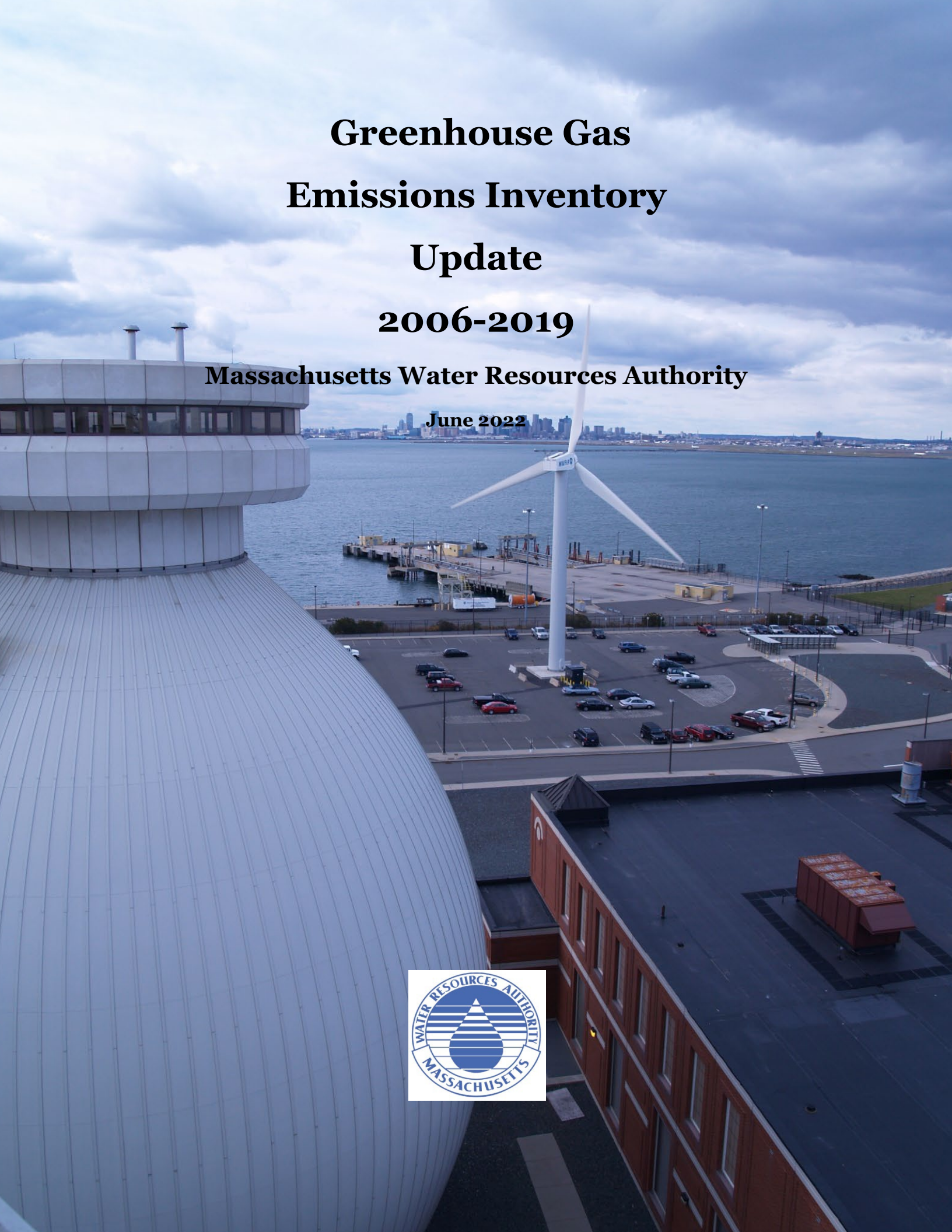

# Greenhouse Gas Emissions Inventory Update 2006-2019

## Massachusetts Water Resources Authority

June 2022

This report updates the December 2017 Massachusetts Water Resource Authority (MWRA) report, *Greenhouse Gas Emissions Inventory Update 2006-2016*, with the latest available data in order to present and examine MWRA GHG emissions from 2006-2019.

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Disclaimer: All calculations presented in this report are based on data collected and estimated by MWRA as well as emissions factors and global warming potentials published by the Intergovernmental Panel on Climate Change (IPCC), Environmental Protection Agency (EPA), Massachusetts Department of Environmental Protection (MassDEP), and the Australian Government Department of the Environment. Every effort has been made to ensure the accuracy of the data. This report is intended to provide a reasonable estimation of greenhouse gas emissions and provide information from which MWRA can base policy decisions.

# FIGURES AND TABLES

## FIGURES



## TABLES

# Introduction

## Overview and Background

Massachusetts Water Resources Authority (MWRA) provides wholesale water and sewer services to over 3.1 million people and 5,500 industrial and commercial users in 61 metro Boston communities.

Commited to being a leader in environmental stewardship, MWRA has implemented many energy conservation programs to reduce the energy demand required to provide safe drinking water and high quality wastewater treatment to its member communities. This report serves as an update to MWRA's *2006-2016 Greenhouse Gas Emission Inventory* and is part of MWRA's ongoing mission to reduce energy use, save money on energy costs, and reduce overall greenhouse gas (GHG) emissions.

An Overview and Background section providing more detail and information on MWRA's Energy Demand and Energy Initiatives can be found in MWRA's *2006-2014 Greenhouse Gas Emission Inventory*[1].

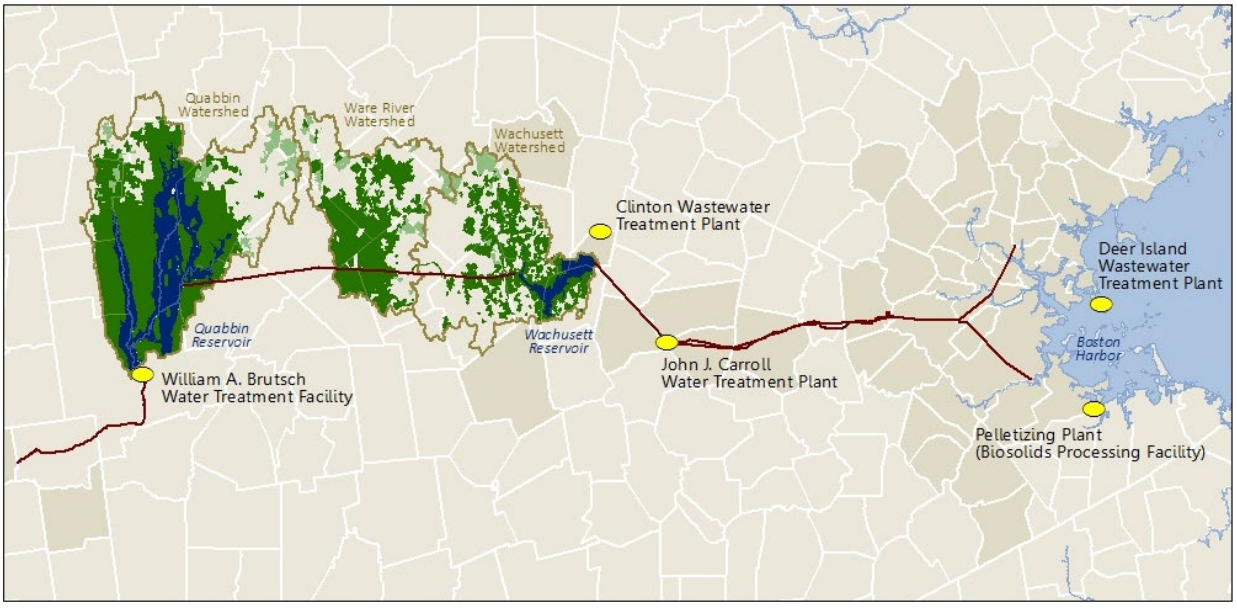



**Figure 1**: MWRA Water and Wastewater Treatment Facility Locations

[1] www.mwra.state.ma.us/sustainability/GHG_Inventory_HORIZ_DRAFT5%20.pdf

Objectives

The objectives of the GHG Emissions Inventory are threefold:

- Calculate GHG emissions to identify major sources and reveal trends
- Highlight successes to date regarding GHG emission reductions
- Identify emissions reduction opportunities

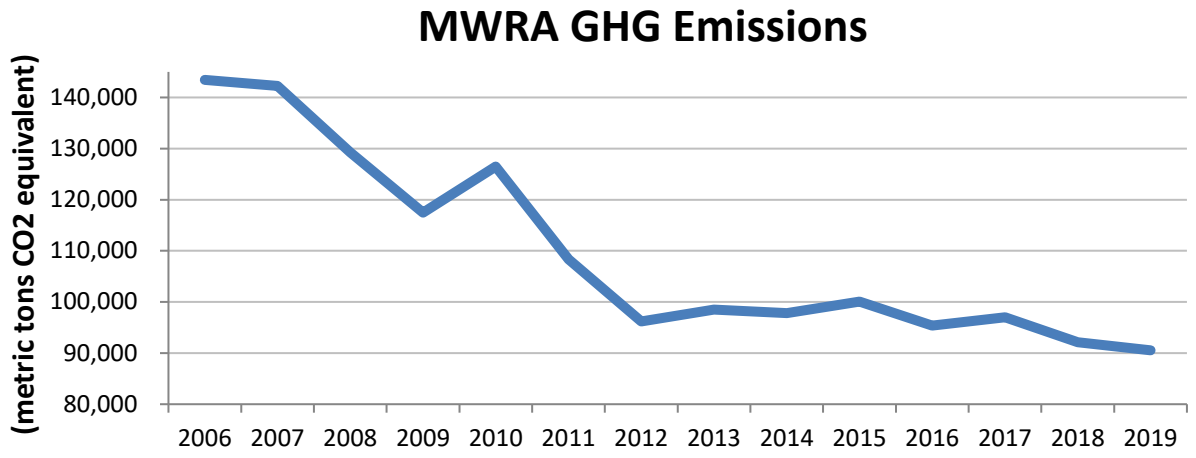
As outlined in the methodology section, the analysis followed standard GHG reporting protocols, involving significant data collection and staff input.

**Figure 2**: Loring Road Hydroelectric Turbine Generator during construction. This turbine generates on average 1.2 million kilowatt hours per year.

## Greenhouse Gas Emissions Summary

As shown in Figure 3 below, MWRA's GHG emissions have fallen by 36.9 percent[2] (between 2006 and 2019), including a 5.1 percent reduction from 2016 to 2019. The reduction from 2016 to 2019 is mostly associated with the greening of the Massachusetts electrical grid which is reflected in lower emission factors for electricity purchased (see Appendix B) and lower methane emissions at the Deer Island Wastewater Treatment Plant. By continuing to measure and analyze GHG emissions, MWRA tracks the progress from on-going energy reduction and efficiency efforts, and largest areas for future emission mitigation.

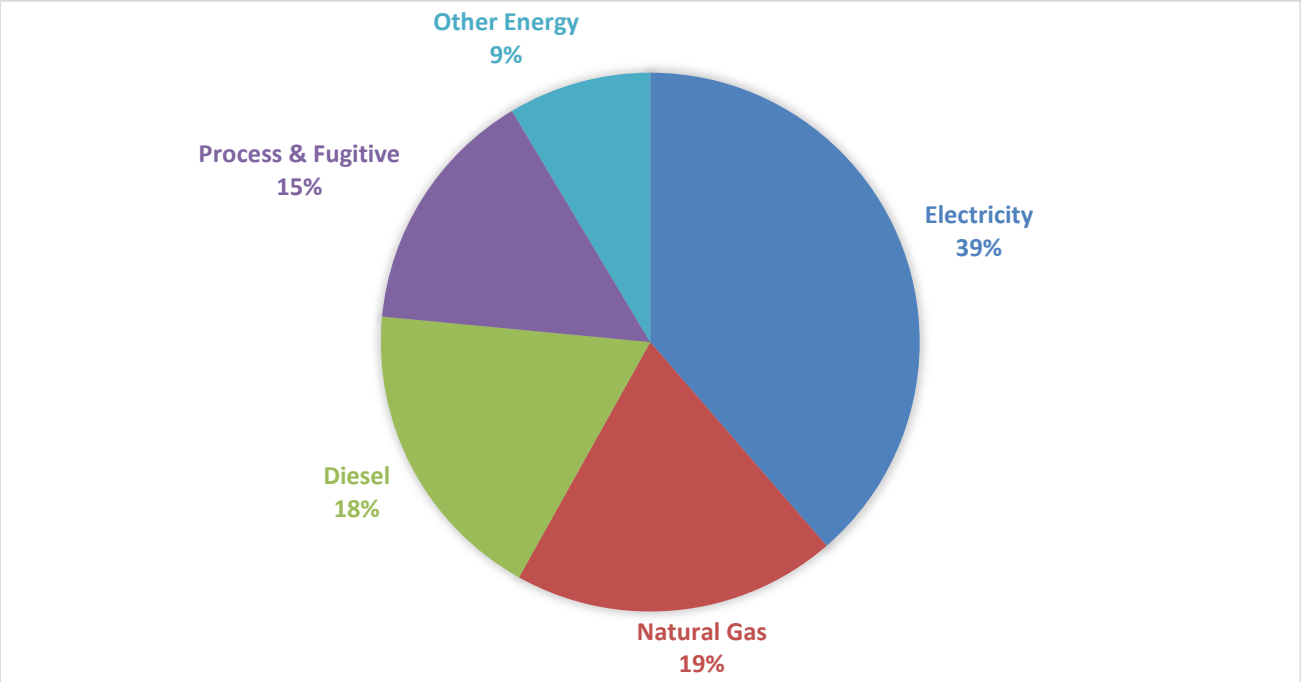
**Figure 3[3]: MWRA GHG Emissions, Metric Tons of $CO_2$ Equivalents (2006 – 2019)**




[2] 36.9% reduction includes total emissions from Scopes 1 and 2, which are the two emissions categories directly or indirectly owned and controlled by MWRA. Emissions from electricity purchased (Scope 2) are calculated using Massachusetts DEP and energy supplier based Emission Factors (EF's) which were available up to 2018 at the time of reporting 2019 emissions.. Scopes are defined in the Methodology section and Appendix A.

[3] The spike in emissions in 2010 was associated with unusual weather patterns that necessitated the extended use of the backup Combustion Turbine Generators (CTGs) at the Deer Island Wastewater Treatment Plant, to ensure continuous pumping and treatment during extreme high flows which significantly increased diesel fuel usage for that year.

**Figure 4: MWRA GHG Emissions Sources, 2019**




As shown in Figure 4 above, in 2019 the major sources of GHG emissions in the MWRA's operations (as a percent of total emissions) include:

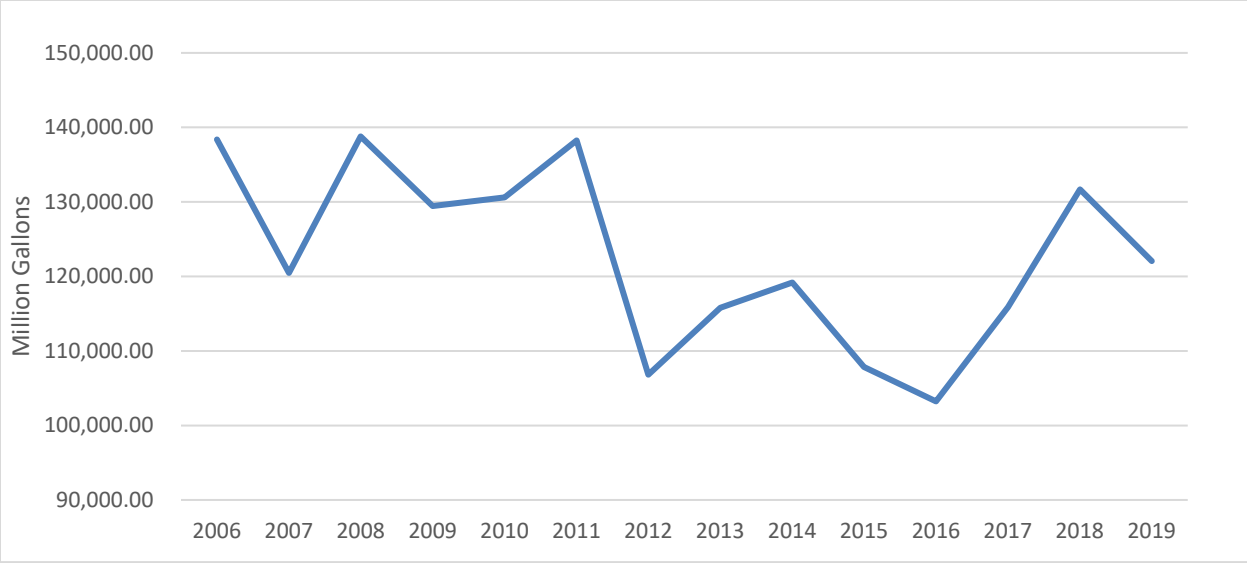
- Electricity (includes water & wastewater treatment plants, pump stations, and headworks facilities), 39%
- Natural gas (dryers at the sludge pelletizing plant, heating), 19%
- Diesel (backup generators, heating), 18%
- Process and Fugitive (nitrous oxide and methane emissions at wastewater treatment plants, landfills, and the sludge pelletizing plant ), 15%[4]
- Other Energy (stationary CH4 emissions from the incomplete combustion of Digester Gas at WWTP with Anaerobic Digestion of Biosolids, vehicle fleet), 9%
- Other (refrigerants), 0.1%

[4] Fugitive emissions are emissions of gases that escape from pressurized equipment, such as wastewater treatment plants, while process emissions are emissions from physical or chemical processes.

## Electricity

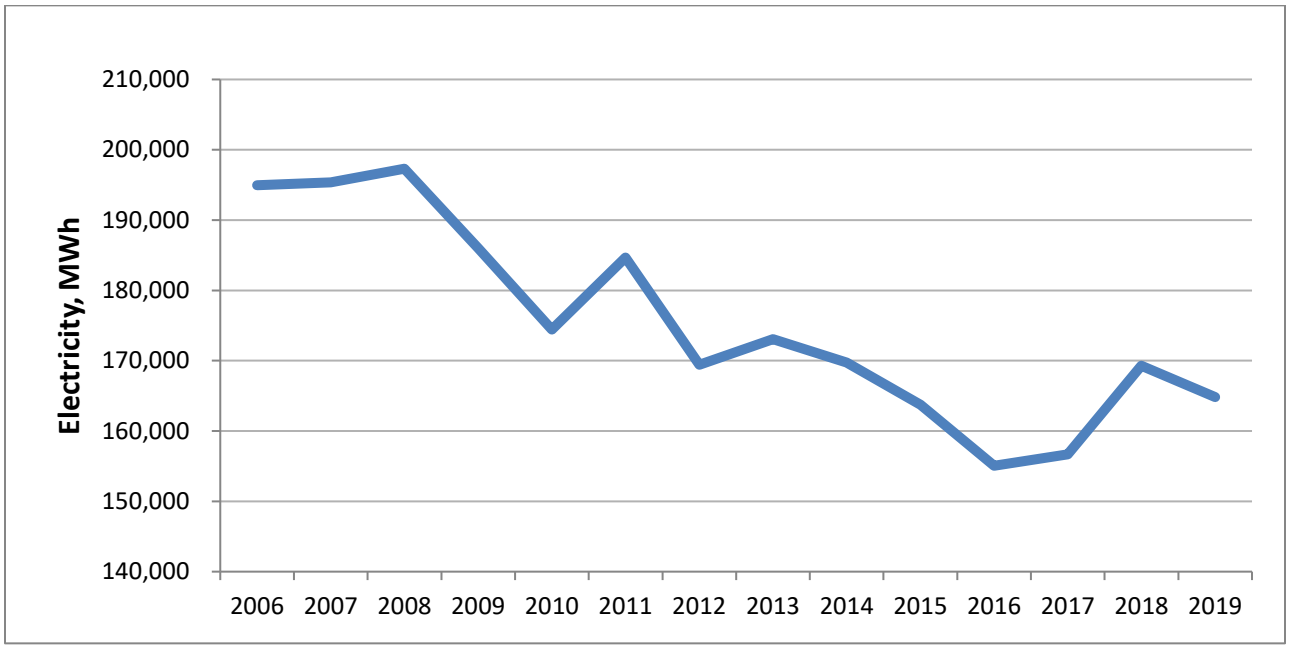
Electricity is the largest purchased energy source, representing over 74% of MWRA utility spending on energy in 2019. As one of the largest wastewater treatment plants in the United States, Deer Island Treatment Plant (DITP) alone accounts for an average of 63% of all MWRA electricity purchased (over last 10 years). The level of wastewater flow varies from year to year and drives electricity usage at DITP. As shown in Figure 5 below, wastewater flow to DITP fell by 11.8% from 2006 to 2019, but increased by 18.2% from 2016 to 2019 (mostly due to a 50% increase in rainfall). Despite wastewater flow increasing from 2016 to 2019, total MWRA GHG emissions fell (see Figure 3) due to MWRA's renewable energy and energy efficiency efforts, as well as the greening of the electrical grid.

**Figure 5: Deer Island Treatment Plant Total Flows, Million Gallons (2006-2019)**



Some of the reduction in electricity purchased (Figure 6 below) can be tied to deployment of the backup generators at DITP. Normally, a 115 kW submerged cable, starting in South Boston and running under the Boston Harbor, provides electrical power to DITP. Cable shut downs during December 2016, early 2017, and August 2019 related to planned harbor dredging required MWRA to use its backup generators to fully power DITP for extended periods of time. This substitution of diesel-powered backup generators for grid supplied electricity at DITP can be seen in relatively higher greenhouse gas emissions (see Figure 3) despite lower electricity purchases (see Figure 6) at MWRA.

**Figure 6: Total Electricity Purchased by MWRA, MWh (2006-2019)**



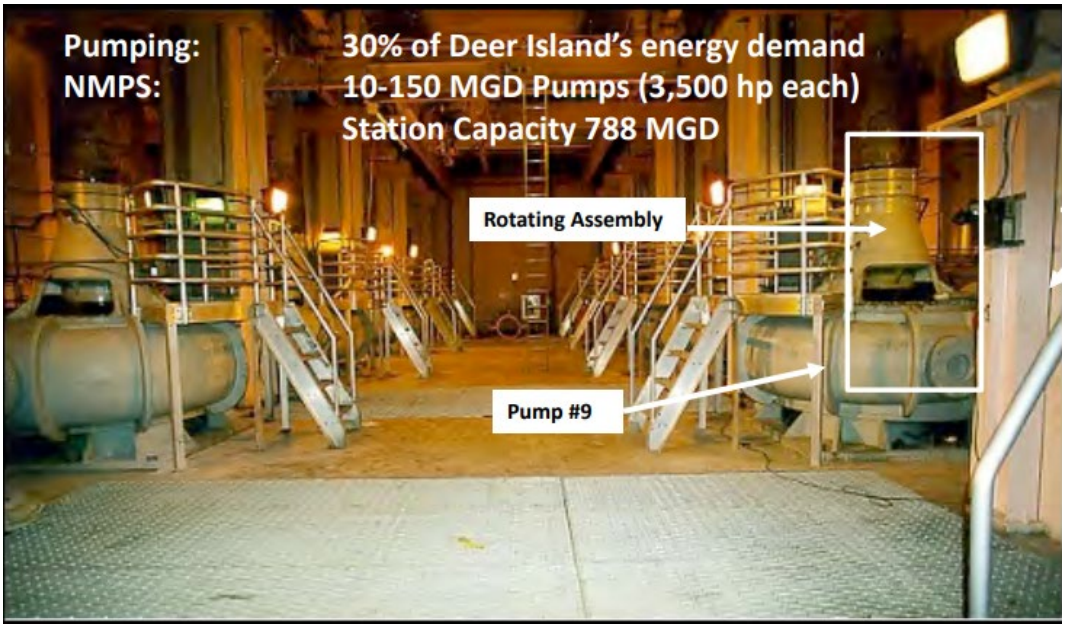

As shown in Figure 6, there has been a 15.5% reduction in MWRA electricity purchased from 2006 to 2019. This is partly due to increases in renewable electricity production, lower annual wastewater flows, energy efficiency improvements made throughout the MWRA system, and increased use of DITP backup generators as part of the Boston Harbor dredging project.

## Energy Efficiency

A number of examples of MWRA energy efficiency projects were outlined in MWRA's *2006-2014 Greenhouse Gas Emission Inventory*. Implementation of initiatives to reduce energy demand and the continued assessment of sustainable cost-saving opportunities are long-standing goals of the MWRA. As part of this comprehensive energy strategy, staff continue to explore opportunities to reduce MWRA's reliance on purchased power and implement cost-effective energy efficiency measures. Examples include:

- Deer Island has ten raw wastewater pumps in the North Main Pump Station (NMPS). MWRA staff routinely maintain these pumps to ensure they operate at maximum efficiency. Any repairs on these pumps are considered a priority and are performed promptly. In an effort to identify opportunities for optimization of the pumping equipment for energy savings, Pump Number 9 was identified as operating below an acceptable pump efficiency level. In December 2019, Pump Number 9 was refurbished, including an epoxy resin recoating, and returning it to a new-like condition thereby increasing energy efficiency, reliability, and extending the pump's useful life (see Figure 7 below). This project provides an estimated 236,000 kWh savings per year.

**Figure 7: DITP North Main Pump Station - Pump 9**



- Wachusett Aqueduct Pumping Station (WAPS) is a critical component of MWRA's water transmission redundancy plan and a model for sustainability. Completed in 2019, WAPS includes: 1) enhanced building envelope and subgrades insulation; 2) a cold roof that was added to the project to minimize energy transfer from the sun and outside air into the building; 3) a geothermal heat pump that circulates forebay water into the building, where it interacts with a heat exchanger that is connected to a water-cooled heat pump (see Figure 8); 4) LED lights connected to motion and daylight sensors; and 5) 76 kW of roof top and ground mount solar panels.

**Figure 8: WAPS Geothermal Heat Pump and Solar Power Installation**

- Six facility LED lighting upgrade projects (390,600 kWh saved annually)
- Pipe insulation at Loring Road to decrease the need for dehumidification (50,370 kWh saved annually)
- Installation of Variable Frequency Drives (VFDs) on the ventilation at Union Park Combined Sewer Overflow Facility to avoid constant running at full throttle (23,400 kWh saved annually)

## Methodology

The approach to building the MWRA GHG inventory is consistent with international and national standards and best practices. Both the Greenhouse Gas Protocols[5] - Corporate Accounting and Reporting Standard[6], and the Local Government Operations Protocol (LGOP), version 1.1[7], were used as the core guiding documents. The EPA Climate Leadership for Greenhouse Gas Inventories[8] was used to identify emissions factors and the IPCC Fourth Assessment Report[9] was referenced for global warming potentials. The Australian National Greenhouse and Energy Reporting[10] (NGER) protocol was used to estimate nitrogen emissions from WWTP effluent to receiving bodies of water.[11] Massachusetts Department of Environmental Protection electricity emission factors were used along with supplier specific factors in substitute of EPA estimated factors for the New England Region; this represents a more accurate estimate of emissions from electricity purchases in Massachusetts.

In addition, interviews were conducted with MWRA's facilities managers, operators, and engineers in order to identify any additional potential emissions sources.

There are seven major greenhouse gases[12] included in the GHG Protocol, however the five listed below are the only ones that MWRA's operations contribute to:

- Carbon dioxide ($CO_2$)
- Methane ($CH_4$)

[5] See Appendix A: Methodology and Appendix E: Endnotes for more details on the methodology and sources for protocols
[6] https://ghgprotocol.org/corporate-standard
[7] http://www.arb.ca.gov/cc/protocols/localgov/pubs/lgo_protocol_v1_1_2010-05-03.pdf
[8] http://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf
[9] https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html
[10] http://www.cleanenergyregulator.gov.au/NGER
[11] The NGER is referenced as being a more advanced method for estimating emissions from WWTP effluent from a research article in the Water Environment Research journal titled "Wastewater GHG Accounting Protocols as Compared to the State of GHG Science". This article compares major GHG estimating protocols and methodologies for wastewater treatment.
[12] The two greenhouse gases that MWRA does not contribute to are perfluorocarbons (PCFs) and nitrogen trifluoride (NF3).

- Nitrous oxide ($N_2O$)
- Hydrofluorocarbons (HFCs) (minor contribution)
- Sulphur hexafluoride ($SF_6$) (minor contribution)

The GHG Protocol breaks down emissions into three categories, or Scopes:

– *Scope 1* includes direct emissions from on-site energy use and process emissions from MWRA operations

– *Scope 2* includes indirect emissions associated with the consumption of fuels for operational purposes (e.g. electricity)

– *Scope 3* includes indirect emissions not included in Scope 2 and are from facilities or operations not owned or controlled by the MWRA, such as those from employee vehicles used to commute to work and emissions from the cities and towns in MWRA's service area (Scope 3 is optional to report on). An analysis of some Scope 3 emissions for MWRA can be found in the 2014 GHG Report[13].

The electricity emission factors also play a role in the reduction of GHG emissions over time. Annual emission factors are calculated by MassDEP to best represent the actual emissions from electricity sold in Massachusetts. MassDEP emission factors (EF's) include emissions from all electricity generating plants in Massachusetts divided by the total power (MWh) sold to customers. Retail-Level Emission Factors take into account 5.7% average line loss power from generators to customers  Electricity emission factors are expected to decrease each year as more renewable energy replaces fossil fuels in the Massachusetts grid, resulting in less emissions per MWh of electricity used by MWRA.

MWRA has used a combination of emission factors from specific electrical suppliers (contracted energy suppliers) and MassDEP factors (where supplier specific data was unavailable).

See Appendix A and B for more detail on Methodology and Emission Factors as well the 2006-2014 GHG Report.

[13] www.mwra.state.ma.us/sustainability/GHG_Inventory_HORIZ_DRAFT5%20.pdf

## Emissions by System – Water and Wastewater

MWRA's mission is to provide an average of 200 MGD of clean, safe drinking water to 53 cities and towns and treat an average of 350 MGD of wastewater from 43 communities (61 total communities served), therefore the GHG emissions contributed individually by water and wastewater systems is of interest. Table 1 shows the Scope 1 and 2 GHG emissions by water and wastewater systems. Since MWRA's wastewater system uses more energy for treatment and pumping of wastewater compared to the water system, there are more emissions from the wastewater system.

From 2006 to 2019, on average 10 percent of MWRA's GHG emissions were from transporting and treating drinking water, while 90 percent were from the transport and treatment of wastewater. On a unit basis, one million gallons of water generates 0.14 metric tons of $CO_2$ equivalents, while one million gallons of wastewater generates 0.67.

**Table 1: GHG Emissions by System – Water and Wastewater**

| GHG Emissions (Scope 1 & 2) | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|
| Water (metric tons CO2e) | 16,163 | 17,509 | 14,128 | 13,401 | 13,350 | 11,478 | 10,598 | 11,166 | 10,539 |
| Wastewater (metric tons CO2e) | 127,273 | 124,766 | 115,135 | 104,077 | 113,136 | 96,871 | 85,595 | 87,313 | 87,270 |
| **Total (metric tons CO2e) Scope 1 & 2** | **143,436** | **142,275** | **129,263** | **117,477** | **126,486** | **108,349** | **96,193** | **98,479** | **97,809** |

| 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|
| 11,569 | 10,064 | 9,670 | 9,668 | 9,477 |
| 88,475 | 85,330 | 87,351 | 82,463 | 81,066 |
| **100,044** | **95,395** | **97,021** | **92,131** | **90,543** |

## Greenhouse Gas Emissions Reductions to Date

As shown in Figure 3, MWRA's optimization and onsite renewable energy efforts have resulted in a reduction of total GHG emissions by 36.9% or 52,893 $tCO_2e$ (Scope 1 and 2 emissions) from 2006 through 2019. This has occurred even as new facilities have come online to meet new regulatory requirements. A breakdown of the percent change in total GHG emissions by activity is shown below:

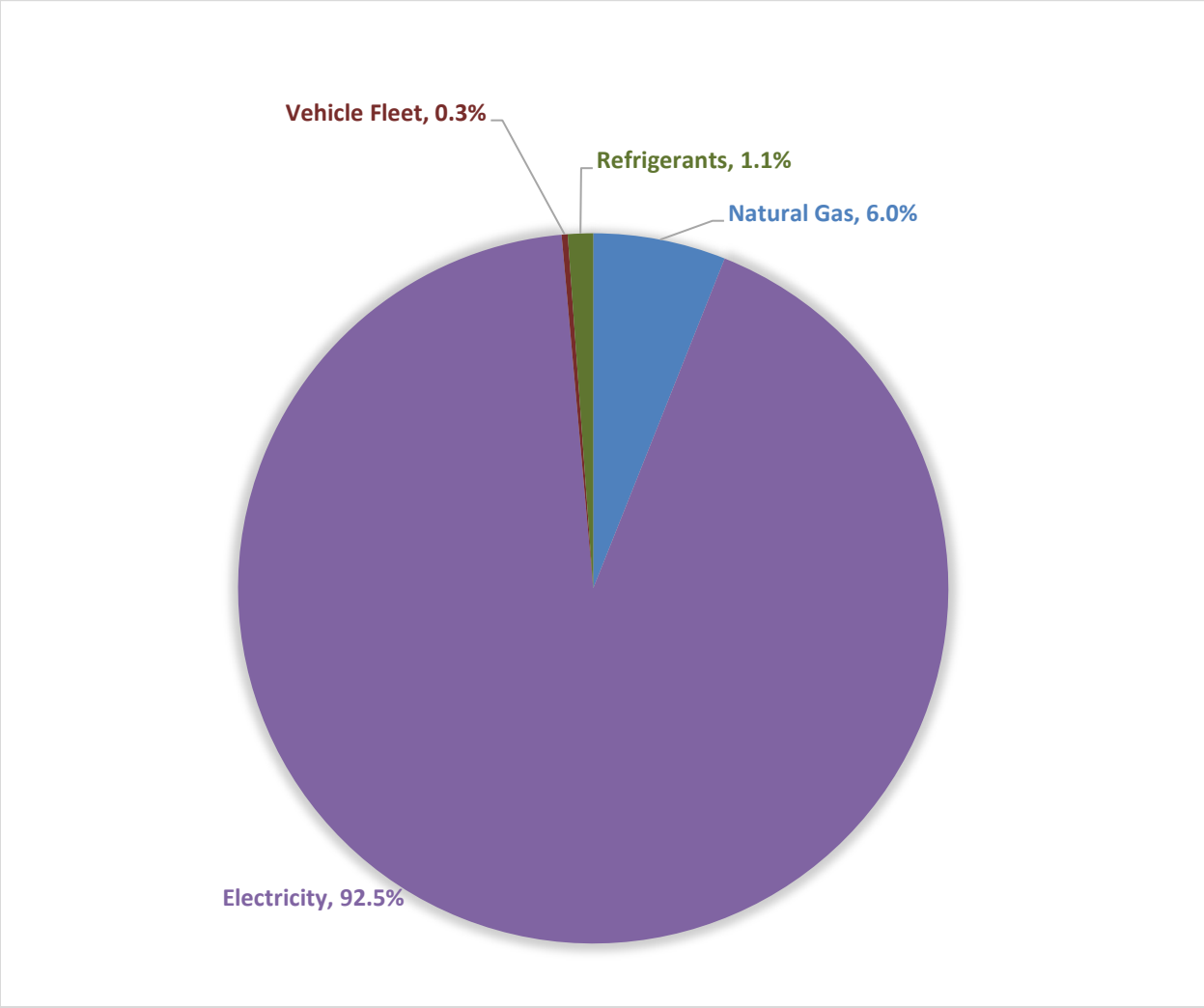
- **59.5%** reduction in emissions from **electricity use**
- **16%** reduction in emissions from **natural gas use**
- **7.1%** reduction in emissions from the **vehicle fleet**
- **22%** reduction in emissions from **digester gas flaring**
- **91%** reduction in fugitive emissions from **refrigerants**
- **100%** reduction in emissions from **digester gas venting**[14]

[14] GHG emissions from digester gas venting were reduced from 0.28 $tCO_2e$ in 2006 to 0.00 $tCO_2e$ in 2016.

Reductions in emissions from energy usage reflect the progress made in the renewable energy and energy efficiency programs at MWRA. Reductions in natural gas are primarily due to increased operating efficiency at the Biosolids Processing Facility.

The pie chart below compares only those sources that had substantive reductions in order to demonstrate the relative emissions reductions by source. Looking at reductions only, electricity accounts for the largest reduction in emissions - about 93 percent of MWRA's entire GHG emissions reductions from 2006 to 2019. Overall, MWRA has reduced GHG emissions from Scope 2 (indirect emissions from electricity production) by almost 60 percent.

**Figure 9: Percent Contribution to GHG Emissions Reductions by Source (2006 to 2019)**



## Renewable Energy and Avoided Emissions

Renewable electricity generated by MWRA from 2006 through 2019 accounts for 366,153 metric tons of $CO_2e$ of avoided GHG emissions. This is equivalent to avoiding the GHG emissions from 908 million miles driven by an average passenger vehicle.[15]

In 2019 alone, the renewable electricity generated by MWRA, a total of 55,845 MWh, prevented the emission of 27,491 metric tons of $CO_2e$. This level of avoided emissions is equal to more than 68 million miles driven by an average passenger vehicle.[13]

***Inset box on William A. Brutsch Hydroelectric Facility and the McLaughlin Fish Hatchery Pipeline:*** *Since 2017, MWRA has operated a hydroelectric turbine at the Brutsch Treatment Facility and a pipeline to the Division of Fisheries and Wildlife's (DFW) McLaughlin Fish Hatchery. This successful project has multiple benefits, including reducing MWRA's greenhouse gas emissions by generating renewable hydroelectric power, providing revenue to MWRA through energy sales to the electrical grid, reducing the hatchery's carbon footprint by eliminating electrical demand associated with pumping water from the Swift River, and delivering cold, well oxygenated water to the fish hatchery without pumping, benefiting the health and growth of the fish.*

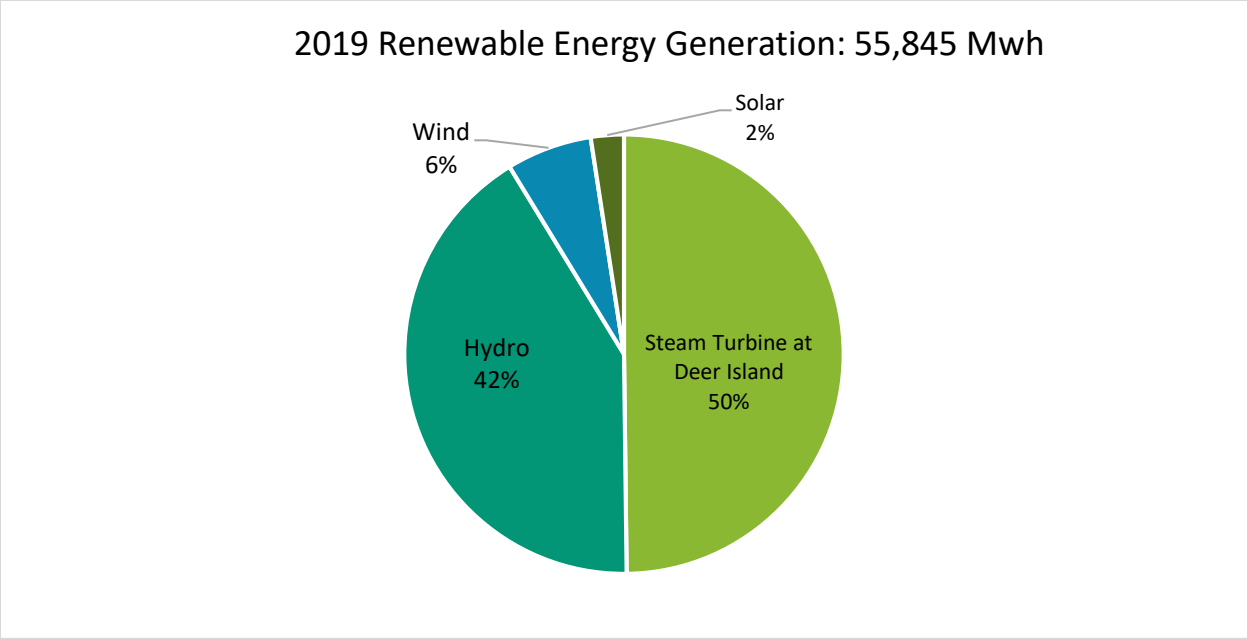
MWRA generates renewable energy through many facilities (Table 2) and by four main sources (Figure 10).

**Table 2: List of Renewable Electricity Generation Facilities and Rated Capacities**

| Facility | Rated Capacity |
|---|---|
| **Digester Gas Powered Steam** | |
| Deer Island Steam Turbine Generator | 19 MW |
| **Hydroelectric Generators** | |
| Oakdale | 3.5 MW |
| Deer Island | 2 @ 1 MW |
| Cosgrove | 2 @ 1.7 MW |
| Loring Road | 200 kW |
| Brutsch Treatment Facility (Hatchery) | 60 kW |
| **Wind Turbines** | |
| Charlestown | 1.5 MW |
| Deer Island 1 | 600 kW |
| Deer Island 2 | 600 kW |
| **Photovoltaic Solar** | |
| Carroll Water Treatment Plant | 496 kW |
| Four Locations at Deer Island | 736 kW |

[15] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

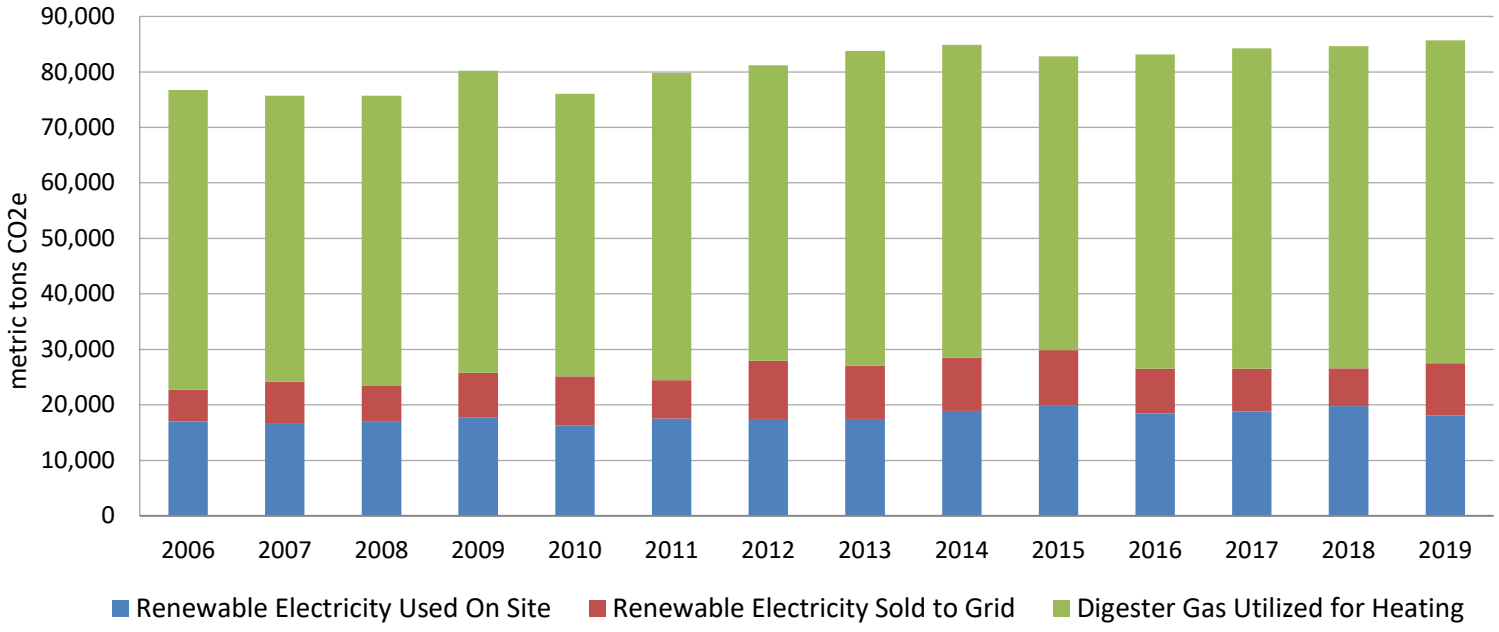
**Figure 10: MWRA Renewable Energy by Source in 2019 (MWh)**




Additionally, the use of digester gas at the Deer Island and Clinton wastewater treatment plants has allowed MWRA to avoid significant diesel and electricity use for plant operations. If diesel was used for heating instead of digester gas for the period of 2006 to 2019, there would have been an additional purchase of approximately 75 million gallons of fuel oil and 768,505 metric tons of $CO_2e$ emissions.

The chart below illustrates the impact of renewable electricity generated and used on site, renewable electricity generated and sold to the grid, the use of digester gas for heating, and the associated avoided GHG emissions in metric tons $CO_2e$ since 2006.

**Figure 11: Renewable Energy Generation & Associated Avoided Emissions, Metric Tons of $CO_2$ (2006 – 2019)**




In addition to renewable energy generation, MWRA purchases renewable energy certificates (RECs) to ensure that much of the electricity we purchase is from renewable sources. MWRA captures the economic value of RECs for the benefit of our water and sewer rate payers by selling them for renewable power MWRA produces. Although not reflected in this 2019 inventory, in November of 2021, Deer Island Treatment Plant, which accounts for two-thirds of MWRA's total electricity demand, began to purchase enough voluntary New England based RECs to ensure that 100% of the facility's electricity is from renewable energy.

## Recommendations & Next Steps

Based on this GHG inventory, opportunities for future emissions reductions continue to be related to diesel, natural gas, and electricity usage. MWRA continues to focus on both reducing its energy demand and identifying opportunities for green power production. MWRA will continue to work on reducing the use of diesel fuel, both in stationary equipment and in the vehicle fleet, as these sources account for 18 percent of total emissions.

Some recent steps that MWRA has taken to further reduce emissions in the near future include: a plan to purchase 15 dual port level II chargers (enough for 30 vehicles) and 5 DC Fast chargers for the Chelsea Operations Facility, 4 chargers at Deer Island, and 5 for the Southborough Western Operations Facility. Additionally, as of the April 2022 Interval Accounts contract award, MWRA will be buying enough RECs to bring total electricity supply up to 96% renewable.

**Additional energy projects include:**

- Battery storage pilots at Brattle Court Pumping station and our Chelsea Administration facility in order to determine the feasibility of expansion
- Investigating adding more solar to Deer Island, the Norumbega and Loring Road Underground Water Storage Tanks, and three smaller facilities
- Lighting efficiency upgrades at the Clinton Wastwater Treatment Plant, the John Carroll Water Treatment Plant, and the Nut Island Headworks facility
- Energy efficiency improvements incorporated into several facility rehabilitation projects, including the Chelsea Creek, Ward Street, and Columbus Park Head Works, Braintree Weymouth, Alewife Brook, Hingham and Hayes Pump Stations, and the Quabbin Reservoir Administration building.
- Deer Island Combined Heat and Power (CHP) Study, which aims to evaluate the existing Thermal/Power Plant and develop recommendations to reliably and economically meet Deer Island's long-term energy needs while also maximizing onsite generation and reduction of electricity purchasing.
    - Fuel Oil Use Reduction: *Executive Order 594, Leading by Example: Decarbonizing and Minimizing Environmental Impacts of State Government* sets as one of its goals the reduction of fuel oil use for heating. The new CHP will reduce Deer Island's fuel oil consumption by approximately 300,000 gallons per year, which will result in the elimination of 30 tanker truck deliveries per year.
    - Increase On-Site Generation: Along with greenhouse gas reduction is the goal of increasing the percentage of energy used at Deer Island that is generated on site. Currently, Deer Island generates 57% (by energy) to 65% (by cost) of its energy demand from onsite resources. With the new CHP, Deer Island would generate approximately 74% (by energy) to 78% (by cost) of its energy demand from on-site resources.
    - Greenhouse Gas Emissions Reduction: The new CHP would reduce the greenhouse gas emissions of Deer Island by reducing the amount of fuel oil consumed and electricity purchased. The reduction in greenhouse gas emissions expressed in metric tons per year and, to put it into perspective, the number of miles one would have to drive an automobile are summarized as follows:
      − Fuel Oil Consumed: 300,000 gallons/year reduction = 3,000 metric tons greenhouse gas /year = 8 million car miles/year
      − Electricity Purchased: 40 GWh/year reduction = 13,800 metric tons greenhouse gas /year = 34 million car miles/year
      − Total Reduction in Greenhouse Gas Emissions: 16,800 metric tons greenhouse gas /year = 42 million car miles/year

# Appendices

## Appendix A: Methodology

This inventory was designed to help the MWRA evaluate the greenhouse gas emissions associated with its operations and provide a baseline for tracking emission trends.

In line with the stated objectives of the GHG Protocol[i] in developing this inventory, the MWRA seeks to:

- Create an inventory that represents a true and fair account of its GHG emissions, through the use of standardized approaches and principles.
- Provide useful and actionable information to build an effective strategy to manage and reduce GHG emissions
- Ensure consistency and transparency in GHG accounting and reporting

The Local Government Operations Protocol (LGOP), version 1.1 and the Greenhouse Gas Protocol developed by World Resources Institute and the World Business Council for Sustainable Development were used to guide the methodology in this inventory. These tools are the standard for local government agencies in the United States, are consistent with methodologies used throughout the world, and represent best practices with regard to reporting emissions.

The Australian National Greenhouse and Energy Reporting (NGER)[ii] protocol was used in substitute for the estimation of nitrogen emissions from WWTP effluent to receiving bodies of water, due to the lack of research in the current LGOP protocol for this emission source.

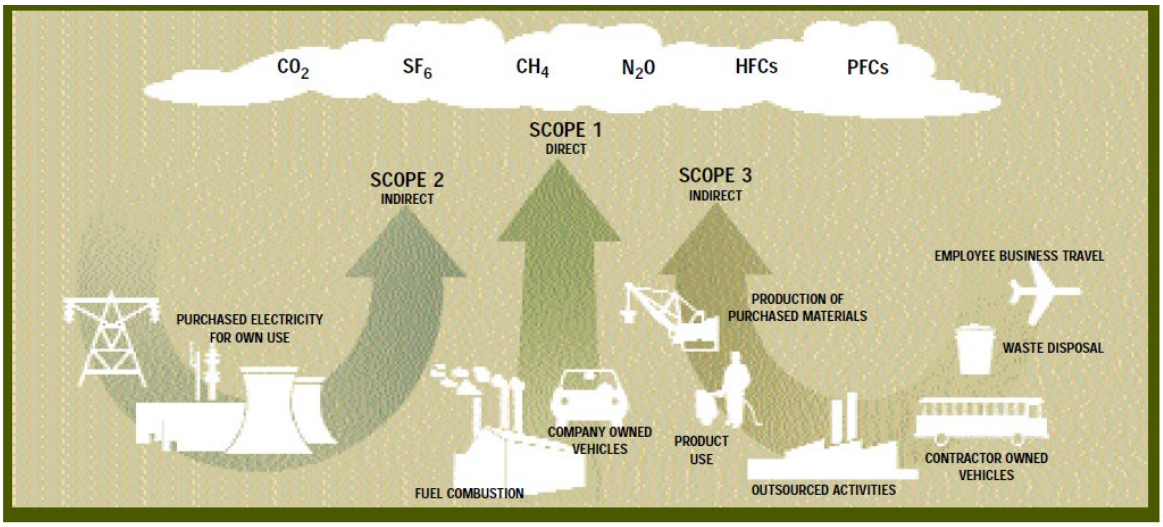
Massachusetts Department of Environmental Protection electricity emission factors[iii] were used along with supplier specific factors in substitute of EPA estimated factors for the New England Region; this represents a more accurate estimate of emissions from electricity purchases in Massachusetts.

MWRA has adhered to the principles of relevance, completeness, consistency, transparency, and accuracy for sound GHG accounting and reporting.[iv] All GHG emissions in Scope 1 and 2 occurring during the selected calendar years have been included. The Local Government Operations Protocol (LGOP) indicates that reporting on a calendar year basis is considered standard under existing international, national, state, and voluntary reporting programs, therefore MWRA has reported on a calendar year basis.

The base year for this greenhouse gas inventory is 2006 because it is the earliest year with consistent and reliable data for all emissions sources. As the MWRA monitors and tracks progress over time in reducing GHG emissions, consideration will be given for extending the base year further back.

## Operational Boundaries

In order to categorize direct and indirect emissions, to improve transparency, to standardize accounting practices, and to identify different types of climate policies and goals, emissions are reported within the bucket of one of three Scopes:




Source: GHG Protocol

Scope 1 includes process and fugitive emissions:
Process emissions include:

- Process $CH_4$ from WWTP
- Process $N_2O$ from WWTP without nitrification
- Process $N_2O$ from WWTP with nitrification
- Process $N_2O$ from effluent discharge to receiving aquatic environments

Fugitive emissions include:

- $CH_4$ from incomplete combustion of digester gas
- $CH_4$ emissions from venting digester gas
- $CH_4$ fugitive emissions from distribution
- $CO_2$ fugitive emissions from dry tonnage sludge
- $CH_4$ from landfill without LFG collection

Scope 2 emissions include:

- Emissions from electricity purchased estimated with MassDEP and supplier-based emission factors

Biogenic emissions were also accounted for, but not included in the inventory (aggregate emissions) per standard practices and guidance from the GHG Protocol and LGOP (See Appendix C).

**Biogenic emissions include:**

- Digester gas combustion and flaring ($CO_2$)
- Process $CO_2$ from digester gas
- Mobile emissions from biodiesel and ethanol

**Biogenic vs. Anthropogenic Emissions**[v]

The combustion of biomass and biomass-based fuels (such as wood, wood waste, landfill gas, ethanol, etc.) emit $CO_2$ emissions, but these $CO_2$ emissions are distinct from Scope 1 emissions generated by combusting fossil fuels. The $CO_2$ emissions from biomass combustion are tracked separately because the carbon in biomass is of a biogenic origin—meaning that it was recently contained in living organic matter—while the carbon in fossil fuels has been trapped in geologic formations for millennia. Because of this biogenic origin, the IPCC Guidelines for National Greenhouse Gas Inventories requires that $CO_2$ emissions from biomass combustion be reported separately.[vi]

**Not included in the MWRA GHG inventory:**

*Scope 1*

- Refrigerants from field operations (Deer Island and Biosolids Processing Facility refrigerants are included)
- $CH_4$ and $N_2O$ emissions from operating field equipment
- Deer Island landfill (assumed negligible)

*Scope 3*

- Grit & screenings disposed of in landfills by MWRA contractor
- Life cycle emissions of chemicals used (including liquid oxygen and soda ash)
- Contracted transportation
- Energy extraction/production/transportation
- Contracting construction and new projects
- Life cycle emissions of goods and services procured
- Waste emissions

**Rationale for exclusion of certain emissions sources**

Per the guidelines set forth in the LGOP, the water and wastewater systems at MWRA were studied and interviews conducted with facilities managers and engineers in order to identify any additional potential emissions sources.

Emissions from refrigerants were only accounted for at the Deer Island and Biosolids Processing facilities for the following reasons:

1) emissions from refrigerants in field operations were perceived to be insignificant relative to other sources based on the mandatory reporting of HFCs by MWRA for the Deer Island Wastewater Treatment facility and the Biosolids Processing Facility
2) the data was difficult to collect and in some cases not available
3) insufficient time during this phase of the project.

Several Scope 3 emissions sources, which are by definition optional to report, were excluded during this phase of the project. Future updates may be expanded to include Scope 3 emissions from sources such as contracted transportation (trucks, trains, barges), life cycle of chemicals (especially liquid oxygen and soda ash), and energy extraction and distribution. Scope 3 emissions, despite being indirect, often provide important and actionable information. For this reason, MWRA conducted an authority-wide Employee Commuter Survey to assess Scope 3 emissions associated with employee commuting. The results of this commuter survey will aid in the strategic emissions reduction plan.

**Calculation methods:**

Activity data[vii] are the relevant measurement of energy use or other GHG generating processes. Examples of activity data referenced in this Protocol include fuel consumption by fuel type, metered energy consumption, and vehicle mileage by vehicle type. Activity data are used in conjunction with an emission factor (see Appendix B) to determine emissions using the following generalized equation:

Activity Data x Emission Factor = Emissions

## Appendix B: Emission Factors and Global Warming Potentials

Emission factors[viii] are calculated ratios relating GHG emissions to a proxy measure of activity at an emissions source. Emission factors are used to convert activity data, like energy usage, into the associated GHG emissions and thus are central to creating an emissions inventory. Emissions factors are usually expressed in terms of emissions/energy used (e.g., lbs. of $CO_2$/kWh).

Emission factors are determined by means of direct measurement, laboratory analyses or calculations based on representative heat content and carbon content. The Local Government Operations Protocol (LGOP) provides default emission factors for most calculation methodologies.

When available, the MWRA has worked to identify location-based and supplier-specific emission factors for electricity that are representative of the technology and energy mix employed.

Location-based (local eGrid subregion) method reflects the average emissions intensity of electricity grids on which energy consumption occurs (using mostly grid-average emission factor data).[ix]

Supplier-specific method reflects emissions from electricity that companies have purposefully chosen (or their lack of choice). It derives emission factors from contractual instruments, which include any type of contract between two parties for the sale and purchase of energy bundled with attributes about the energy generation, or for unbundled attribute claims.[ix]

Massachusetts-based (MassDEP) approach reflects the average emissions of electricity generation for all energy that is consumed by the state. [x]

Where supplier-specific or MWRA-specific data or emissions factors were not available, default data were used that was made available by either the LGOP v1.1 or the MassDEP. The default data are gathered by federal agencies and other sources covering the default emission factors and system assumptions needed to calculate emissions according to the LGOP.

### Stationary Scope 1 Emissions Factors

| Natural Gas | CO2 | CH4 | N2O |
|---|---|---|---|
| | kg CO2/mmBtu | g CH4 / mmBtu | g N2O / mmBtu |
| | 53.06 | 1 | 0.1 |
| | kg CO2/mmBtu | kg CH4 / mmBtu | kg N2O / mmBtu |
| | 53.06 | 0.001 | 0.0001 |

Source: EPA Climate Leaders Emission Factors, updated April 2021

| Digester Gas | CO2 | CH4 | N2O |
|---|---|---|---|
| | kg CO2 / MMBtu | kg CH4 / mmBtu | kg N2O / mmBtu |
| | 52.07 | 0.0032 | 0.00063 |

Source: EPA Climate Leaders Emission Factors, updated April 2021

| Diesel Fuel (Mobile) | CO2 | CH4 | N2O |
|---|---|---|---|
| | kg CO2 / gallon | kg CH4 / gallon | kg N2O / gallon |
| | 10.21 | 0.00041 | 0.00008 |

Source: EPA Climate Leaders Emission Factors, updated April 2021

| Diesel (Stationary) - Distillate Fuel #2 | CO2 | CH4 | N2O |
|---|---|---|---|
| | kg CO2 / MMBtu | kg CH4 / mmBtu | kg N2O / mmBtu |
| | 73.96 | 0.003 | 0.0006 |

Source: EPA Climate Leaders Emission Factors, updated April 2021

| Propane | CO2 | CH4 | N2O |
|---|---|---|---|
| | kg CO2/mmBtu | g CH4 / mmBtu | g N2O / mmBtu |
| | 62.87 | 3 | 0.6 |
| | kg CO2/mmBtu | kg CH4 / mmBtu | kg N2O / mmBtu |
| | 62.87 | 0.003 | 0.0006 |

Source: EPA Climate Leaders Emission Factors, updated April 2021

## Mobile Emissions Factors

| Vehicle Fuel Use | CO2 |
|---|---|
| Mobile Combustion CO2 | kg CO2 / gallon |
| Motor Gasoline | 8.78 |
| Diesel Fuel | 10.21 |
| Ethanol | 5.75 |
| Biodiesel | 9.45 |

Source: EPA Climate Leaders Emission Factors, updated April 2021

| Vehicle Mileage | | | |
|---|---|---|---|
| | | CH4 | N2O |
| Vehicle Type | Vehicle Year | kg/mile | kg/mile |
| Diesel Heavy-Duty Vehicle | 1960-present | 0.0000051 | 0.0000048 |
| Diesel Light-Duty Truck | 1983-1995 | 0.0000005 | 0.000001 |
| Diesel Light-Duty Truck | 1996-present | 0.0000005 | 0.000001 |
| | | | |
| CNG Light-Duty Truck | All | 0.000737 | 0.00005 |
| | | | |
| Gasoline Heavy-Duty Vehicle | 1990-1995 | 0.0003246 | 0.0001142 |
| Gasoline Heavy-Duty Vehicle | 1997 | 0.0000924 | 0.0001726 |
| Gasoline Heavy-Duty Vehicle | 1998 | 0.0000641 | 0.0001693 |
| Gasoline Heavy-Duty Vehicle | 1999 | 0.0000578 | 0.0001435 |
| Gasoline Heavy-Duty Vehicle | 2000 | 0.0000493 | 0.0001092 |
| Gasoline Heavy-Duty Vehicle | 2001 | 0.0000528 | 0.0001235 |
| | | | |
| Gasoline Light-Duty Truck | 1987-1993 | 0.0000813 | 0.0001035 |
| Gasoline Light-Duty Truck | 1994 | 0.0000646 | 0.0000982 |
| Gasoline Light-Duty Truck | 1995 | 0.0000517 | 0.0000908 |
| Gasoline Light-Duty Truck | 1996 | 0.0000452 | 0.0000871 |
| Gasoline Light-Duty Truck | 1997 | 0.0000452 | 0.0000871 |
| Gasoline Light-Duty Truck | 1998 | 0.0000391 | 0.0000728 |
| Gasoline Light-Duty Truck | 1999 | 0.0000321 | 0.0000564 |
| Gasoline Light-Duty Truck | 2000 | 0.0000346 | 0.0000621 |
| Gasoline Light-Duty Truck | 2001 | 0.0000151 | 0.0000164 |
| Gasoline Light-Duty Truck | 2002 | 0.0000178 | 0.0000228 |
| Gasoline Light-Duty Truck | 2003 | 0.0000155 | 0.0000114 |
| Gasoline Light-Duty Truck | 2004 | 0.0000152 | 0.0000132 |
| Gasoline Light-Duty Truck | 2005 | 0.0000157 | 0.0000101 |
| Gasoline Light-Duty Truck | 2006 | 0.0000159 | 0.0000089 |
| Gasoline Light-Duty Truck | 2007 | 0.0000161 | 0.0000079 |
| Gasoline Light-Duty Truck | 2008-present | 0.0000163 | 0.0000066 |
| | | | |
| Gasoline Passenger Car | 1992 | 0.0000704 | 0.0000647 |
| Gasoline Passenger Car | 1995 | 0.0000358 | 0.0000473 |
| Gasoline Passenger Car | 1996 | 0.0000272 | 0.0000426 |
| Gasoline Passenger Car | 1998 | 0.0000249 | 0.0000393 |
| Gasoline Passenger Car | 2000 | 0.0000178 | 0.0000273 |
| Gasoline Passenger Car | 2002 | 0.0000107 | 0.0000153 |
| Gasoline Passenger Car | 2003 | 0.0000114 | 0.0000135 |
| Gasoline Passenger Car | 2009-present | 0.0000173 | 0.0000036 |

Source: EPA Climate Leaders Emission Factors, updated April 2021

**Process and Fugitive Emissions Factors**

| | |
|---|---|
| **Emission factor for a WWTP without nitrification/ denitrification (g N2O/person/year)** | **3.2** |
| **Emission factor for a WWTP with nitrification/denitrification (g N2O/person/year)** | **7** |
| **Emission factor [kg N2O-N/kg sewage-N produced]** | **0.005** |
| **Natural Gas Fugitve Emissions from Distribution: Simplified Estimation Method: Emissions Factor (mt CH4/mile of pipe)** | **1.611** |

Source: LGOP v1.1 & GRP electric power sector, ST-07

**Electricity Emissions Factors**

| Supplier-specific electricity emissions factors | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| lbs CO2e / kWh | 0.977 | 1.005 | 0.906 | 0.838 | 0.846 | 0.701 | 0.638 | 0.649 | 0.615 | 0.697 | 0.615 | 0.580 | 0.486 | 0.468 |

Source: Massachusetts Department of Enviornmental Protection

**Renewables and Avoided GHG Emissions Factors**

| eGrid: Northeast Power Coordinating Council (NPCC) New England | | |
|---|---|---|
| **lbs CO2 / kWh** | **lbs CH4 / kWh** | **lbs N2O / kWh** |
| **1.07973** | **0.0000677** | **0.0000129** |

Source: NPCC Emissions Factors, eGrid year 2012. (October 2015)
Important: The emissions factors for Renewables and Avoided Emissions are the "Annual Non-Baseload Output Emissions Rates"

**Global Warming Potentials (GWP)** are conversion factors used to compare all greenhouse gas emissions to carbon dioxide equivalent units. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation. All calculations presented in this report are based on global warming potentials published by the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report[xi].

| Global Warming Potentials | |
|---|---|
| **CO2** | **1** |
| **CH4** | **25** |
| **N2O** | **298** |

Source: IPCC, AR4

| Global Warming Potentials | |
|---|---|
| R-134a | 1,430 |
| R-404A | 3,922 |
| R-407C | 1,774 |
| R-410A | 2,088 |

Source: IPCC, AR4

## Appendix C: Emissions Tables (including Biogenic)

Emissions by Scope:

MWRA's contributions to greenhouse gas emissions, in metric tons of $CO_2e$[16] by Scope and year are shown in Table 2 below. It is important to note that 2006 was established as the base year since it was the earliest year for which reliable and comprehensive data was available. Some of the categories that are impacted by external factors such as weather, regulations, and customer demand, show variation in emissions from year to year rather than a steady trend. For example, emissions spiked in 2010 as a result of increased diesel fuel usage for that year. There was an extended period of record rainfall that necessitated the use of the emergency backup generators at DITP to ensure the plant had reliable power to support continuous wastewater pumping and treatment.

**Table 3: GHG Emissions by Scope – 2010 through 2019[17]**

| Metric tons CO2e by type | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| Scope 1 (direct) | | | | | | | | | | |
| Stationary | 40,774 | 28,196 | 27,787 | 27,959 | 28,771 | 29,077 | 31,385 | 34,913 | 34,559 | 34,902 |
| Mobile | 2,155 | 2,131 | 2,083 | 2,099 | 2,081 | 2,142 | 1,966 | 2,060 | 2,047 | 1,989 |
| Process | 5,599 | 7,777 | 6,082 | 5,780 | 8,115 | 7,253 | 7,877 | 7,511 | 6,796 | 6,794 |
| Fugitive | 11,001 | 11,544 | 11,227 | 11,671 | 11,458 | 9,836 | 10,913 | 11,327 | 11,418 | 11,895 |
| Total Scope 1 | 59,529 | 49,649 | 47,179 | 47,508 | 50,425 | 48,308 | 52,141 | 55,810 | 54,820 | 55,580 |
| Scope 2 (indirect) | | | | | | | | | | |
| Electricity (MA DEP/supplier | 66,957 | 58,700 | 49,014 | 50,971 | 47,384 | 51,736 | 43,254 | 41,210 | 37,312 | 36,328 |
| **Total (metric tons CO2e) Scope 1 & 2** | **126,486** | **108,349** | **96,193** | **98,479** | **97,809** | **100,044** | **95,395** | **97,021** | **92,131** | **91,908** |

As the data in Table 2 shows, MWRA's total GHG emissions have decreased over the last 10 years, due primarily to reductions in emissions from electricity purchased. Most of the other categories have been relatively stable with the exception of emissions from stationary sources which vary with the need for the diesel generators being used during wet weather events. These reductions are due to MWRA's efforts to reduce the energy used by its pump stations, headworks, and water and wastewater treatment plants in addition to the increase of on-site renewable energy at some of these stationary MWRA facilities. There has also been a slight decrease in mobile emissions due to the use of more fuel efficient fleet vehicles.

As Table 2 shows, indirect energy consumption is the largest single source of emissions. These emissions were calculated using Massachusetts Department of Environmental Protection electricity emission factors along with supplier specific factors in substitute of EPA estimated

[16] $CO_2e$ is carbon dioxide equivalent, which is a measure that allows the comparison of the emissions of other greenhouse gases relative to one unit of $CO_2$.
[17] Annual data based on Calendar Year (January 1 – December 31).

factors for the New England Region; this represents a more accurate estimate of emissions from electricity purchases in Massachusetts.

Large contributors to direct energy consumption associated GHG emissions include natural gas use - primarily by the heaters and dryers at the Biosolids Processing Facility, and diesel use - most significantly by the backup generators at DITP, and in the MWRA's vehicle fleet.

Below Table 3 includes estimated biogenic emissions from MWRA. This includes digester gas used to generate heat on Deer Island. LGOP reporting standard requires that these emissions be reported separately from anthropogenic emissions and Scope 1 emissions.

"Local governments should, at a minimum, quantify and report all Scope 1 and Scope 2 emissions. Reporting of Scope 3 emissions is optional - see Sections 4.6 and Chapter 12 for more information on Scope 3 emissions. Biogenic CO2 emissions from the combustion of biomass should also be quantified and reported, but should not be included in Scope 1 emissions. Biogenic emissions from combustion should instead be reported separately from the Scopes (see Section 4.5)."[xii]

**Table 4: MWRA Biogenic Emissions**

| tCO2e by type | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| Biogenic Biogas Combustion CO2 | 48774 | 52296 | 50612 | 53003 | 53382 | 50194 | 53474 | 54599 | 54982 | 55248 |
| Biogenic Biogas Flaring CO2 | 1854 | 1202 | 1414 | 1324 | 1689 | 998 | 1560 | 1065 | 637 | 1710 |
| Biogenic Ethanol CO2 | 64 | 62 | 61 | 60 | 60 | 57 | 57 | 58 | 57 | 54 |
| Biogenic Biodiesel CO2 | 61 | 62 | 60 | 62 | 60 | 66 | 57 | 61 | 61 | 61 |
| Digester Gas Process CO2 | 30480 | 33754 | 33039 | 32435 | 32613 | 33276 | 32215 | 33240 | 34222 | 34632 |

## Appendix D: Glossary[xiii]

Anthropogenic emissions: Emissions that are human-made and not a result of the natural carbon cycle. In the instance of the combustion of digester gas, methane (CH4) and nitrous oxide (N2O) emissions are considered anthropogenic, while carbon dioxide (CO2) emissions are considered biogenic.

Base Year: A measurement, calculation, or time used as a basis for comparison. According to LGOP, it is good practice to aim for a base year that is likely to be representative of the general level of emissions over the surrounding period.

BAU: Business As Usual. Used to refer to a future scenario in which there are no changes to the status quo.

Biogenic: Biogenic emissions or fuels are produced by the biological processes of living organisms. Note that this term refers only to recently produced (i.e., non-fossil)

BOD5: Biological Oxygen Demand. The amount of oxygen consumed in five days by decomposing waste, used to measure the amount of waste input or output into a system.

BPF: Biosolids Processing Facility (aka Pellet Plant)

Btu: British Thermal Units, a measure of energy

CEMS: Continuous Emissions Monitoring System

CFC: chorofluorocarbon, a greenhouse gas.

CHP: combined heat and power

$CO_2$: Carbon dioxide

$CO_2e$: Carbon dioxide equivalent emissions. This is determined by multiplying the emissions of methane and nitrous oxide by their Global Warming Potential.

$CH_4$: Methane. Methane is a greenhouse gas with a GWP that is 21 times that of $CO_2$. It is produced through anaerobic decomposition of waste, enteric fermentation, production of natural gas and petroleum products, and other industrial processes.

Denitrification: The process by which microorganisms remove nitrogen from its fixed form in the soil and release it into the atmosphere in the form of nitrous oxide ($N_2O$)

Direct Emissions: The emissions generated on-site (as opposed to electricity delivered through a grid system), such as from the combustion of fossil fuels

DITP: Deer Island Treatment Plant

EF: See Emission Factor.

Effluent: The treated or untreated wastewater that flows out of a source

Emissions Factor: The value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., grams of carbon dioxide emitted per barrel of fossil fuel consumed). An emission factor is an amount of GHG emissions associated with a unit of activity data. For example, kg $CO_2$ emitted per kWh electricity produced (kg $CO_2$/kWh), or lb $CO_2$ emitted per gallon of gasoline (lb $CO_2$/gal)**.**

EPA: United States Environmental Protection Agency

FOD: first-order decay

Fossil Fuel: Any fuel derived from the pre-historic burial of organic matter. Examples include natural gas (methane or $CH_4$) and petroleum products (gasoline, diesel, kerosene, propane, and others). Combustion of petroleum products releases greenhouse gases into the atmosphere.

FTE: full-time employee

Fugitive Emissions: Emissions of gases that escape from pressurized equipment, such as fuel transportation pipelines or wastewater treatment plants.

g: gram(s)

GHG: Greenhouse gas

GRP: General Reporting Protocol

GWP: Global Warming Potential. Conversion factor used to compare all greenhouse gas emissions to carbon dioxide equivalent units. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation.

HCFC: hydrochlorofluorocarbon

HFC: hydrofluorocarbon

HHV: higher heating value

ICLEI : International Council for Local Environmental Initiatives **- Local Government for Sustainability** is an international association of local governments as well as national and regional organizations that have made a commitment to sustainable development.

Indirect emissions: Refers to indirect emissions associated with the consumption of purchased or acquired electricity, steam, heating, or cooling. These emissions can be allocated in an inventory to an entity, but are generated offsite. An example is electricity that is not generated directly at a facility. A facility uses electricity on-site, but the fuels used to generate the electricity are combusted off-site, perhaps at a regional power plant. If the generation source is at a different site that is also operated by the city, it is not an indirect emission source.

IPCC: Intergovernmental Panel on Climate Change

kg: kilogram(s)

kWh: kilowatt-hour(s)

lb(s): pound(s)

LFG: landfill gas

LGOP: Local Government Operations Protocol

LHV: lower heating value

mcf: thousand cubic feet of natural gas

MG: million gallons

mmBtu: million British Thermal Units, a measure of energy

Mobile combustion: The combustion of fuels to power a moving vehicle, such as gasoline or diesel fuel in a car or truck

mpg: miles per gallon

MT $CO_2e$: Metric tons of carbon dioxide equivalent. This is the standard unit for measuring greenhouse gas emissions.

MWh: megawatt-hour(s)

MWRA: Massachusetts Water Resources Authority

$N_2O$: nitrous oxide

$NF_3$: nitrogen trifluoride

Nitrification: Biological process in which ammonia is converted to nitrate ($NO_3$).

Operational control: A local government has operational control over an operation if it has the full authority to introduce and implement its operating procedures

PFC: perfluorocarbon

Process Emissions: emissions from physical or chemical processes such as CO2 from the calcination step in cement manufacturing, CO2from catalytic cracking in petrochemical processing, PFC emissions from aluminum smelting, etc.

REC: renewable energy certificates

S1: see Scope 1 emissions

S2: See Scope 2 emissions

S3: See Scope 3 emissions

Scope 1 Emissions: All direct GHG emissions

Scope 2 Emissions: Indirect GHG emissions from the consumption of purchased electricity, heat, or steam.

Scope 3 Emissions: Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, outsourced activities, etc. The Scope 3 emissions included in this inventory are employee commutes, imported water consumption, waste generation, urban forestry, and agriculture & land management.

Short tons: American ton, equal to 2,000 lbs. One short ton = 0.907 metric tons

Stationary Combustion: The on-site combustion of fuels to produce electricity, heat, or motive power using equipment in a fixed location

$SF_6$: sulfur hexafluoride

T&D: transmission and distribution (electricity)

tCO2e: metric tons carbon dioxide equivalent. This is the standard unit for measuring greenhouse gas emissions.

WBCSD: World Business Council for Sustainable Development

WRI: World Resources Institute

WW: Wastewater

WWTP: Wastewater treatment plant**Appendix E: Endnotes**

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i Greenhouse Gas Protocol Corporate Standard: http://www.ghgprotocol.org/standards/corporate-standard

ii http://www.cleanenergyregulator.gov.au/NGER

iii http://www.mass.gov/eea/agencies/massdep/climate-energy/climate/approvals/ma-greenhouse-gas-emissions-reporting-program.html#1

iv Greenhouse Gas Protocol Corporate Standard: http://www.ghgprotocol.org/standards/corporate-standard

v See EPA Accounting Framework for Biogenic CO2 Emissions from Stationary Sources: http://www.epa.gov/climatechange/Downloads/ghgemissions/Biogenic-CO2-Accounting-Framework-Report-Sept-2011.pdf

vi See the LGOP v1.1, http://www.arb.ca.gov/cc/protocols/localgov/localgov.htm

vii See the LGOP v1.1, http://www.arb.ca.gov/cc/protocols/localgov/localgov.htm

viii See the LGOP v1.1, http://www.arb.ca.gov/cc/protocols/localgov/localgov.htm

ix GHG Protocol: Scope 2 Guidance: http://ghgprotocol.org/files/ghgp/Scope2_ExecSum_Final.pdf

x Technical Support Document: Draft 2013 GHG Emission Factors: http://www.mass.gov/eea/docs/dep/air/climate/rse13tsd.pdf

xi https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

xii See the LGOP v1.1, http://www.arb.ca.gov/cc/protocols/localgov/localgov.htm

xiii Definitions provided by the EPA's Local Greenhouse Gas Inventory Tool: http://epa.gov/statelocalclimate/resources/local-GHG-inventory-tool.html