.2 | 21.2 | 25.1 |
| Electricity | 19.3 | 16.4 | 18.6 | 20.2 | 16.5 | 13.0 |
| **Total** | **53.5** | **51.4** | **58.8** | **60.0** | **48.2** | **48.5** |

**Table 1-3. Residential Sector Proportions of Total Emissions by Fuel Type, 1990–2014 (%)**

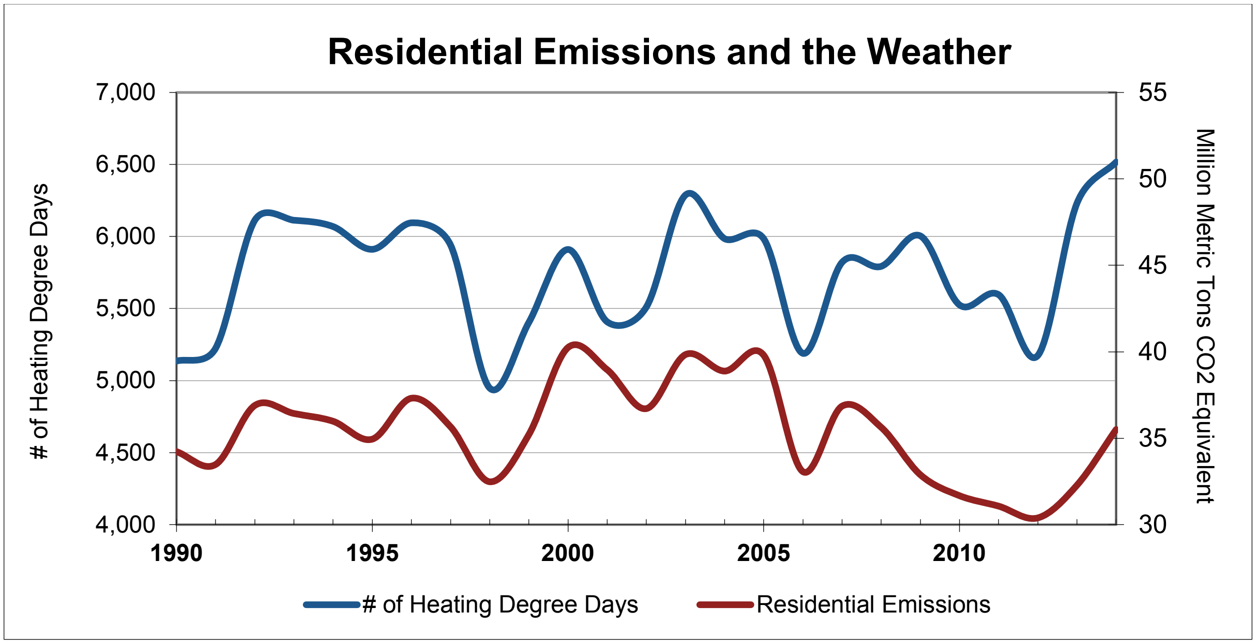
The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table 1-2

| Fuel Type | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Other | 0.9% | 1.0% | 1.2% | 0.7% | 0.3% | 0.4% |
| Petroleum | 28.6% | 27.0% | 29.9% | 28.7% | 21.4% | 21.0% |
| Natural Gas | 34.6% | 40.0% | 37.3% | 37.0% | 44.1% | 51.8% |
| Electricity | 36.0% | 32.0% | 31.6% | 33.6% | 34.3% | 26.8% |

The trend in GHG emissions from fuel combustion for the Residential sector, excluding emissions associated with electricity use, correlates with the trend in the number of heating degree days for each year from 1990–2014, as demonstrated in the comparison in Figure 1-2.[14] The two sets of data show a correlation coefficient of 0.60. Although the magnitude of the effect of heating degree days on emissions varies over time, the important point to note is that the peaks and valleys of both sets of data occur in the same years. In years with a greater number of heating degree days, the emissions are also generally higher, and in years with a low number of heating degree days, such as 1998 and 2006, GHG emissions from Residential sector were also lower.

14 Heating degree days provide a measurement of how cold a location is relative to a base temperature, which is typically 65° F, over a period of time. The measure is calculated by subtracting the average of a day's high and low temperatures from the base temperature, with negative values set to equal zero.

**Figure 1-2. Residential Sector Heating Demand and GHG Emissions, 1990–2014**




## 1.3.2 Commercial/Institutional Sector

The emissions inventory for the Commercial/Institutional sector presented in Figure 1-3 was developed from the emissions data in Table 1-4. Table 1-5 shows the relative contributions of emissions associated with each fuel type to total Commercial/Institutional sector emissions.

For the Commercial/Institutional sector, emissions from direct fuel use (including heating and hot water) and electricity decreased from approximately 54 $MMtCO_2e$ in 1990 to 42 $MMtCO_2e$ in 2014. Electricity use was the largest source of all Commercial/Institutional sector emissions at 51 percent in 1990, decreasing slightly to 48 percent by 2014. Petroleum emissions accounted for 28 percent of Commercial/Institutional sector emissions in 1990, declining to 11 percent in 2014. In 1990, natural gas consumption accounted for approximately 20 percent of total commercial/institutional emissions and increased to 42 percent by 2014. Commercial/Institutional sector emissions associated with the use of coal accounted for approximately one percent of total commercial/institutional emissions in 1990 and less than one percent of total commercial/institutional emissions in 2014. The Commercial/Institutional sector's share of total RCI emissions from direct fuel use and electricity use was 38 percent in 1990 and 39 percent in 2014.

**Figure 1-3. Commercial/Institutional Sector GHG Emissions from Fuel Combustion and Electricity, 1990–2014**

The Other category includes emissions associated with coal and wood combustion. Wood is considered a biomass fuel, and carbon dioxide emissions from biomass fuels grown sustainably are not counted (i.e., the $CO_2$ emissions are zero), as per EPA guidance. Consequently, the GHG emissions associated with this category include methane and nitrous oxide. In general, GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

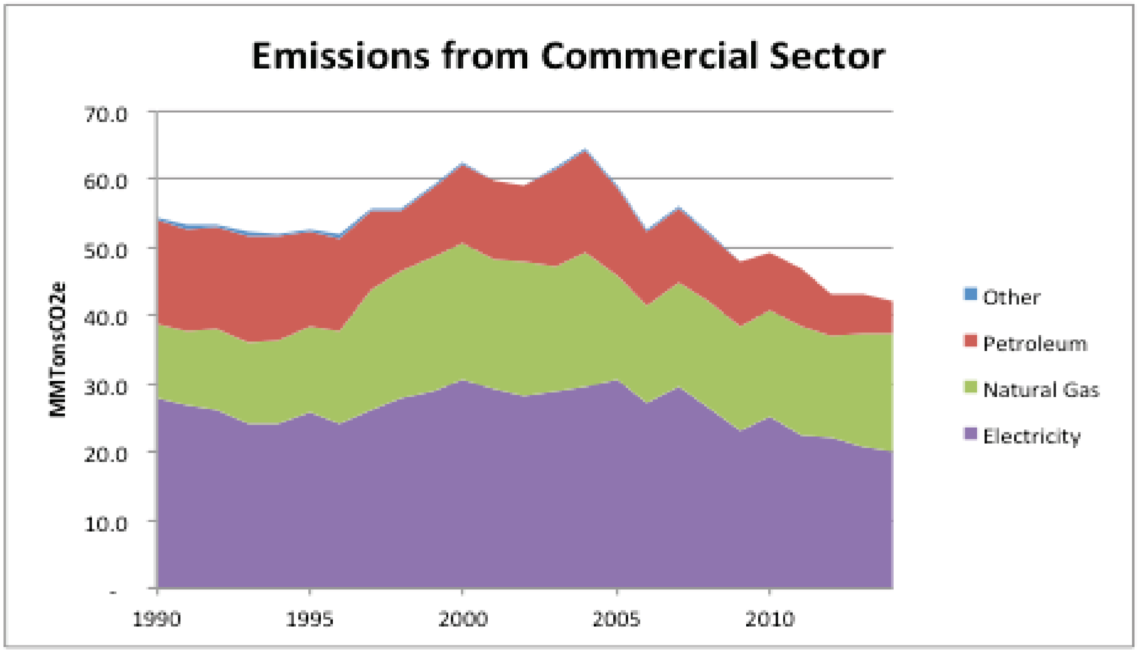



**Table 1-4. Commercial/Institutional Sector Emissions Inventory, 1990–2014 ($MMtCO_2e$)**

The Other category includes emissions associated with coal and wood combustion. Wood is considered a biomass fuel, and carbon dioxide emissions from biomass fuels grown sustainably are not counted (i.e., the $CO_2$ emissions are zero), as per EPA guidance. Consequently, the GHG emissions associated with this category include methane and nitrous oxide. In general, GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

| Fuel Type | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Other | 0.5 | 0.5 | 0.2 | 0.4 | 0.0 | 0.0 |
| Petroleum | 15.2 | 13.8 | 11.8 | 13.1 | 8.5 | 4.4 |
| Natural Gas | 10.6 | 12.7 | 20.0 | 15.0 | 15.6 | 17.5 |
| Electricity | 28.0 | 25.8 | 30.4 | 30.6 | 25.0 | 20.0 |
| **Total** | **54.4** | **52.7** | **62.5** | **59.1** | **49.1** | **41.9** |

**Table 1-5. Commercial/Institutional Sector Proportions of Total Emissions by Fuel Type (%)**

The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table 1-4.

| Fuel Type | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Other | 1.0% | 0.9% | 0.4% | 0.6% | 0.0% | 0.0% |
| Petroleum | 28.0% | 26.1% | 18.8% | 22.2% | 17.3% | 10.6% |
| Natural Gas | 19.6% | 24.0% | 32.1% | 25.4% | 31.7% | 41.8% |
| Electricity | 51.4% | 48.9% | 48.7% | 51.8% | 51.0% | 47.6% |

### 1.3.3 Industrial Sector

The emissions inventory for the Industrial sector presented in Figure 1-4 was developed from the emissions data in Table 1-6. Table 1-7 shows the relative contributions of emissions associated with each fuel type to total Industrial sector emissions.

For the Industrial sector, emissions from direct fuel use and electricity in 1990 were approximately 36 $MMtCO_2e$, but decreased to approximately 16 $MMtCO_2$ in 2014. In 1990, the emissions associated with electricity use accounted for the largest share of industrial emissions, at 44 percent of the Industrial sector's total. However, this contribution declines to 30 percent in 2014. In contrast, emissions from petroleum fuels accounted for 18 percent of the Industrial sector emissions in 1990, but account for 20 percent of industrial emissions in 2014. The share of emissions from natural gas consumption increased from 16 percent of industrial fuel use emissions in 1990 to 38 percent of these emissions in 2014. Coal consumption accounted for approximately 22 percent of total industrial emissions in 1990 and decreased to approximately 13 percent of total industrial emissions in 2014. The Industrial sector's share of total RCI emissions from direct fuel use and electricity use was 25 percent in 1990 and decreased to 15 percent in 2014.

**Figure 1-4. Industrial Sector GHG Emissions from Fuel Combustion and Electricity, 1990–2014**

Emissions associated with wood combustion are too small to be seen on this graph. Wood is considered a biomass fuel, and carbon dioxide emissions from biomass fuels grown sustainably are not counted (i.e., the $CO_2$ emissions are zero), as per EPA guidance. Therefore, the $CO_2$ emissions are zero. Consequently, the GHG emissions associated with this category include methane and nitrous oxide. In general, GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

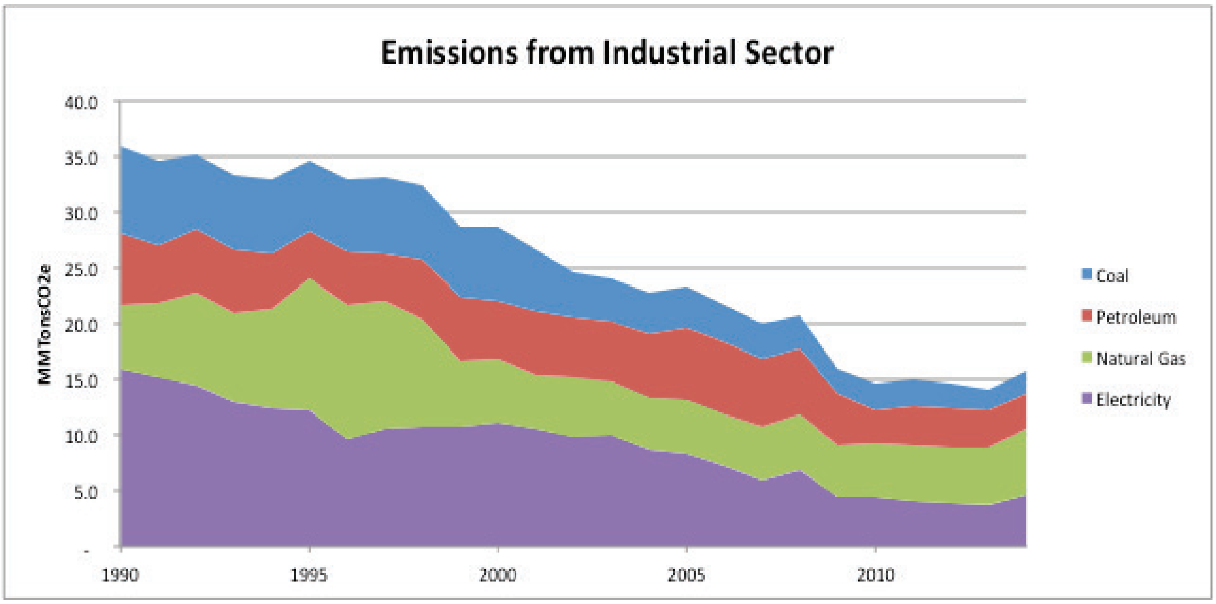



**Table 1-6. Industrial Sector Emissions Inventory, 1990–2014 ($MMtCO_2e$)**

The Other category includes emissions associated wood combustion. Wood is considered a biomass fuel, and carbon dioxide emissions from biomass fuels grown sustainably are not counted. Therefore, the $CO_2$ emissions are zero, as per EPA guidance. Consequently, the GHG emissions associated with this category include methane and nitrous oxide. In general, GHG emissions include all six standard GHGs, expressed in $MMtCO_2e$.

| Fuel Type | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Coal | 7.7 | 6.3 | 6.5 | 3.7 | 2.3 | 2.0 |
| Petroleum | 6.5 | 4.2 | 5.3 | 6.4 | 3.1 | 3.1 |
| Natural Gas | 5.7 | 11.9 | 5.6 | 4.9 | 4.8 | 5.9 |
| Electricity | 16.0 | 12.1 | 11.2 | 8.2 | 4.3 | 4.7 |
| **Total** | **35.9** | **34.6** | **28.6** | **23.2** | **14.6** | **15.7** |

**Table 1-7. Industrial Sector Proportions of Total Emissions by Fuel Type (%)**

The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table 1-5.

| Fuel Type | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Coal | 21.6% | 18.3% | 22.8% | 15.7% | 16.0% | 12.7% |
| Petroleum | 18.0% | 12.1% | 18.5% | 27.6% | 21.0% | 20.0% |
| Natural Gas | 15.9% | 34.4% | 19.5% | 21.1% | 33.1% | 37.5% |
| Electricity | 44.4% | 35.1% | 39.0% | 35.5% | 29.8% | 29.8% |

# 2 Industrial Non-Fuel Combustion Processes

## 2.1 Overview

Emissions from industrial non-fuel combustion sources span a wide range of industrial processes and energy supply activities. The following sections describe those processes and activities that exist in the State and their estimated emissions in this inventory.

### 2.1.1 Sources of Carbon Dioxide ($CO_2$) Emissions

*Cement production:* Greenhouse gas (GHG) emissions related to cement production can come from both clinker and cement kiln dust. Clinker is an intermediate product used to make finished Portland and masonry cement. Clinker production releases $CO_2$ when calcium carbonate is heated in a cement kiln to form lime (calcium oxide) and $CO_2$.[15] About 0.02 metric tons (Mt) of $CO_2$ is emitted for every Mt of cement kiln dust produced, relative to the $CO_2$ emitted during the production of an Mt of clinker.[16]

*Iron and steel production*: The production of iron and steel generates process-related $CO_2$ emissions. The process of reducing iron ore with metallurgical coke in a blast furnace to create pig iron, which is then used as a raw material in the production of steel, emits $CO_2$. The production of metallurgical coke from coking coal produces $CO_2$ emissions as well.

*Limestone and dolomite use:* Limestone and dolomite are basic raw materials used by a wide variety of industries, including the construction, agriculture, chemical, glass manufacturing, and environmental pollution control industries as well as metallurgical industries such as magnesium production. The industrial processes sector also includes the emissions associated with the use of limestone and dolomite to manufacture steel and glass, and their use in flue-gas desulfurization scrubbers to control sulfur dioxide emissions from the combustion of coal in boilers.[17]

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[15] For further detail, see EIIP. 2006. "Chapter 6: Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes." Volume VIII.

[16] EIIP. 2006. "Chapter 6: Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes." Volume VIII.

[17] In accordance with EIIP Chapter 6 methods, emissions associated with the following uses of limestone and dolomite are not included in this category: (1) crushed limestone consumed for road construction or similar uses (because these uses do not result in $CO_2$ emissions), (2) limestone used for agricultural purposes (which is counted under the methods for the agricultural sector), and (3) limestone used in cement production (which is counted in the methods for cement production).

*Soda ash use*: Commercial soda ash (sodium carbonate) is found in many consumer products such as glass, soap and detergents, paper, textiles, and food. Consuming soda ash releases carbon dioxide.[18]

Other industrial processes that produce $CO_2$ emissions, but are not found in New York State or for which reliable or complete data are lacking, are taconite and lime production and ammonia production. In addition, $CO_2$ emissions can also result from urea consumption. While the SIT provides default data for urea consumption in the State, the estimated amount of emissions from this source is small and is excluded from the inventory.[19]

### 2.1.2 Sources of Methane ($CH_4$) Emissions

*Natural gas leakage*: Methane emissions are associated with the transmission, storage, and distribution of natural gas in the State.[20] Transmission pipelines are large diameter, high-pressure lines that transport gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to local distribution companies or to large volume customers. Sources of $CH_4$ emissions from transmission pipelines include leaks, compressor fugitives, vents, and pneumatic devices. Distribution pipelines are extensive networks of generally small diameter, low-pressure pipelines that distribute gas within cities or towns. Sources of $CH_4$ emissions from distribution pipelines include leaks, meters, and regulators.

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[18] For further detail, see EIIP. 2006. “Chapter 6 Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes.” Volume VIII.

[19] The default SIT data indicate that $CO_2$ emissions from urea consumption amounted to <0.005 $MMtCO_2e$ annually between 1990 and 2014.

[20] Note that $CH_4$, $N_2O$, and $CO_2$ emissions from natural gas consumed as lease fuel (used in well, field, and lease operations), plant fuel (used in natural gas processing plants), and pipeline fuel (used in pipeline compressor station internal combustion engines) are included in Chapter 1 in the industrial fuel combustion category.

New York State imports the vast majority of its natural gas via pipeline from other states and Canada. The Transcontinental and Tennessee Gas Transmission pipelines from the Gulf Coast and the Iroquois pipeline from Canada link up with local gas distribution networks that supply the New York City metropolitan area and Long Island. Other parts of the State receive gas from Pennsylvania and Canada via other gas transmission systems.

### 2.1.3 Sources of Perfluorocarbon (PFC) Emissions

*Aluminum production*: Emissions of tetrafluoromethane and hexafluoroethane, both PFCs, occur during the reduction of alumina in the primary smelting process. Based on EPA's SIT methodology, the aluminum production industry is the largest source of these two PFCs.

*Semiconductor manufacturing*:[21] Manufacturers of semiconductors use fluorinated GHGs in the plasma etching and plasma enhanced chemical vapor deposition processes. Plasma etching of dielectric films creates the pattern of pathways connecting individual circuit components in semiconductors. Vapor deposition chambers used for depositing the dielectric films are periodically cleaned using fluorinated gases. Converting fluorinated gases to fluorine atoms in plasma etches away dielectric material or cleans the chamber walls and hardware. Un-dissociated fluorinated gases and other products end up in the waste streams and, unless captured by abatement systems, into the atmosphere. Some fluorinated compounds can transform into other compounds (e.g., $CF_4$ generated from $C_2F_6$) during the plasma processes. If these other compounds are not captured by emission control systems, the process-generated gases are also releaseed into the atmosphere.[22]

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21 Emissions from semiconductor manufacturing were estimated using the EPA's State Greenhouse Gas Inventory Tool (SIT) software, with reference to EIIP. 2006. "Chapter 6 Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes." Volume VIII. Though SIT provides an aggregate emissions value for PFCs, hydrofluorocarbons, and sulfur hexafluoride, it is assumed PFCs constitute the majority of the emissions.

22 California Environmental Protection Agency, Air Resources Board. 2009. California's 1990–2004 Greenhouse Gas Emissions Inventory and 1990 Emissions Level: Technical Support Document.

### 2.1.4 Sources of Hydrofluorocarbon (HFC) Emissions

*Ozone-depleting substances (ODS) substitutes*: HFC emissions result from the consumption of substitutes for ozone-depleting substances used in cooling and refrigeration equipment.[23] The most notable HFC substitution is for CFCs, which are also potent warming gases that have global warming potentials on the order of thousands of times that of $CO_2$ per unit of mass. This substitution is in compliance with the Montreal Protocol and the Clean Air Act. Amendments of 1990.[24] In October of 2016, the Montreal Protocol was amended to limit HFC usage. Even low amounts of HFC emissions (e.g., from leaks and other releases associated with normal use of the products) can lead to high GHG emissions on a $CO_2e$ basis. HCFC-22 production is another industrial process that can result in HFC emissions. However, specific data for New York State in this source category are lacking.

### 2.1.5 Other Sources of Non-Fuel Combustion Emissions

*Nitrous Oxide Emissions*: Nitric acid production is an industrial process that can result in nitrous oxide emissions. However, specific data for New York State in this source category are lacking.

*Sulfur Hexafluoride Emissions*: Magnesium production and processing are industrial processes that can result in sulfur hexafluoride emissions. However, specific data for New York State in this source category are lacking.

## 2.2 Emissions Inventory Data and Methodology

GHG emissions for 1990 through 2014 were estimated using the following methods. For most sources, emissions were estimated using the SIT tool and the methods provided in the EIIP guidance document for industrial processes.[25]

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23 Environmental Protection Agency. 2016. Draft User's Guide for Estimating Carbon Dioxide, Nitrous Oxide, HFC, PFC, and SF6 Emissions from Industrial Processes Using the State Industrial Tool. Substitutes for ozone-depleting substances, which include chlorofluorocarbons, halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons, are used in a variety of industrial applications including refrigeration and air conditioning equipment, aerosols, solvent cleaning, fire extinguishing, foam blowing, and sterilization. Although their substitutes, HFCs, are not harmful to the stratospheric ozone layer, they are powerful GHGs.

24 As noted in EIIP Chapter 6, ODS substitutes are primarily associated with refrigeration and air conditioning, but also many other uses including as fire control agents, cleaning solvents, aerosols, foam blowing agents, and in sterilization applications. The applications, stocks, and emissions of ODS substitutes depend on technology characteristics in a range of equipment types. For the U.S. national inventory, a detailed stock vintaging model was used to track ODS substitutes uses and emissions, but this modeling approach has not been completed at the state level.

25 GHG emissions were calculated using SIT, with reference to EIIP. 2006. "Chapter 6: Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes." Volume VIII.

### 2.2.1 Sources of $CO_2$ Emissions

*Cement production:* Emissions from cement production are calculated using the SIT methodology by multiplying annual metric tons of clinker production by emission factors to estimate emissions associated with the clinker production process (0.507 Mt of $CO_2$ emitted per Mt of clinker produced) and cement kiln dust (0.020 $MtCO_2$ emitted per Mt of clinker $CO_2$ emitted). Data on the Mt of clinker produced in the State were derived from the cement statistics in United States Geological Survey's (USGS) Minerals Yearbook.[26] This information is available within the SIT module.

*Iron and steel production:* New York State's emissions from iron and steel production were pro-rated from the EPA's estimates of total U.S. emissions[27] based on the State's market share of national iron and steel manufacturing derived from American Iron and Steel (AISI) data.[28] The basic activity data used are the quantities of crude steel produced (defined as first cast product suitable for sale or further processing). This information is available within the SIT module as default. For inventory years 2011–2014, an annual average of data from production facilities reported to EPA through its *Facility Level Information on GreenHouse gases* Tool (FLIGHT) was used.

*Limestone use:* Historical State emissions were pro-rated from the EPA's estimates of total U.S. emissions from limestone and dolomite consumption[29] based on the quantity of crushed stone sold in the State derived from USGS data.[30] This information is available within the SIT module as default.

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26 U.S. Geological Survey. 2016. "Minerals Yearbook: Cement Statistics and Information" Last modified 15 November 2016. http://minerals.usgs.gov/minerals/pubs/commodity/cement/index.html#myb. The metric tons of cement clinker produced in New York State are assumed to be half of the total production value for Maine and New York.

27 Environmental Protection Agency. 2016. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014." https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990–2014.

28 NY's Market Share of U.S. Iron & Steel Manufacture was prorated from national data provided by the American Iron and Steel (AISI) Annual Statistics Report 2009 (AISI 2011) within the SIT Module.

29 Environmental Protection Agency. 2016. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014." https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990–2014.

30 U.S. Geological Survey. 2016 "Minerals Yearbook Crushed Stone Statistics and Information." Last modified 17 August 2016. http://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/.

*Soda ash use:* Emissions from soda ash use are calculated within the SIT module by scaling national soda ash consumption (estimated using sales data) based on the ratio of state to national population.[31] Data on the metric tons of soda ash consumed in the U.S. were derived from the soda ash statistics in the USGS Minerals Yearbook.[32] This information is available within the SIT module as default.

### 2.2.2 Sources of $CH_4$ Emissions

*Natural gas leakage*: The EPA published estimates[33] of national $CO_2$e emissions for natural gas systems for 1990 through 2014.[34] These estimates are reported for four processes:

- Production.
- Processing.
- Transmission and storage.
- Distribution.

Natural gas leakage in the State was analyzed for the last two processes, given the limited occurrence of production and processing in New York State. Emissions from natural gas transmission, storage, and distribution were estimated by scaling the U.S. GHG emissions from these processes based on the ratio of the State's natural gas consumption to national natural gas consumption. The State's natural gas consumption estimates for 2014 were obtained from NYSERDA's *Patterns and Trends* report[35] and national consumption estimates were compiled from Energy Information Administration (EIA) State Energy Data System (SEDS) data.[36] The science underlying methane emissions calculation is advancing quickly, and methods of estimating emissions may require reevaluation and refinement going forward in accordance with evolving standards and best practices.

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31 U.S. Census Bureau. 2010. http://www.census.gov/2010census/

32 U.F S. Geological Survey. 2016. "Minerals Yearbook: Soda Ash Statistics and Information." Last modified 15 November 2016. http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/.

33 A recent study found that measured emissions of methane from natural gas systems are approximately 1.5 times greater than those published in the U.S. Environmental Protection Agency national GHG inventory. A commensurate scaling of this analysis would increase the emissions from natural gas leakage to 3.3 MMTons$CO_2$e or 1% of total emissions. See Brandt, et al. 2014. "Methane Leaks from North American Natural Gas Systems." *Science* 343, February.

34 Environmental Protection Agency. 2016. "Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2014." (https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990–2014)

35 NYSERDA. 2016. "Patterns and Trends, New York State Energy Profiles: 1999–2014." https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Patterns-and-Trends.

36 U.S. Energy Information Administration. 2016. "State Energy Data System 1960–2014." http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=US.

### 2.2.3 Sources of PFC Emissions

*Aluminum production:* Emissions from aluminum production are calculated using the SIT Industrial Processes module methodology based on the annual quantity of aluminum production. Data on the metric tons of aluminum produced in New York were derived from the aluminum statistics in the USGS Minerals Yearbook.[37]

*Semiconductor manufacturing:* Historical emissions associated with semiconductor manufacturing were estimated using the SIT calculation methodology. The SIT calculates these emissions based on Economic Census data indicating the State's portion of the national dollar value of semiconductor shipments along with estimates of national emissions per shipment dollar from the EPA national GHG inventory.

### 2.2.4 Sources of HFC Emissions

*ODS substitutes*: Historical emissions from ODS substitutes are calculated within the SIT by scaling national emissions from the EPA's GHG inventory[38] based on the ratio of state to national population.[39]

## 2.3 Results

Figure 2-1 shows emissions from industrial non-fuel combustion processes from 1990–2014, which are based on the historical emission values in Table 2-1. Total State GHG emissions for these sources totaled approximately 8.2 MMt$CO_2$e in 1990 and grew to 14.1 MMt$CO_2$e in 2014. Emissions growth is primarily associated with the increasing use of ozone-depleting substances (ODS) substitutes, as shown in Figure 2-1.

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37 U.S. Geological Survey. 2016. "Minerals Yearbook, Aluminum Statistics and Information." Last modified 25 October 2016. http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/.

38 Environmental Protection Agency. 2016. "Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-–2014." https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990–2014.

39 U.S. Census Bureau. 2010. http://www.census.gov/2010census/

**Figure 2-1. GHG Emissions from Industrial Non-Fuel Combustion Processes by Source, 1990–2014**

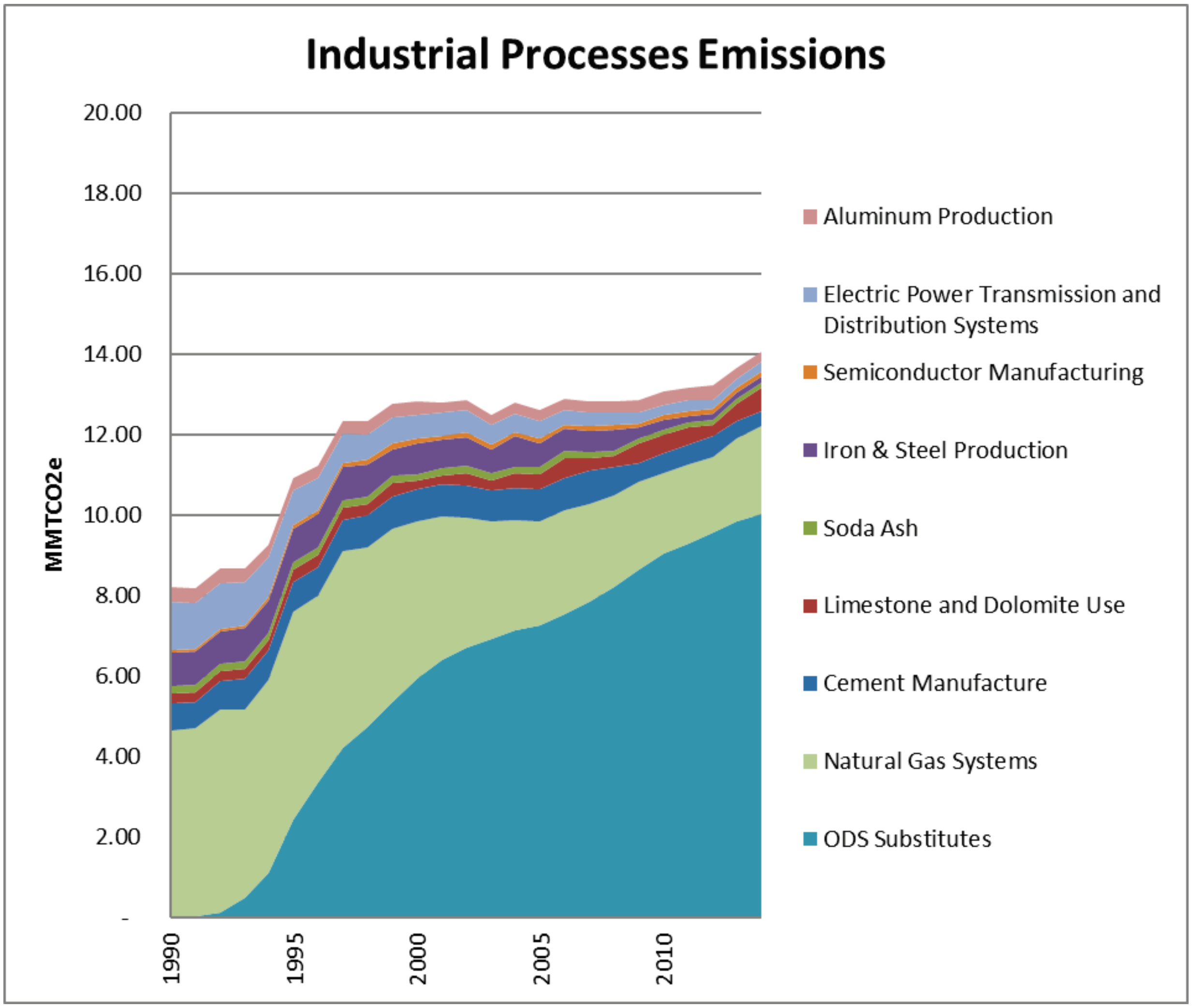

**Table 2-1. Emissions Inventory for Industrial Non-Fuel Combustion Processes, 1990–2014 ($MMtCO_2e$)**

| Industrial Process | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| ***$CO_2$ Emissions*** | | | | | | |
| Cement Manufacture | 0.7 | 0.8 | 0.8 | 0.8 | 0.5 | 0.4 |
| Iron & Steel Production | 0.8 | 0.8 | 0.8 | 0.6 | 0.2 | 0.1 |
| Limestone & Dolomite Use | 0.2 | 0.3 | 0.2 | 0.4 | 0.4 | 0.6 |
| Soda Ash | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 |
| ***CH4 Emissions*** | | | | | | |
| Natural Gas Systems | 4.6 | 5.2 | 3.9 | 2.6 | 2.0 | 2.2 |
| ***PFC Emissions*** | | | | | | |
| Aluminum Production | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 |
| Semiconductor Manufacturing | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| ***HFC Emissions*** | | | | | | |
| ODS Substitutes | 0.0 | 2.4 | 6.0 | 7.3 | 9.1 | 10.0 |
| Electric Power Transmission and Distribution Systems | 1.2 | 0.9 | 0.6 | 0.4 | 0.3 | 0.2 |
| **TOTAL** | **8.2** | **11.0** | **12.8** | **12.6** | **13.1** | **14.1** |

## 2.3.1 Sources of $CO_2$ Emissions

*Cement manufacturing*: Emissions estimates from this source were approximately 0.7 $MMtCO_2e$ in 1990, decreasing slightly to 0.4 $MMtCO_2e$ in 2014, as shown in Figure 2-1 and Table 2-1.

*Iron and steel production:* Emissions in 1990 were 0.8 $MMtCO_2e$ and decreased to about 0.1 $MMtCO_2e$ in 2014, as shown in Figure 2-1 and Table 2-1.

*Limestone and Dolomite use:* Emissions from limestone consumption were approximately 0.2 $MMtCO_2e$ in 1990 and 0.6 $MMtCO_2e$ in 2014.

*Soda ash use:* Emissions estimates from soda ash consumption were approximately 0.2 $MMtCO_2e$ in 1990 and 0.1 $MMtCO_2e$ in 2014.

### 2.3.2 Sources of $CH_4$ Emissions

*Natural gas leakage:* Natural gas leakage is currently the second highest contributor to GHG emissions from industrial non-fuel combustion processes in the State. Emissions estimates from this source were 4.6 $MMtCO_2e$ in 1990 and 2.2 $MtCO_2e$ in 2014.[40] This methane emissions trajectory is methodologically tied to EPA's emissions assumptions from natural gas transmission, distribution, and storage, and driven by EPA's assumptions that emissions from these elements of the natural gas system have declined from 1990 through 2014. Note that EPA has revised its national estimates of fugitive methane emissions from natural gas extraction sites from 1990–2014 higher to better reflect current scientific research on methane leakage. These emissions are assumed to occur outside of the State. The science underlying methane emissions calculation is advancing quickly, and methods of estimating emissions may require reevaluation and refinement going forward in accordance with evolving standards and best practices.

### 2.3.3 Sources of PFC Emissions

*Semiconductor manufacturing*: Emissions from this source are fairly low, at 0.1 $MMtCO_2e$, in New York throughout the analytic period, as shown in Figure 2-1 and Table 2-1.

*Aluminum production:* GHG emissions estimates from aluminum production in the State were 0.4$MMtCO_2e$ and 0.2 $MMtCO_2e$ in 2014.

### 2.3.4 Sources of HFC Emissions

*ODS substitutes:* Estimates of emissions from ODS substitutes in New York State have increased from 0.02 $MMtCO_2e$ in 1990 to about 10 $MMtCO_2e$ in 2014. ODS substitutes (and as a result, HFCs) have increased due to the provisions of the Montreal Protocol. While the protocol was effective at protecting the ozone layer by phasing out ODSs, it has led to an increase in HFCs, which are a potent GHG. Given the risk HFCs pose to the climate, the EPA has enacted new rules to limit emissions from HFCs under its Significant New Alternatives Policy.[41] More recently, the Montreal Protocol was amended in October 2016 to limit HFC usage.

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40 A recent study found that measured emissions of methane from natural gas systems are approximately 1.5 times greater than those published in the U.S. Environmental Protection Agency national GHG inventory. A commensurate scaling of this analysis would increase the emissions from natural gas leakage to 3.3 $MMTonsCO_2e$ or 1% of total emissions. See Brandt, et al. 2014. "Methane Leaks from North American Natural Gas Systems." *Science* 343, February.

41 Environmental Protection Agency. 2016. "Significant New Alternatives Policy." Last modified 11 October 2016. https://www.epa.gov/snap/snap-regulations.

# 3 Transportation Energy Use

## 3.1 Overview

The transportation sector is one of the largest sources of GHG emissions in the State. Carbon dioxide ($CO_2$) accounts for the majority of the transportation GHG emissions from fuel use. Most of the remaining GHG emissions from the transportation sector are due to nitrous oxide ($N_2O$) emissions from on-road gasoline-fueled vehicles.

### 3.1.1 On-Road Vehicle Fuels

*Gasoline:* Gasoline combusted by passenger cars, light-duty trucks, heavy-duty vehicles, and motorcycles produces $CO_2$, $N_2O$, and $CH_4$ emissions. Although gasoline contains virtually no $CH_4$, this GHG is a byproduct of gasoline combustion and is influenced by various factors such as emission control technologies, combustion conditions, and fuel composition. Gasoline contains up to 10 percent ethanol by volume; however, per the EPA's EIIP guidance documents[42] ethanol is considered a biofuel, so no $CO_2$ emissions associated with the combustion of ethanol blended into gasoline are included in the inventory.[43]

*Diesel:* Distillate fuel combusted by passenger cars, light-duty trucks, and heavy-duty vehicles produces $CO_2$, $N_2O$, and $CH_4$ emissions. Although diesel contains virtually no $CH_4$, it is a byproduct of diesel combustion and is influenced by various factors such as emission control technologies, combustion conditions, and fuel composition. To the extent that diesel fuel is blended with biodiesel, $CO_2$ emissions from this biofuel are not included in the inventory per EPA guidance.

*Natural gas:* Natural gas combusted by light-duty and heavy-duty alternative fuel vehicles produces $CO_2$, $N_2O$ and $CH_4$ emissions. [44]

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42 EIIP. 2006. "Chapter 1: Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels." Volume VIII.

43 Carbon dioxide emissions associated with fuels produced from sustainably grown biomass are not counted. For cases where biomass is not grown sustainably, the GHG impact would be captured as a land use change.

44 Note that natural gas use for transportation application is often called 'compressed natural gas' or 'CNG' in other state and federal documents and databases.

### 3.1.2 Off-Road Vehicle Fuels

*Gasoline:* $CO_2$, $N_2O$, and $CH_4$ emissions are produced from gasoline combusted by sources such as marine vehicles.

*Diesel:* $CO_2$, $N_2O$, and $CH_4$ emissions are produced from distillate fuel combusted by such sources as locomotives and marine vehicles.

*Residual oil:* $CO_2$, $N_2O$, and $CH_4$ emissions are produced from residual fuel combusted by marine vehicles.

*Liquefied petroleum gas*: $CO_2$, $N_2O$, and $CH_4$ emissions are produced from LPG combusted by internal combustion engines.[45]

*Jet fuel (kerosene)*: $CO_2$, $N_2O$, and $CH_4$ emissions are produced from jet fuel combusted by aircraft.

### 3.1.3 Lubricants

$CO_2$ emissions are produced from lubricants that are consumed during vehicle operation. Lubricants have an assumed oxidation factor of 1.00,[46] which represent the fraction of consumed product (on an energy-content basis) that is combusted and leads to GHG emissions.

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45 U.S. Energy Information Administration. State Energy Data System Technical Notes and Documentation, Consumption, Section 4: Petroleum. http://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf.

The LPG data from the United States Department of Energy's Energy Information Administration (EIA) captures LPG sales for the internal combustion engines of highway vehicles, forklift, industrial tractors, and for use in oil field drilling and production. It is assumed that New York State has very few highway vehicles that consume LPG, therefore all LPG data is attributed to off-road vehicles.

46 The oxidation factor for lubricants was derived from EPA's State Inventory Tool CO2FFC Module, with reference to EIIP. 2006. "Chapter 1: Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels." Volume VIII.

## 3.2 Emissions Inventory Data and Methodology

Historical GHG emissions estimates use the SIT and the methods provided in the EIIP guidance document for the sector.[47,48]

The SIT module was used to determine emissions from the following sources: Highway vehicles, aviation, boat and marine vessels, alternative fuel vehicles. Options for locomotives and "other non-highway sources" were not utilized. Default emissions factors were used.

### 3.2.1 On-Road Vehicle Fuels

The SIT $CO_2$ Fossil Fuel Combustion Module was used to calculate $CO_2$ emissions based on the energy content, in British thermal units (Btu), of fuel and lubricants consumed. The default SIT fuel consumption values for the State were replaced with State-specific information calculated from annual vehicle miles of travel (VMT) data provided by NYS Department of Transportation (DOT) and fuel economy data provided by Oak Ridge National Laboratory (ORNL) and Federal Highways Administration (FHWA). The SIT Mobile Combustion Module was used to calculate $N_2O$ and $CH_4$ emissions based VMT for on-road vehicles, with the SIT default data for VMT replaced with DOT data for New York State.

*Gasoline and diesel*: New York State annual VMT data for gasoline and diesel on-road vehicles were allocated to differing vehicle types to calculate the VMT by vehicle type for 1990, 2002, 2007, and 2014 shown in Table 3-1.[49] The fraction of VMT by vehicle type for years 1991–2001, 2002–2007, and 2008–2014 were calculated by interpolation and the fractions for years after 2014 were held constant at the 2011 levels. These fractions, applied to the corresponding annual statewide total VMT value to produce annual VMT by vehicle type, were input into the SIT Mobile Combustion Module to calculate emissions of $N_2O$ and $CH_4$.

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47 $CO_2$ emissions were calculated using SIT, with reference to EIIP. 2006. "Chapter 1: Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels." Volume VIII.

48 $CH_4$ and $N_2O$ emissions were calculated using SIT, with reference to EIIP. 2006. "Chapter 3 Methods for Estimating Methane and Nitrous Oxide Emissions from Mobile Combustion." Volume VIII.

49 New York State Department of Transportation VMT modeling.

**Table 3-1. New York State VMT by Vehicle Type (million miles)**

| Vehicle Type | 1990 | 2002 | 2007 | 2014 |
|---|---|---|---|---|
| Heavy Duty Diesel Vehicle | 4,056 | 4,538 | 8,022 | 4,255 |
| Heavy Duty Gasoline Vehicle | 206 | 320 | 1,414 | 1,120 |
| Light Duty Diesel Truck | 582 | 1,890 | 1,459 | 1,119 |
| Light Duty Diesel Vehicle | 26 | 20 | 19 | 18 |
| Light Duty Gasoline Truck | 17,552 | 61,268 | 64,119 | 60,321 |
| Light Duty Gasoline Vehicle | 84,372 | 64,420 | 60,817 | 59,987 |
| Motorcycle | 107 | 603 | 887 | 4,080 |
| Total | 106,900 | 133,058 | 136,737 | 130,889 |

Annual fuel efficiency data were applied to the annual VMT by vehicle type to calculate the quantity of on-road fuel consumption. ORNL and FHWA provided the historical fuel efficiency data. Consumption of biofuel within blended fuels was estimated by applying ethanol fractions of motor gasoline and biodiesel fractions of diesel sold to the calculated consumption numbers. The biofuel fractions were obtained from EIA's State Energy Data System (SEDS) for New York State. The estimated consumption of the biofuels was then subtracted from the gasoline and diesel totals and the resultant consumption data were input into the SIT $CO_2$FFC Module to calculate emissions of $CO_2$.

*Natural Gas*: Historical transportation natural gas consumption data obtained from EIA's SEDS were input into the $CO_2$FFC Module to calculate $CO_2$ emissions.

Consumption data from EIA's SEDS and fuel efficiency data from ORNL and FHWA provided the base for the State's annual natural gas historical VMT data by vehicle type calculations. The resultant VMT values were then input into the SIT Mobile Combustion Module to calculate emissions of $N_2O$ and $CH_4$.

### 3.2.2 Off-Road Vehicle Fuels

*Gasoline*: Estimates for historical off-road motor gasoline consumption are based on FHWA marine vehicle gasoline sales data for New York State. These data were divided by the FHWA national motor gasoline sales data to calculate the fraction of sales associated with New York State marine vehicles. These fractions scale the national motor gasoline consumption data from SEDS to estimate New York State off-road motor gasoline consumption. Gasoline consumption data in Btu were subsequently input into the SIT $CO_2$FFC and Mobile Combustion Modules to produce GHG emissions estimates.

*Diesel:* For historical analysis, estimates for off-road diesel consumption use the off-road diesel sales data from SEDS. The diesel sales data were then adjusted using national data on the ratio of diesel consumption to diesel sales in the U.S. in order to approximate off-road diesel consumption. Diesel consumption data in Btu were subsequently input into the SIT $CO_2$FFC and Mobile Combustion Modules to produce GHG emissions estimates.

*Residual oil, liquefied petroleum gas, and jet fuel (kerosene)*: For these other off-road fuels, emissions estimates were calculated within the SIT $CO_2$FFC and Mobile Combustion modules using fuel consumption data in Btu from NYSERDA's *Patterns and Trends* report.[50]

### 3.2.3 Lubricants

Historical emissions estimates were calculated using fuel consumption data in Btu from NYSERDA's *Patterns and Trends* and the historical $CO_2$ emission estimates were calculated within the SIT $CO_2$FFC module.

## 3.3 Results

Gasoline consumption accounts for the largest share of transportation GHG emissions, as shown in Table 3-2 and Figure 3-1. From 1990–2014, emissions from gasoline increased by about 4 percent to account for approximately 73 percent of total transportation emissions in 2014. GHG emissions from diesel fuel remained consistent from 1990–2014, accounting for approximately nine percent of total transportation emissions in 2014. Emissions from jet fuel also accounted for approximately 11 percent of transportation emissions in 2014. Emissions from residual oil accounted for about five percent of total transportation emissions in 2014, while emissions from all other categories combined (natural gas, LPG, and lubricants) contributed approximately one percent of total transportation emissions in 2014.

50 NYSERDA. 2016. "Patterns and Trends, New York State Energy Profiles: 2000–2014," (https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Patterns-and-Trends)

**Figure 3-1. Transportation GHG Emissions by Fuel, 1990–2014**

LPG is liquefied petroleum gas.

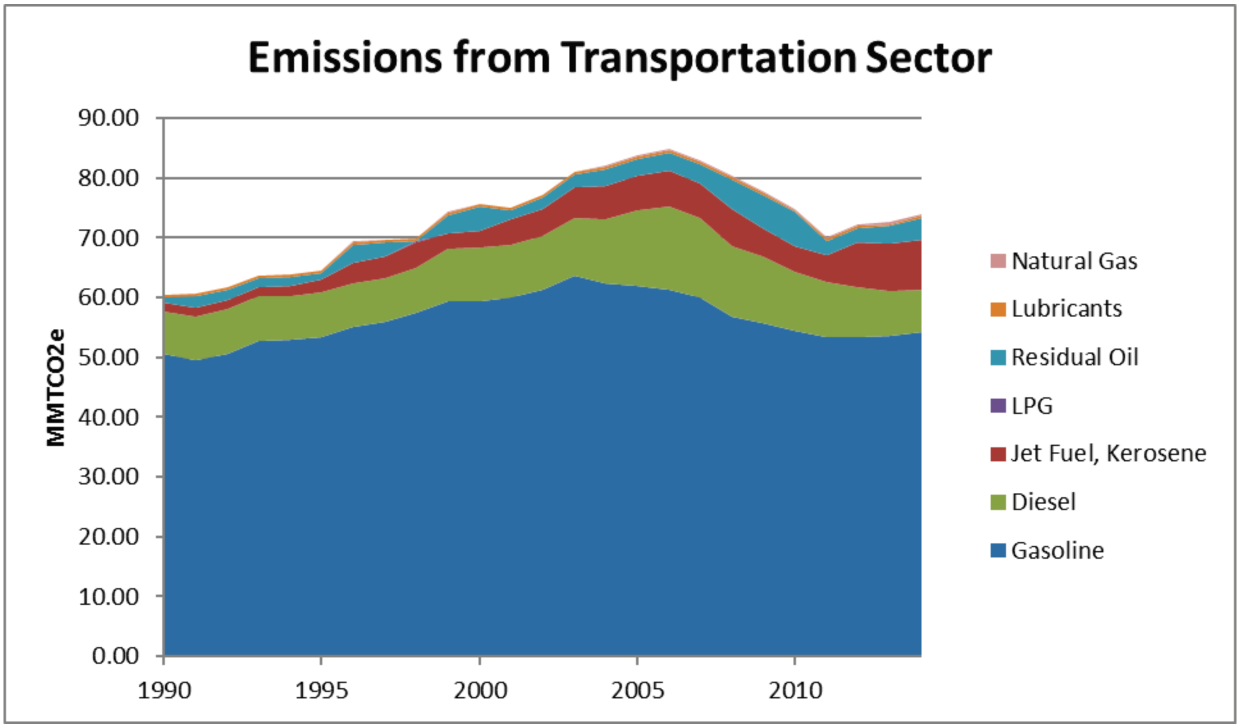


**Table 3-2. Transportation Sector Emissions Inventory, 1990–2014 ($MMtCO_2e$)**

| Fuel Type | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Gasoline | 50.62 | 53.43 | 59.44 | 61.97 | 54.38 | 54.25 |
| Jet Fuel, Kerosene | 1.54 | 2.19 | 2.75 | 5.81 | 4.24 | 8.32 |
| Diesel | 7.07 | 7.36 | 9.03 | 12.66 | 9.96 | 7.06 |
| Residual Oil | 0.65 | 1.09 | 3.87 | 2.70 | 5.68 | 3.60 |
| Lubricants | 0.48 | 0.46 | 0.49 | 0.42 | 0.39 | 0.36 |
| LPG | 0.04 | 0.03 | 0.06 | 0.02 | 0.03 | 0.08 |
| Natural Gas | 0.00 | 0.02 | 0.05 | 0.15 | 0.23 | 0.34 |
| **Total** | **60.40** | **64.57** | **75.68** | **83.73** | **74.91** | **74.01** |

# 4 Power Supply and Delivery

## 4.1 Overview

The generation, transmission, and distribution of electric power to meet electricity demand in New York State produces carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and sulfur hexafluoride ($SF_6$) emissions. The power supply and delivery sector GHG emission sources and sinks are subdivided into three primary categories: fuel combustion, electricity distribution, and municipal waste combustion.

### 4.1.1 Fuel Combustion

*Electricity generation:* This source category captures $CO_2$, $CH_4$, and $N_2O$ emissions that result from the burning of various fuels by in-State power plants.

*Net imports of electricity:* New York State has historically imported more electricity than it has exported. Net imports are the difference between total in-State imports and exports. This source category includes $CO_2$, $CH_4$, and $N_2O$ emissions associated with net imported electricity.

### 4.1.2 Electricity Distribution

This source category captures $SF_6$ emissions associated with the transmission and distribution (T&D) of electricity. $SF_6$ is used as an electrical insulator and interrupter in the electric power T&D system. Because of its high dielectric strength and arc-quenching abilities, the largest use for $SF_6$ is as an insulator in T&D equipment such as gas-insulated high-voltage circuit breakers, substations, transformers, and transmission lines. Not all of the electric utilities in the U.S. use $SF_6$; use of this gas is more common in urban areas where the space occupied by electric power T&D facilities is more valuable.[51]

[51] Environmental Protection Agency. 2013 User's Guide for Estimating Carbon Dioxide, Nitrous Oxide, HFC, PFC, and $SF_6$ Emissions from Industrial Processes Using the State Inventory Tool. Prepared by ICF International.

### 4.1.3 Municipal Waste Combustion

Some of New York State's municipal waste is combusted in facilities equipped to use the heat produced by the incineration process to generate electricity. This source category includes the $CO_2$ and $N_2O$ emissions produced during the incineration process at these waste-to-energy facilities. Chapter 6 covers emissions associated with other forms of waste management (i.e., those that are not associated with the production of electricity).

## 4.2 Emissions Inventory Data and Methodology

GHG emissions related to the power supply represent emissions produced at the point of electric generation only. In addition, according to the EPA emission inventory protocols and the methodologies prescribed in the eGRID2010 Technical Support Document,[52] the carbon dioxide emissions from the combustion of biogenic fuels (e.g., wood, landfill gas, and the biomass component of municipal waste) are not included in estimates of GHG emissions.

### 4.2.1 Fuel Combustion

Estimates for emissions from direct fuel used the SIT software and the methods provided in the EIIP guidance document for electric sector fuel combustion.[53]

*Electricity generation:* The default historical fuel consumption data in the SIT for New York State came from the SEDS and are updated with fuel consumption data from NYSERDA's *Patterns and Trends.*[54]

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52 Environmental Protection Agency. 2014. *The Emissions & Generation Resource Integrated Database for 2007 (eGRID2007) Technical Support Document.* http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_Technical_Support_Document.pdf.

53 GHG emissions were calculated using SIT, with reference to EIIP. 2006 "Chapter 1: Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels.", and. "Chapter 2: Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion." Volume VIII.

54 NYSERDA. 2016. "Patterns and Trends, New York State Energy Profiles: 2000–2014" https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Patterns-and-Trends.

*Net imports of electricity:* Emissions from net imports of electricity were based on output from the Integrated Planning Model (IPM®), an electricity sector modeling software platform developed by ICF International, to support the development of the New York State Energy Plan. IPM is a linear programming model that incorporates electricity systems throughout the U.S. and Canada, including those managed by NYISO, the New England Independent System Operator (ISO-NE), and the Pennsylvania-New Jersey-Maryland Interconnection (PJM). Key input data include existing and planned generation units, annual electricity demand by zone, load shapes, transmission system capacities and transfer limits, generation unit level operation and maintenance costs and performance characteristics, fuel prices, new capacity and emission control technology costs and performance characteristics, zonal reliability requirements, national and state environmental regulations, and financial market assumptions. For imports, the emission factor was estimated based on modeled emissions from neighboring electric service territories.

### 4.2.2 Electricity Distribution

Emissions estimates from T&D used the SIT and the methods provided in the EIIP guidance document for industrial process emissions.[55] The default data assumed that $SF_6$ consumption is equivalent to $SF_6$ sales. The default historical $SF_6$ data in SIT came from the EIA's Electric Power Annual report.[56]

### 4.2.3 Municipal Waste Combustion

Emissions from waste combustion were based on waste-to-energy facility-specific tonnage data from EPA's SIT module from 1990–2007 and from the New York State Department of Environmental Conservation's (NYSDEC) Solid Waste Information Management System (SWIMS) data from 2008 to 2014. These data were input into the SIT, and the methods provided in the EIIP guidance document for municipal solid waste emissions were used to estimate the $CO_2$ and $N_2O$ produced.[57]

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55 GHG emissions were calculated using SIT, with reference to EIIP. 2006. "Chapter 6: Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes." Volume VIII.

56 U.S. Energy Information Administration. 2013. *Electric Power Annual 2011.* Volume I. http://www.eia.gov/electricity/annual/archive/2011/.

57 GHG emissions were calculated using SIT, with reference to EIIP. "Chapter 13: Methods for Estimating Greenhouse Gas Emissions from Municipal Solid Waste." Volume VIII.

## 4.3 Results

Figure 4-1 provides a 2014 breakdown of electricity generation and net imports of electricity for New York by source category. The primary energy sources were natural gas (34 percent) and nuclear power (27 percent) followed by conventional hydropower (16 percent) and net imports of electricity (14 percent). Figure 4-1 shows that nearly half of the State's electricity generation comes from sources that produce little or no emissions, such as conventional hydropower, nuclear power, and wind energy.

**Figure 4-1. Proportion of New York State Electricity Generation and Net Imports by Source Category, 2014**

The Wood category includes wood waste.

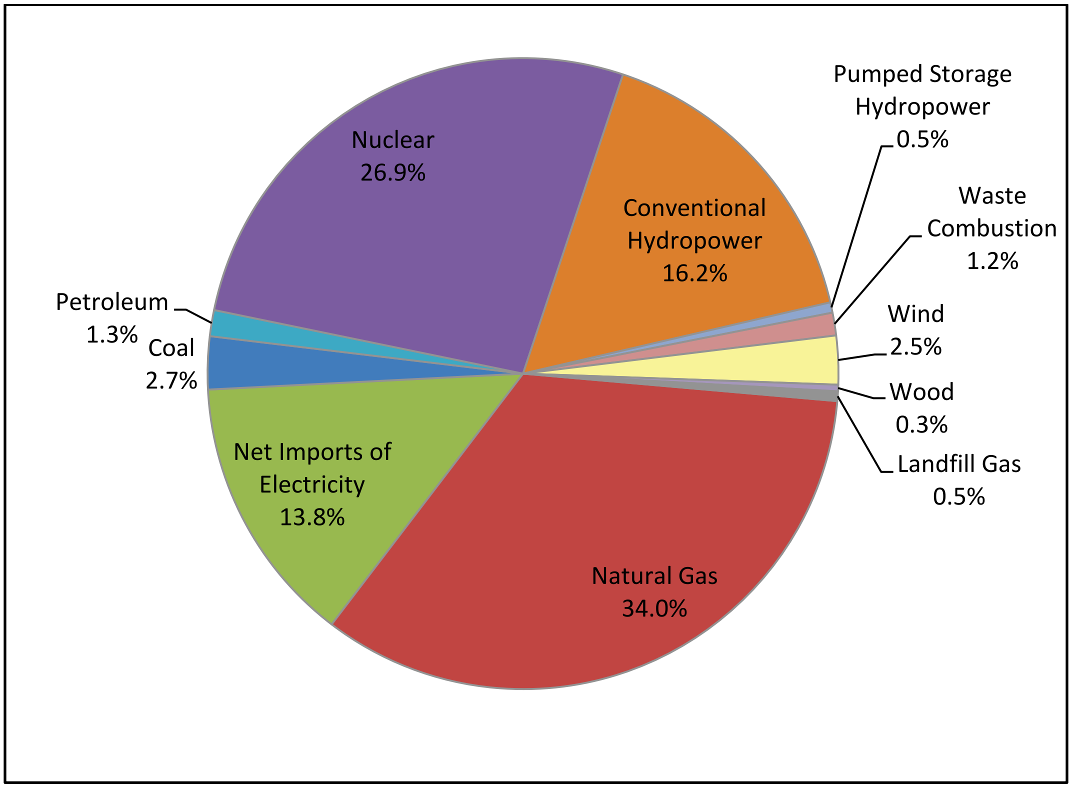


Figure 4-2 provides a 2014 breakdown by percentage of emissions from power supply and delivery within New York State by source category. While the majority of emissions come from natural gas combustion (59 percent), coal is the second-highest source of emissions percentage-wise (10 percent), though it only provides a relatively small proportion of the State's electricity generation (2.7 percent). Net imports of electricity also contribute approximately 19 percent of GHG emissions, however there is some uncertainty associated with the estimation of emissions from this out-of-state source category. $SF_6$ emissions from the transmission and distribution of electricity and petroleum emissions are the smallest sources at only one percent each of total emissions.

**Figure 4-2. Proportion of GHG Emissions from Power Supply and Delivery by Source Category, 2014**

$CO_2$ emissions from Municipal Waste Combustion are assumed to come from the non-biogenic portions of the waste only. In accordance with EPA guidelines, the biogenic portions of the waste are assumed to have no net $CO_2$ emissions.

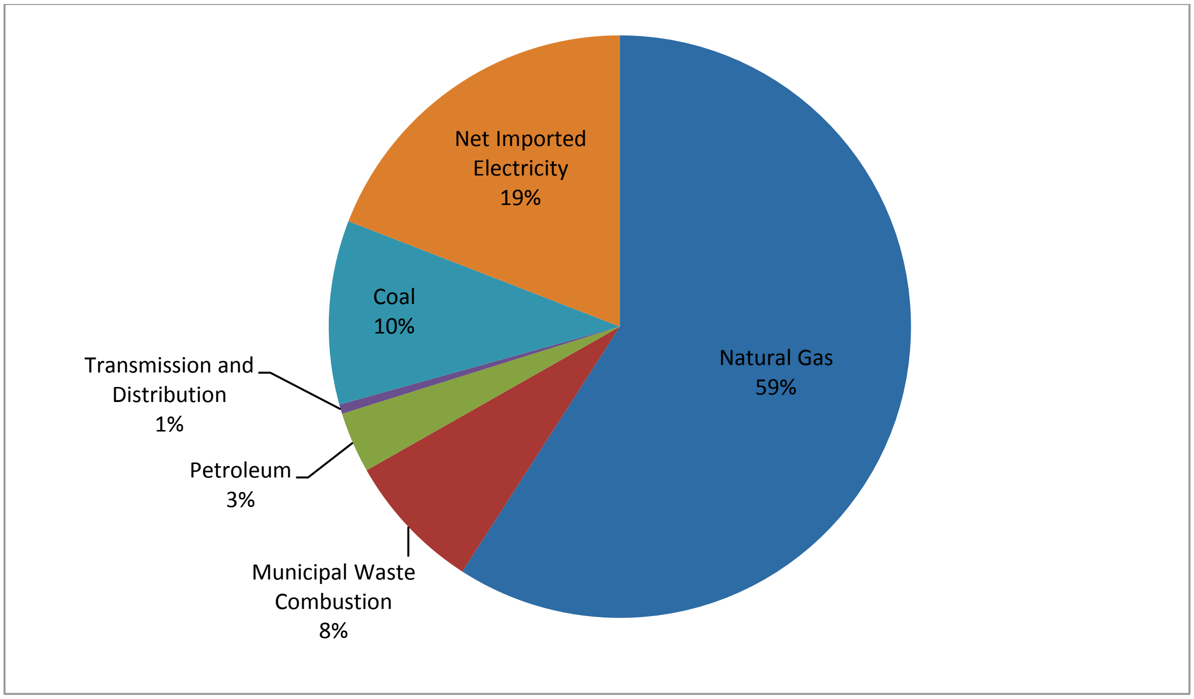


Figure 4-3 shows the electricity generation and net imports of electricity for the State by source category for 1990–2014. During that time period, under existing state policies and economic conditions, the largest absolute increase in electricity generation by source comes from natural gas, which increases from approximately 23,000 GWh of generation in 1990 to approximately 54,000 in 2014. As indicated by Table 4-1, the renewables category, which includes renewable energy sources such as solar, wind, and bioenergy, saw the greatest growth percentage with an estimated average annual growth rate of 2.3 percent between 1990 and 2014. Net imports of electricity have increased substantially, from approximately 5,000 GWh in 1990 to 22,000 in 2014.

**Figure 4-3. New York State Electricity Generation and Net Imports of Electricity by Source Category, 1990–2014**

Note: The Other category includes wood, landfill gas, and waste. The Hydropower category includes both conventional and pumped storage hydropower.

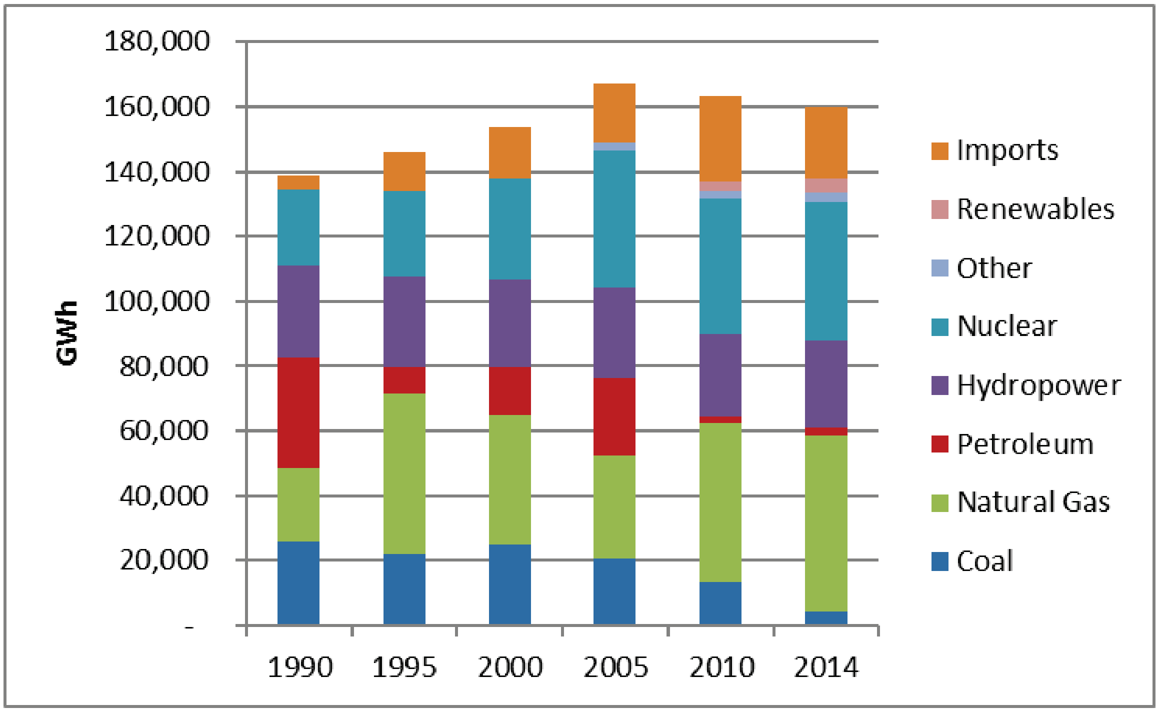


**Table 4-1. Electric Generation (GWh) and Annual Average Growth Rates by Fuel Type**

The Other category includes wood, landfill gas, and waste. The Hydropower category includes both conventional and pumped storage hydropower.

| Energy Source | 1990 | 2014 | Average % Annual Growth 1990 – 2014 |
|---|---|---|---|
| Coal | 25,913 | 4,325 | (0.06) |
| Natural Gas | 22,724 | 54,380 | 0.05 |
| Petroleum | 33,885 | 2,136 | (0.01) |
| Hydropower | 28,188 | 26,823 | 0.00 |
| Nuclear | 23,623 | 43,041 | 0.03 |
| Net Imports of Electricity | 4,519 | 22,103 | 0.15 |
| Renewables | - | 4,595 | 2.29 |
| Other | - | 2,655 | 0.02 |
| **Total** | **138,853** | **160,059** | **0.87** |

Figure 4-4 shows the primary fossil fuel energy use at in-State power stations for natural gas, coal, and petroleum from 1990–2014. The data show natural gas replacing coal and petroleum generation during this time.

**Figure 4-4. Primary Fossil Fuel Energy Use at New York State Power Stations by Fuel Type**

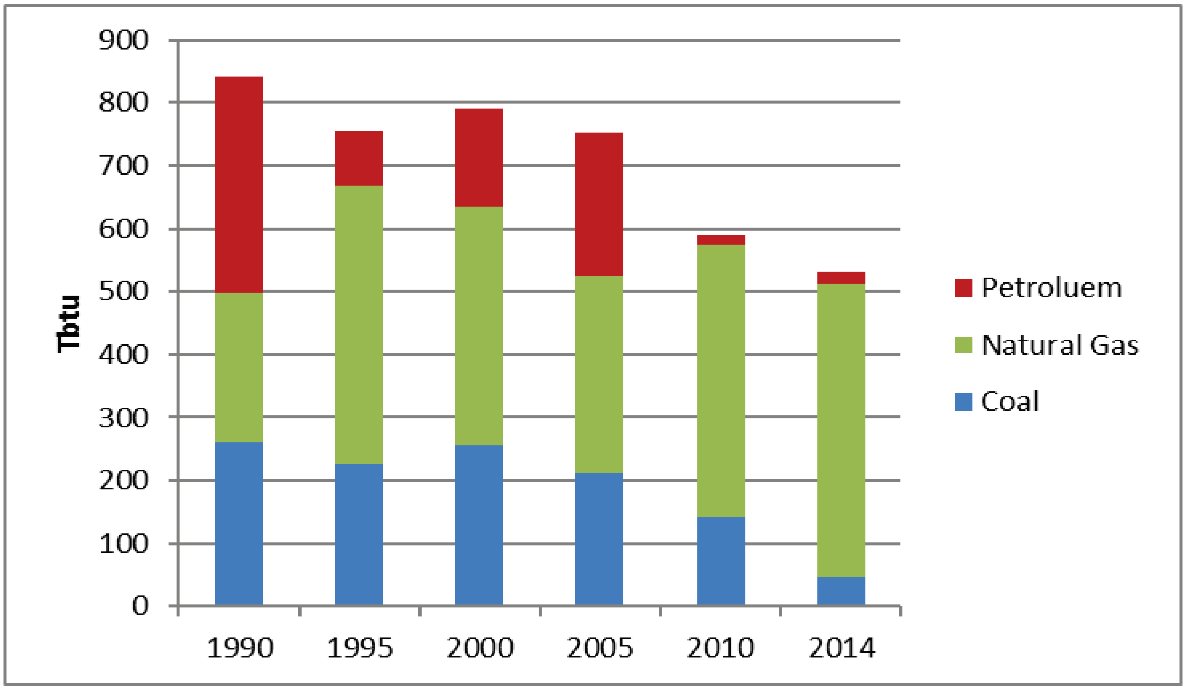


Figure 4-5 shows GHG emissions from power supply and delivery within the State by source category for 1990–2014. Between 1990 and 2014, total GHG emission from power supply and delivery (including imports) decreased by approximately 25.7 million metric tons of carbon dioxide equivalent ($MMtCO_2e$) to reach approximately 41.5 $MMtCO_2e$. Emissions of $SF_6$ from electrical equipment experienced declines since the mid-1990s, mostly due to voluntary action by industry. $SF_6$ emissions from electric power T&D were approximately 1.3 $MMtCO_2e$ in 1990 and decreased to approximately 0.3 $MMtCO_2e$ in 2014.

The largest absolute increase in GHG emissions between 1990 levels and 2014 status quo levels comes from natural gas, with emissions rising from approximately 12.6 $MMtCO_2e$ in 1990 to approximately 24.7 $MMtCO_2e$ in 2014, as indicated by Table 4-2. Emissions associated with coal and petroleum combustion decline from 24.5 $MMtCO_2e$ in 1990 to 4.3 $MMtCO_2e$ in 2014, and 25.9 $MMtCO_2e$ in 1990 to 1.4 $MMtCO_2e$ in 2014, respectively.

**Figure 4-5. GHG Emissions from Power Supply and Delivery by Source Category, 1990–2014**

$CO_2$ emissions from municipal waste combustion are assumed to come from the non-biogenic portions of the waste only. In accordance with EPA guidelines, the biogenic portions of the waste are assumed to have no net $CO_2$ emissions.

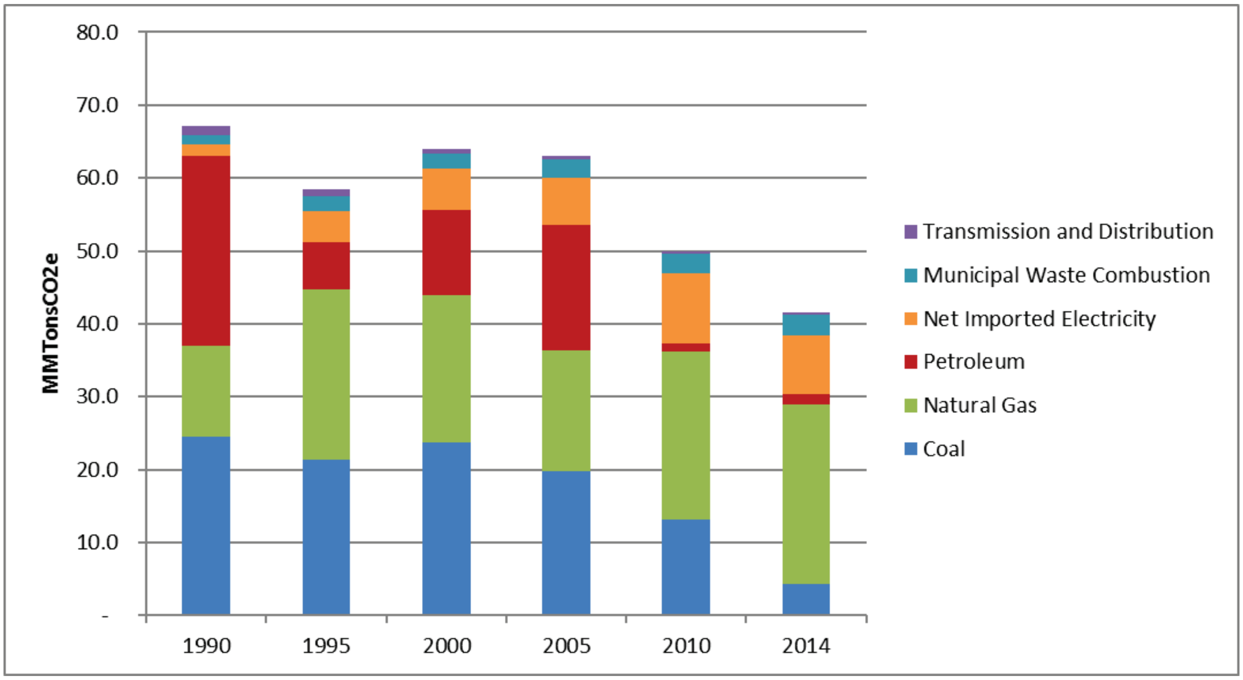


**Table 4-2. GHG Emissions from Power Supply and Delivery by Source Category, 1990–2014 ($MMtCO_2e$)**

$CO_2$ emissions from municipal waste combustion are assumed to come from the non-biogenic portions of the waste only. In accordance with EPA guidelines, the biogenic portions of the waste are assumed to have no net $CO_2$ emissions.

| Source Category | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Natural Gas | 12.6 | 23.4 | 20.2 | 16.5 | 23.0 | 24.7 |
| Coal | 24.5 | 21.4 | 23.7 | 19.8 | 13.2 | 4.3 |
| Petroleum | 25.9 | 6.5 | 11.8 | 17.3 | 1.1 | 1.4 |
| Municipal Waste Combustion | 1.3 | 2.0 | 2.0 | 2.4 | 2.7 | 2.8 |
| Transmission and Distribution | 1.3 | 0.9 | 0.6 | 0.5 | 0.3 | 0.3 |
| Net Imported Electricity | 1.6 | 4.3 | 5.7 | 6.6 | 9.6 | 8.0 |
| **Electric Power Including Imports** | **67.2** | **58.4** | **63.9** | **63.0** | **49.9** | **41.5** |
| **Electric Power Excluding Imports** | **65.5** | **54.1** | **58.3** | **56.4** | **40.3** | **33.5** |

# 5 Agriculture

## 5.1 Overview

The emissions discussed in this chapter refer to non-energy methane ($CH_4$) and nitrous oxide ($N_2O$) emissions from both livestock and crop production. Energy emissions related to agricultural practices (combustion of fossil fuels to power agricultural equipment) are included in the residential, commercial, and industrial (RCI) fuel consumption sector estimates (see Chapter 1).

The inventory accounts for both direct and indirect emissions of $N_2O$-related to livestock and crop production. Direct emissions occur at the site of application of manure, fertilizer, and sewage sludge to agricultural soils. When nitrogen is applied to soils, indirect emissions can occur through the volatilization of ammonia and oxides of nitrogen. These products can then be re-deposited, enter the nitrification/denitrification cycle, and be emitted as $N_2O$ in another location. Indirect emissions can also occur through leaching or runoff of nitrogen, which can enter the nitrification/denitrification cycle on or off-site and then be emitted as $N_2O$.

The primary agricultural GHG sources—livestock and agricultural soils—are further subdivided as described in the following sections.

### 5.1.1 Livestock

*Enteric Fermentation:* $CH_4$ emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit $CH_4$ as a by-product. Ruminant livestock produce more $CH_4$ than non-ruminant livestock because of digestive activity in the large fore-stomach.

*Manure management:* $CH_4$ and $N_2O$ emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more $CH_4$ is produced because decomposition is aided by $CH_4$-producing bacteria that thrive in oxygen-limited conditions. In contrast, $N_2O$ emissions increase under aerobic conditions.

Emission estimates from manure management are based on manure stored and treated on livestock operations (e.g., dairies, feedlots, swine operations). Emissions from manure deposited directly on land by grazing animals and emissions from manure applied to agricultural soils as an amendment are accounted for under animal production in the following sections.

### 5.1.2 Agricultural Soils

*Fertilizers:* The application of synthetic and organic fertilizers can result in $N_2O$ emissions. Nitrogen additions drive the underlying soil nitrification and denitrification cycle, which produces $N_2O$ as a by-product.

*Crops:* This source category covers $N_2O$ emissions from the decomposition of crop residues and the production of nitrogen fixing crops.

*Animal production:* This source category covers $N_2O$ emissions resulting from animal excretions directly on agricultural soils (e.g., pasture, paddock, or range) or manure spreading on agricultural soils, including leaching and runoff.

## 5.2 Emissions Inventory Data and Methodology

Historical GHG emissions were estimated using the SIT software and the methods provided in the EIIP guidance document for the sector.[58] In general, the SIT methodology applies emission factors developed for the U.S. to activity data for the agriculture sector. Activity data include livestock population statistics, amounts of fertilizer applied to crops, and trends in manure management practices. This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[59,60]

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58 GHG emissions were calculated using SIT, with reference to EIIP. 2006. "Chapter 8: Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management." and "Chapter 10: Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management." Volume VIII.

59 Intergovernmental Panel on Climate Change. 1996. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventorie*s. http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

60 Intergovernmental Panel on Climate Change. 2000. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

Historical data on crop production in New York State and on the number of animals in the State were obtained from the National Agricultural Statistical Service (NASS) of the United States Department of Agriculture (USDA), and incorporated as defaults in the SIT.[61] The default SIT manure management system assumptions for each livestock category were used for this inventory. SIT data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute and are also contained as defaults with the SIT module. Details for each of the livestock and crop production emission sources are provided below.

### 5.2.1 Livestock

*Agricultural animals:* SIT default data on livestock populations are derived from the USDA NASS. Methane emission factors specific to each type of animal by region (e.g., dairy cattle, beef cattle, sheep, goats, swine, and horses) are provided in the SIT. For years 2012–2014, New York State emissions reported in the EPA's 2014 U.S. GHG Inventory are used.

*Manure management:* The same population data used for enteric fermentation are also used as input to estimate $CH_4$ and $N_2O$ emissions from manure management. Population estimates are multiplied by an estimate for typical animal mass and a volatile solids (VS) production rate to estimate the total VS produced. The VS estimate for each animal type is then multiplied by a maximum potential $CH_4$ emissions factor and a weighted $CH_4$ conversion factor to derive total $CH_4$ emissions. The methane conversion factor adjusts the maximum potential $CH_4$ emissions based on the types of manure management systems employed in the State.

Nitrous oxide emissions are derived using the animal population estimates discussed above, multiplied by the typical animal mass and a total Kjeldahl nitrogen (K-nitrogen) production factor. The total K-nitrogen is multiplied by a non-volatilization factor to determine the fraction that is managed in manure management systems. The unvolatilized portion is divided into fractions that are processed in either liquid (e.g., lagoons) or solid waste management systems (e.g., storage piles, composting). Each of these fractions is then multiplied by an $N_2O$ emission factor and the results summed to estimate total $N_2O$ emissions. For years 2012–2014 SIT values are modified to reflect VS and K-nitrogen emissions factors used in EPA's 2014 GHG Inventory.

61 National Agricultural Statistical Service. https://www.nass.usda.gov/Statistics_by_State/New_York/.

### 5.2.2 Agricultural Soils

*Fertilizers:* Calculations for direct and indirect emissions from fertilization use data on the amount of nitrogen applied to the soil in the form of both synthetic and organic fertilizers along with factors on the fraction of nitrogen volatilized and an IPCC-based emission factor for $N_2O$ emissions from the re-deposited nitrogen (0.01 kg $N_2O$-N/kg N re-deposited).

*Crops:* Default data on tonnage of crop production from the USDA NASS were used to calculate $N_2O$ emissions from crop residues and crops that fix nitrogen.

*Animal production:* The calculation of emissions for this source category requires data on animal population, mass and nitrogen emitted per unit of animal mass, as well as the amount of manure left on the soil.

To calculate indirect emissions from this source category, data on nitrogen inputs from animals to crop soils are used along with factors on the fraction of nitrogen volatilized and an IPCC-based emission factor for $N_2O$ emissions from the re-deposited nitrogen (0.01 kg $N_2O$-N/kg N re-deposited).

## 5.3 Results

Annual GHG emissions from agricultural sources in the State range between approximately 5.3 and 6.3 $MMtCO_2e$ during the time period between 1990 and 2014, generally staying stable over time, as shown in Figure 5-1. Detailed information on GHG emissions from agricultural sources is provided in Table 5-1. Enteric fermentation accounted for about 58 percent (3.4 $MMtCO_2e$) of total agricultural emissions in both 1990 and about 57 percent (3.6 $MMtCO_2e$) in 2014. The manure management category accounted for 14 percent (0.8 $MMtCO_2e$) of total agricultural emissions in 1990 and accounts for an estimated 19 percent (1.2 $MMtCO_2e$) of total agricultural emissions in 2014. The agricultural soils category shows 1990 emissions accounting for 28 percent (1.6 $MMtCO_2e$) of total agricultural emissions and 2014 emissions estimated to be about 25 percent (1.6 $MMtCO_2e$) of total agricultural emissions.

**Figure 5-1. GHG Emissions from Agriculture, 1990–2014**

The Agricultural Soil Management category includes emissions from fertilizers, crops (crop residues and nitrogen fixing crops), and animal production. Soil carbon sequestration is not shown (see Table 5-1).

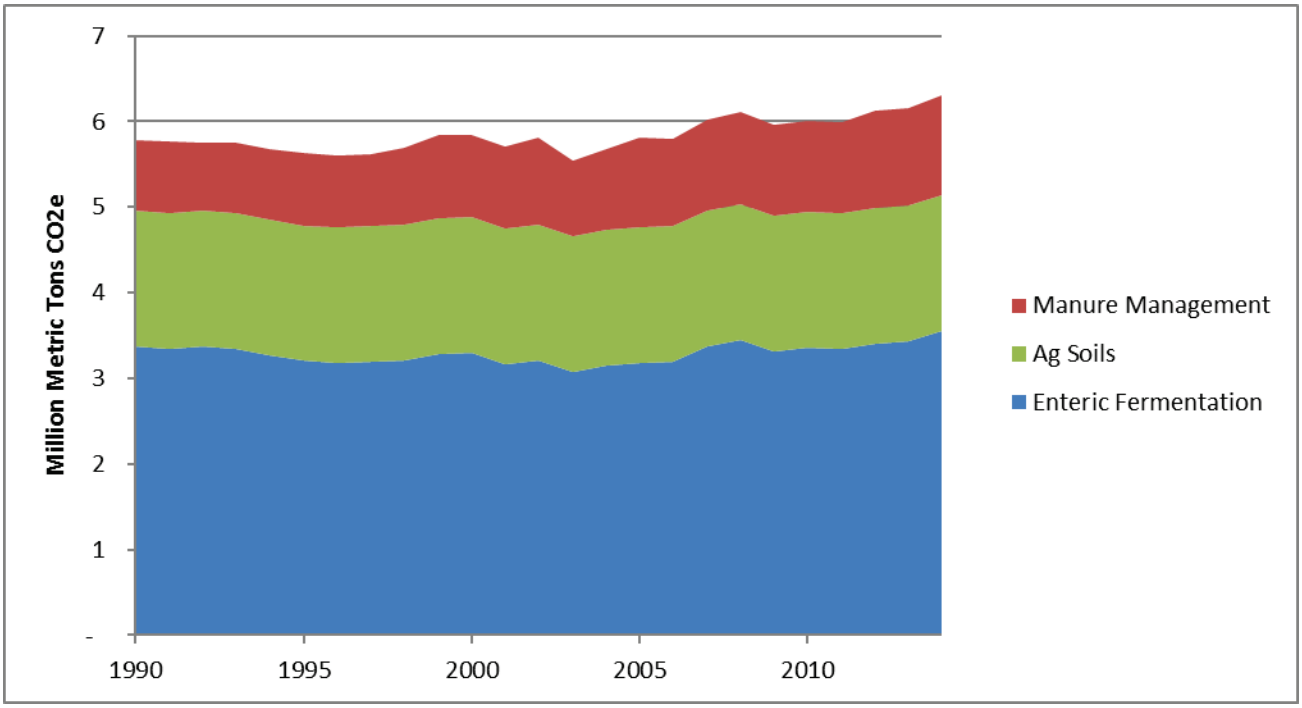


**Table 5-1. GHG Emissions from Agriculture, 1990–2014 ($MMtCO_2e$)**

| Source Category | 1990 | 1995 | 2000 | 2005 | 2010 | 2014 |
|---|---|---|---|---|---|---|
| Enteric Fermentation | 3.4 | 3.2 | 3.3 | 3.2 | 3.4 | 3.6 |
| Manure Management | 0.8 | 0.8 | 1.0 | 1.1 | 1.1 | 1.2 |
| Agriculture Soil Management | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| **Total** | **5.8** | **5.6** | **5.8** | **5.8** | **6.0** | **6.3** |

# 6 Waste Management

## 6.1 Overview

The sources of GHG emissions from waste management included in this inventory report cover both solid waste and wastewater. These primary sources are further subdivided as follows:

### 6.1.1 Landfills

*Municipal solid waste landfills:* Methane ($CH_4$) emissions are generated from the anaerobic decomposition of the organic matter present in landfilled waste by methanogenic bacteria. Some municipal solid waste (MSW) landfills employ control technologies, such as flares that convert the $CH_4$ portion of recovered landfill gas to carbon dioxide ($CO_2$), to reduce the emissions of GHGs to the atmosphere.

*Industrial solid waste landfills:* This source category covers $CH_4$ emissions produced from waste discarded in non-hazardous industrial landfills.

### 6.1.2 Municipal Wastewater Management

This source category covers both $CH_4$ and $N_2O$ emissions produced at municipal wastewater treatment facilities.

In addition to the sources outlined in previous sections, emissions can also result from industrial wastewater treatment, commercial/industrial waste incineration, and MSW combustion for energy production (waste-to-energy combustion). Only municipal wastewater treatment sources were considered based on the information presently available at the State level. There is no significant commercial/industrial waste incineration within the State, and waste-to-energy combustion emissions are accounted for in Chapter 4. Note that this inventory does not currently capture any other forms of waste combustion, including medical waste or hazardous waste incineration.

## 6.2 Emissions Inventory Data and Methodology

### 6.2.1 Landfills

*Municipal solid waste landfills:* For municipal solid waste landfills, emissions for 1990–2014 were calculated in the SIT using tonnage data from EPA's SIT module from 1990–2007 and the DEC's 2008–2014 SWIMS data, as well as estimates of methane flaring and capture from the EPA Landfill Methane Outreach Program (LMOP) database.[62]

### 6.2.2 Wastewater Management

For municipal wastewater treatment, emissions calculations used the SIT methodology, which is based on State population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for $N_2O$ and $CH_4$. Table 6-1 shows the key SIT default values. Municipal wastewater treatment emissions were, therefore, based on the population growth rate for 1990–2014.

**Table 6-1. SIT Key Default Values for Municipal Wastewater Treatment**

*Source: U.S. EPA State Inventory Tool – Wastewater Module; methodology and factors taken from U.S. EPA, Emission Inventory Improvement Program, Volume 8, Chapter 12, December 2006.*

| Variable | Default Value |
|---|---|
| BOD | 0.09 kg /day-person |
| Amount of BOD anaerobically treated | 16.25% |
| $CH_4$ emission factor | 0.6 kg/kg BOD |
| New York residents not on septic | 79% |
| Water treatment $N_2O$ emission factor | 4.0 g $N_2O$/person-yr |
| Biosolids emission factor | 0.005 kg $N_2O$-N/kg sewage-N |

62 Environmental Protection Agency. 2016. "Landfill Methane Outreach Project Index." Last modified October 4, 2016. http://www.epa.gov/lmop/projects-candidates/index.html.

## 6.3 Results

The emission estimates for the waste management sector, shown in Figure 6-1 and Table 6-2, include GHG emissions associated with waste generated in the State. Overall, the sector accounted for 14.8 $MMtCO_2e$ in 1990 and 13.8 $MMtCO_2e$ in 2014. The share of emissions from landfills decreases slightly over the analysis period from 87 percent of the sector total in 1990 to 85 percent in 2014, while the share of emissions from wastewater increases from 13 percent in 1990 to 15 percent in 2014.

**Figure 6-1. GHG Emissions from Waste Management, 1990–2014**

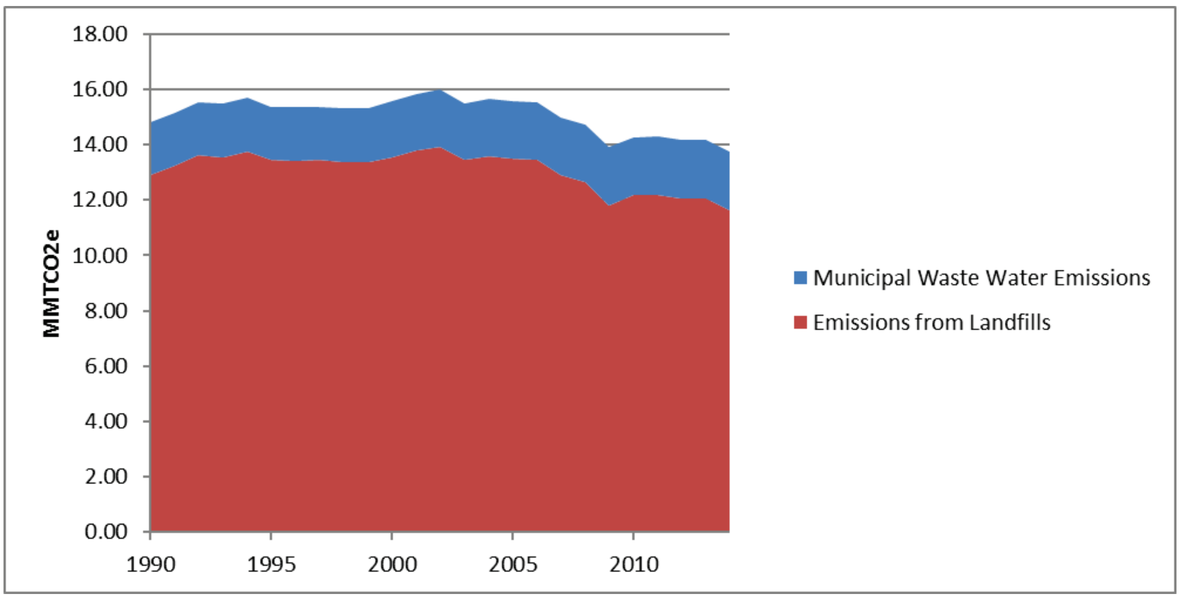


**Table 6-2. GHG Emissions from Waste Management ($MMtCO_2e$), 1990–2014**

| Source Category | 1990 | 1995 | 2000 | 2005 | 2010 | 2012 | 2014 |
|---|---|---|---|---|---|---|---|
| Landfills | 12.89 | 13.43 | 13.52 | 13.49 | 12.17 | 12.06 | 11.63 |
| Municipal Wastewater | 1.91 | 1.94 | 2.04 | 2.07 | 2.09 | 2.11 | 2.12 |
| **Total** | 14.81 | 15.37 | 15.56 | 15.56 | 14.26 | 14.17 | 13.75 |

Many of the materials that comprise MSW – aluminum cans, steel cans, glass, plastic, paper, etc. – represent significant embedded GHG emissions, which are also not included. Embedded emissions include emissions from the entire energy-cycle of a material, including emissions from raw material extraction, transportation of the raw material, manufacture of a product or packaging, and transportation of the good or packaging to the marketplace.

# Appendix A

**Table A-1. Fuel Combustion Emission Factors by Sector**

Values represent aggregate $CO_2$, $CH_4$ and $N_2O$ emissions

| Fuel Type | Emission Factor (lb $CO_2e$ / MMBtu) |
|---|---|
| Aviation Fuel | 159.2 |
| Coal | 204.9 |
| Distillate Fuel Oil (No. 2) | 162.9 |
| Gasoline | 158.0 |
| Kerosene | 161.2 |
| Natural Gas | 117.2 |
| Propane/Liquefied Petroleum Gas | 136.1 |
| Residual Fuel Oil (No. 6) | 166.0 |
| Wood | 18.2 |
| **Source**: Emissions Factors were derived from the U.S. EPA's State Inventory Tool (release Feb, 2016) | |

## A.1 Global Warming Potentials

| Greenhouse Gas | Global Warming Potential |
|---|---|
| $CO_2$ | 1 |
| $CH_4$ | 25 |
| $N_2O$ | 298 |
| HFC-23 | 14,800 |
| HFC-32 | 675 |
| HFC-125 | 3,500 |
| HFC-134a | 1,430 |
| HFC-143a | 4,470 |
| HFC-152a | 124 |
| HFC-227ea | 3,220 |
| HFC-236fa | 9,810 |
| HFC-4310mee | 1,640 |
| PFCs | 7,390-13,300 |
| $SF_6$ | 22,800 |
| **Source**: IPCC Fourth Assessment Report (2007) | |

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