Massachusetts Water Resources Authority

Greenhouse Gas Emissions Inventory Update 2006–2016

December 2017

This addendum is an update to the previous MWRA Greenhouse Gas Inventory which covered years 2006-2014. This addition includes an update for 2015 and 2016. The newer data will be added to the previous reports data to show GHG emissions from 2006-2016.

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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 (MA DEP), 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.

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Overview and Background

Massachusetts Water Resources Authority (MWRA) provides wholesale water and sewer services to over 2.5 million people and 5,500 industrial and commercial users in 61 metro Boston communities.

MWRA has also been a leader in environmental stewardship and as part of this commitment, 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 addition to the 2006-2014 Greenhouse Gas (GHG) Inventory is part of the ongoing work to reduce energy use, save money on energy costs, and reduce overall GHG emissions.

An Overview and Background section describing MWRA's Energy Demand and Energy Initiatives is located in the 2014 GHG Inventory[1].

Solar Panels at Deer Island – contribute to renewable energy generated and used on-site.

Objectives

The objectives of the GHG Emissions Inventory were fourfold:

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

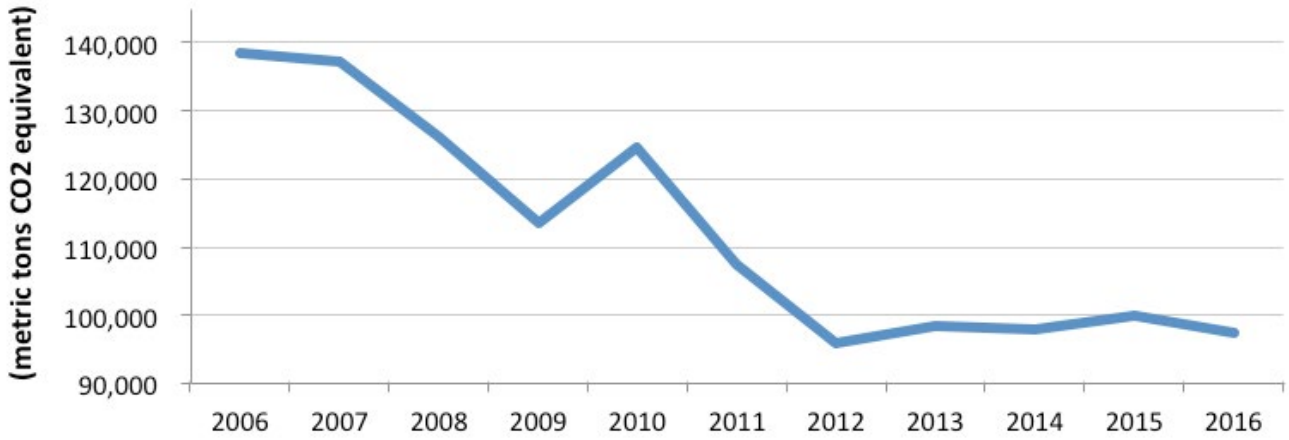
As outlined in the methodology section, the analysis followed standard GHG reporting protocols, involving significant data collection and staff input.

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

Greenhouse Gas Emissions Summary

Over the last eleven years, MWRA has reduced its GHG emissions by 32.1 percent[2] (between 2006 and 2016) as shown in Figure-1 below, and a further 1 percent reduction from the 2014 GHG inventory. The reduction from 2014-2016 is mostly associated with less electricity purchased for Deer Island Treatment Plant and wastewater operations (further discussed below). By continuing to measure and analyze GHG emissions, MWRA is able to quantify its emissions and track the progress it is making from on-going energy conservation efforts, as well as target areas for future reductions.

Figure 1[3]: MWRA GHG Emissions (from 2006 – 2016)



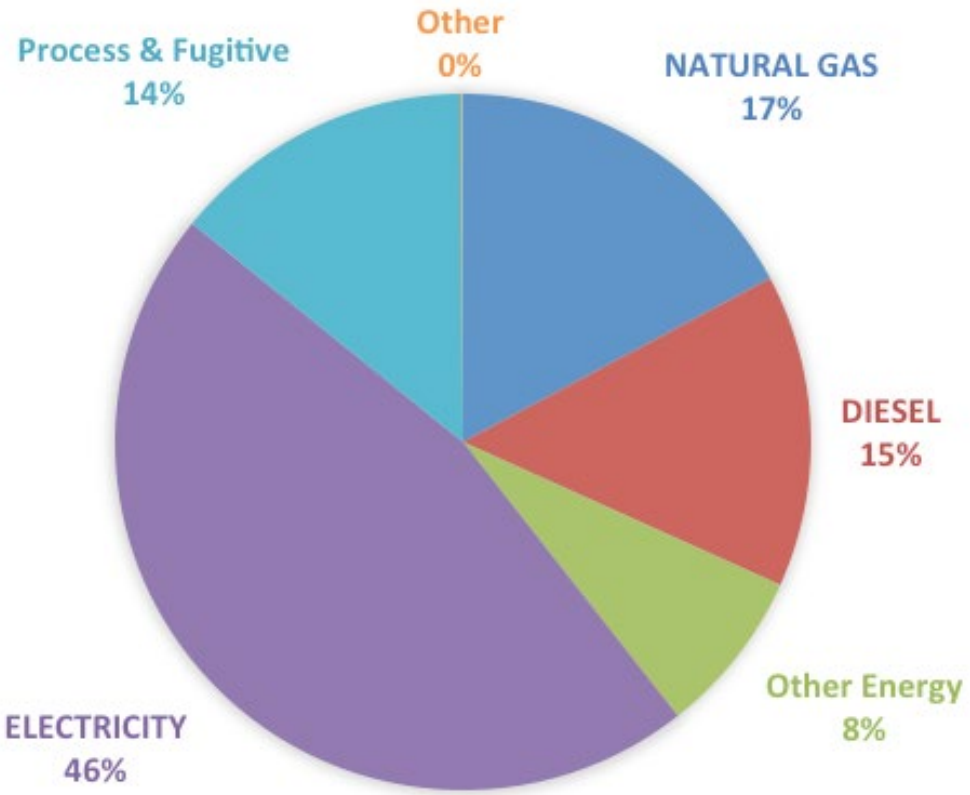
[2] *32.1% reduction includes total emissions from Scopes 1 and 2, which are the two emissions categories directly or indirectly owned and controlled by the reporting entity. Emissions from electricity purchased (Scope 2) are calculated using Massachusetts DEP and energy supplier based Emission Factors (EF's) which were available up to 2015 at the time of reporting 2016 emissions. 2016 EF's are estimated based on available 2015 values and will be updated in future reports. 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.*

In 2016 the major sources of GHG emissions in the MWRA's operations (as a percent of total emissions) include:

- Electricity, 46%
- Natural gas, 17%
- Diesel, 15%
- Various other sources including fleet vehicle emissions, fugitive emissions, and process methane (CH4) emissions make up the remaining 22%.

Figure 2: MWRA GHG Emissions Sources, 2016

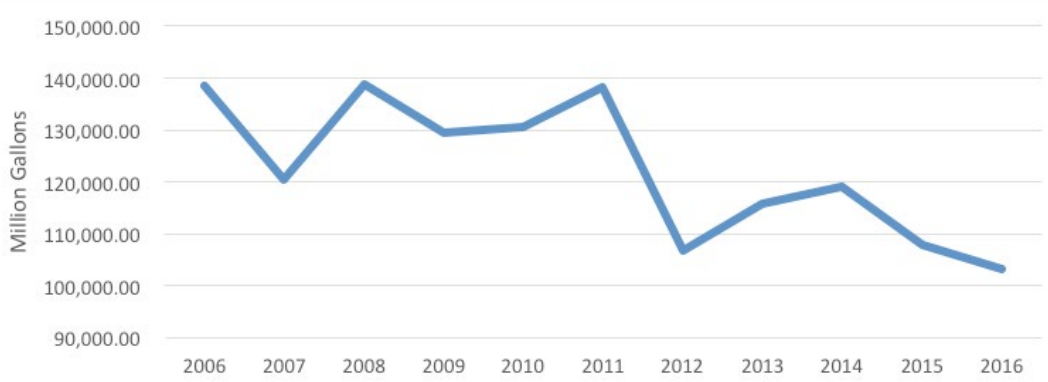


The majority of GHG reductions from 2014 to 2016 are attributed to less electricity purchased from the grid. The primary reasons for significant reduction in electricity purchases are threefold:

- Lower annual wastewater flows
- Energy conservation projects
- HEEC cable work associated with the Boston Harbor dredging project necessitated use of diesel fuel at Deer Island.

There has been a 25.4% reduction in wastewater treated flow from 2006 to 2016 as shown in Figure 3 below.

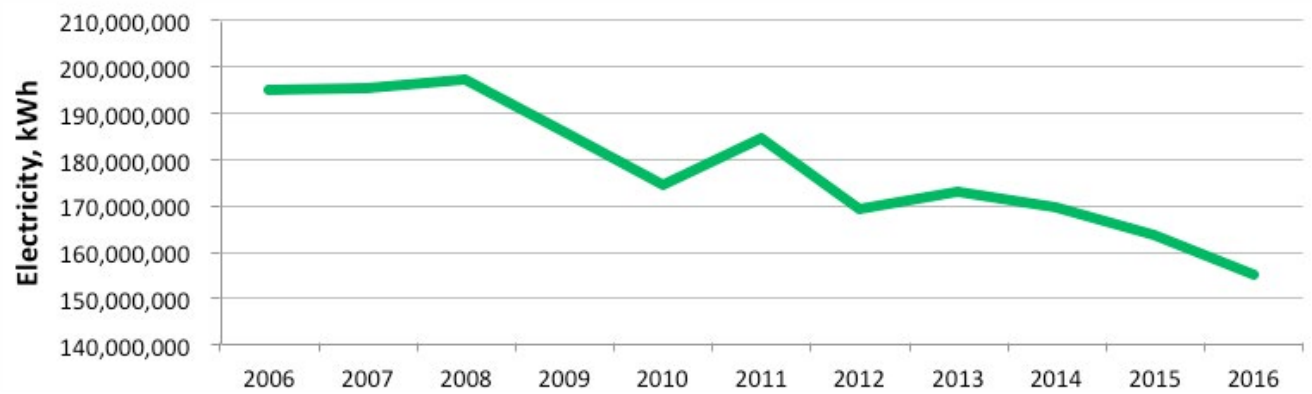
Figure 3: Deer Island Treatment Plant Total Flow Trend, (2006-2016)



Electricity is the principal purchased energy source, representing over 72% of utility spending. Deer Island Treatment Plant (DITP) alone accounts for an average of 69% of all direct purchased electricity (over last 10 years). With a 13% decrease in wastewater flow to Deer Island from 2014 to 2016, there has been a 9% and 17% reduction in electricity purchases (kWh) at Deer Island and other wastewater facilities, respectively.

The primary electric power source for the Deer Island Treatment Plant is the is a 115 kW submerged marine cable that starts at K Street in South Boston and goes under the Boston Harbor to Deer Island (called the HEEC cable). Cable shut downs during December 2016 and early 2017 related to a planned harbor dredging project required MWRA to use its Combustion Turbine Generators (CTG's) to provide electrical power for the entire DITP during those periods. This substitution of diesel powered generators for grid supplied electricity can be seen in fuel usage, electricity purchases and greenhouse gas emissions.

Figure 4: Trend in Electricity Purchased, kWh (2006-2016)



There has been a 20.5% reduction in MWRA electricity purchased from 2006 to 2016. This is partly due to increases in renewable electricity usage, lower annual wastewater flows, energy efficiency improvements made throughout the MWRA system, and in 2016 the HEEC cable work which is part of the Boston Harbor dredging project.

A number of examples of MWRA energy efficiency projects were outlined in the 2014 GHG Inventory. Below is one instance where electricity was saved at a water pumping station. MWRA continues to audit its facilities in order to maximize its energy reductions, energy cost savings, and GHG reductions.

Spring Street Water Pump Station Pipe Insulation – condensation on cold incoming water pipes necessitated the use of dehumidification and resulted in puddles on the floor. Insulation eliminated the condensation problem, thereby significantly reducing the need for dehumidification and created a safer work environment by eliminating the puddling.

Methodology

The approach to building the MWRA GHG inventory is consistent with international and national standards and best practices. Both the Greenhouse Gas Protocols - Corporate Accounting and Reporting Standard, and the Local Government Operations Protocol (LGOP), version 1.1,[6] were used as the core guiding documents. The EPA Climate Leadership for Greenhouse Gas Inventories[7] was used to identify emissions factors and the IPCC Fourth Assessment Report[8] was referenced for global warming potentials. The Australian National Greenhouse and Energy Reporting[9] (NGER) protocol was used to estimate nitrogen emissions from WWTP effluent to receiving bodies of water.[10] 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 included in the Protocol, however the five listed below are the only ones that MWRA's operations contribute to:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs) (minor contribution)
- Sulphur hexafluoride (SF_6) (minor contribution)

[4] *See Appendix A: Methodology and Appendix E: Endnotes for more details on the methodology and sources for protocols*
[5] *http://www.ghgprotocol.org/corporate-standard*
[6] *http://www.arb.ca.gov/cc/protocols/localgov/pubs/lgo_protocol_v1_1_2010-05-03.pdf*
[7] *http://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf*
[8] *https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf*
[9] *https://www.environment.gov.au/system/files/resources/da7bde5c-1be2-43f7-97d7-d7d85bb9ad6c/files/nger-technical-guidelines-2014.pdf*
[10] *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.*

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 (i.e. electricity) and

– 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's 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 Scope 3 emissions for MWRA can be found in the 2014 GHG Report.[11]

The electricity emission factors also play a role in the reduction of GHG emissions over time. Annual emission factors are calculated by MA DEP to best represent the actual emissions from electricity sold in Massachusetts. MA DEP 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. 2016 emission factors were not published by MA DEP in time for this report, and they may change by the next GHG report.

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

See Appendix A and B for more detail on methodology and Emission Factors.

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

Emissions by System – Water and Wastewater

MWRA's mission is to provide clean, safe drinking water to 51 cities and towns and treat an average of 350 MGD of wastewater from 45 communities (61 total communities served), therefore the GHG emissions contributed individually by water and wastewater systems is of interest. Table 5 shows the Scope 1 and 2 GHG emissions by water and wastewater systems. Since MWRA's wastewater systems uses more energy for treatment and pumping of wastewater compared to the water system (which primarily uses gravity for distribution), there are more emissions from the wastewater system.

Eleven percent of MWRA's GHG emissions are from transporting and treating drinking water, while 89 percent are from the transport and treatment of wastewater.

Table 1: GHG Emissions by System – Water and Wastewater

GHG Emissions (Scope 1 & 2)	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Water (metric tons CO_2e)	16,161	17,509	14,128	13,401	13,350	11,478	10,598	11,166	10,539	11,569	10,375
Wastewater (metric tons CO_2e)	127,270	124,766	115,135	104,077	113,136	96,871	85,595	87,313	87,270	88,409	87,006
Total (metric tons CO_2e) S1 & S2	***143,431***	***142,275***	***129,263***	***117,477***	***126,486***	***108,349***	***96,193***	***98,479***	***97,809***	***99,978***	***97,381***

Greenhouse Gas Emissions Reductions to Date

MWRA's optimization and onsite renewable energy efforts have resulted in a reduction of total GHG emissions by 32.1% or 46,050 tCO_2e (Scope 1 and 2 emissions) from 2006 through 2016. 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:

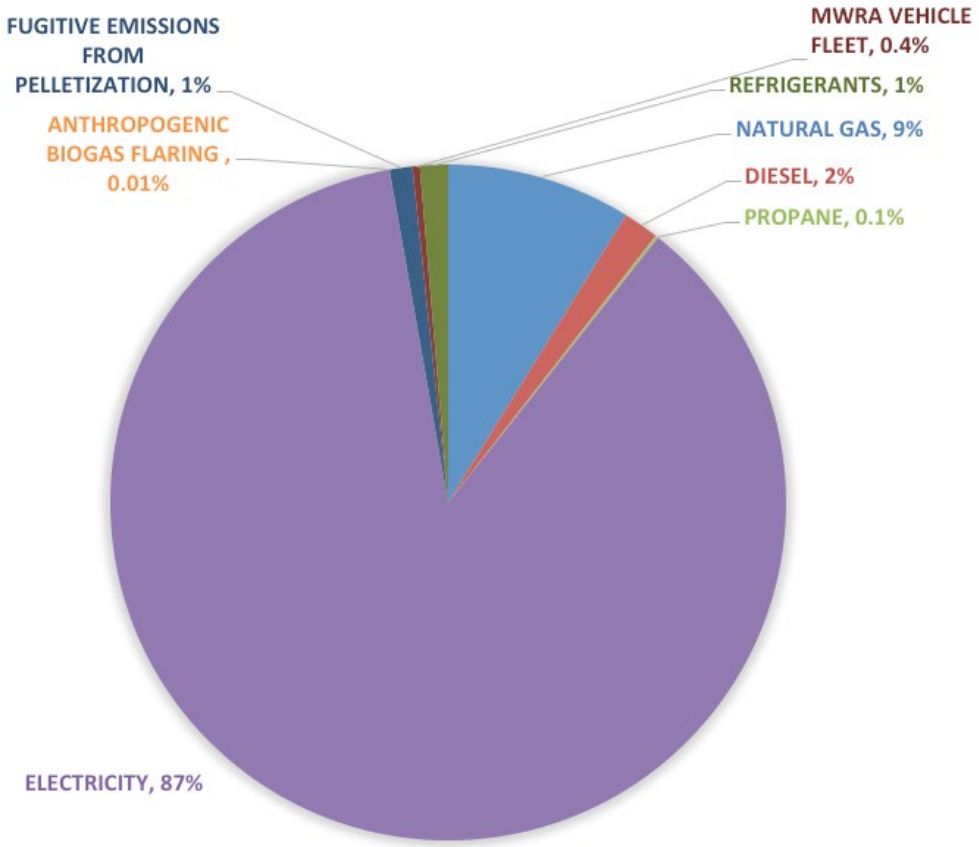
- **47.7%** reduction in emissions from **electricity use**
- **5.4%** reduction in emissions from **diesel use**
- **20%** reduction in emissions from **natural gas use**
- **8%** reduction in emissions from the **vehicle fleet**
- **20.8%** reduction in emissions from **propane use**
- **28.8%** reduction in emissions from **digester gas flaring**
- **91%** reduction in fugitive emissions from **refrigerants**
- **100%** reduction in emissions from **digester gas venting**[12]

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. Diesel emissions reductions are primarily due to a decrease in diesel fuel used for heating and backup generation at DITP as well as a shift to using natural gas for heating at several smaller facilities. Propane use is relatively low although use has decreased further since 2006 primarily due to the decommissioning of the Cosgrove Disinfection Facility once the Carroll plant was fully on-line. Propane use at other facilities has held generally constant.

[12] *GHG emissions from digester gas venting were reduced from 0.28 tCO_2e in 2006 to 0.00 tCO2e in 2016.*

The pie chart below compares only those sources that had reductions in order to demonstrate the relative emissions reductions by source. Looking at just reductions, electricity accounts for the largest reduction in emissions, about 87 percent of MWRA's entire GHG emissions reductions from 2006 to 2016. Overall MWRA has reduced GHG emissions from Scope 2 (indirect emissions from electricity production) by almost 48 percent.

Figure 5: Percent Contribution to GHG Emissions Reductions by Source (from 2006 to 2016)



Renewable Energy and Avoided Emissions

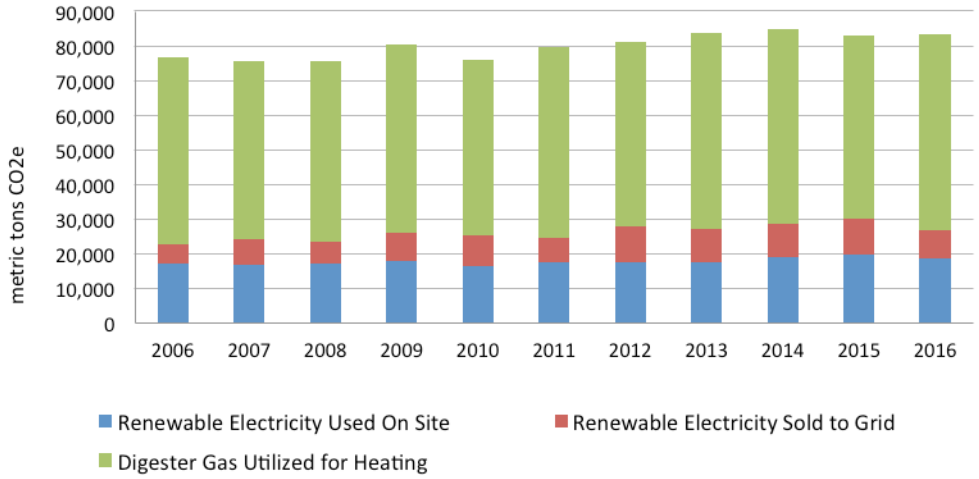
Renewable electricity generated by MWRA from 2006 through 2016, relates to 285,541 metric tons of CO_2e of avoided GHG emissions. This is equivalent to avoiding the GHG emissions from 700 million miles driven by an average passenger vehicle.[13]

In 2016 alone, the renewable electricity generated by MWRA prevented the emission of 26,541 metric tons of CO_2e. This level of avoided emissions is equal to 65 million miles driven by an average passenger vehicle.[13]

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 2016, there would have been an additional purchase of approximately five million gallons of fuel oil and 594,546 metric tons of CO_2e emissions. Considering the 2,901 metric tons of human-made CO_2e emitted from digester gas combustion from 2006 to 2016, the use of digester gas avoided the potential emissions of up to 591,645 metric tons of CO_2e during this period. This is equal to 1.45 billion miles driven by an average passenger vehicle or the carbon sequestered by over 696,000 acres of U.S. forests in one year, a land mass about 12 times that of the Boston area.[13]

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

Figure 6: Renewable Energy Generation & Associated Avoided Emissions



[13] *http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results*

Recommendations & Next Steps

This GHG inventory provides MWRA with the information to help identify areas to target for additional GHG emissions reductions. Based on the inventory, opportunities for future reductions continue to be related to electricity usage and MWRA will continue to focus on both reducing its electrical demand, identifying opportunities for green power production and options for procurement of low-carbon intensive electricity. MWRA will also work to reduce the use of diesel fuel, both in stationary equipment and in the vehicle fleet, as these sources account for 15 percent of total emissions.

Appendices

Appendix A: Methodology

What went into creating the inventory

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.

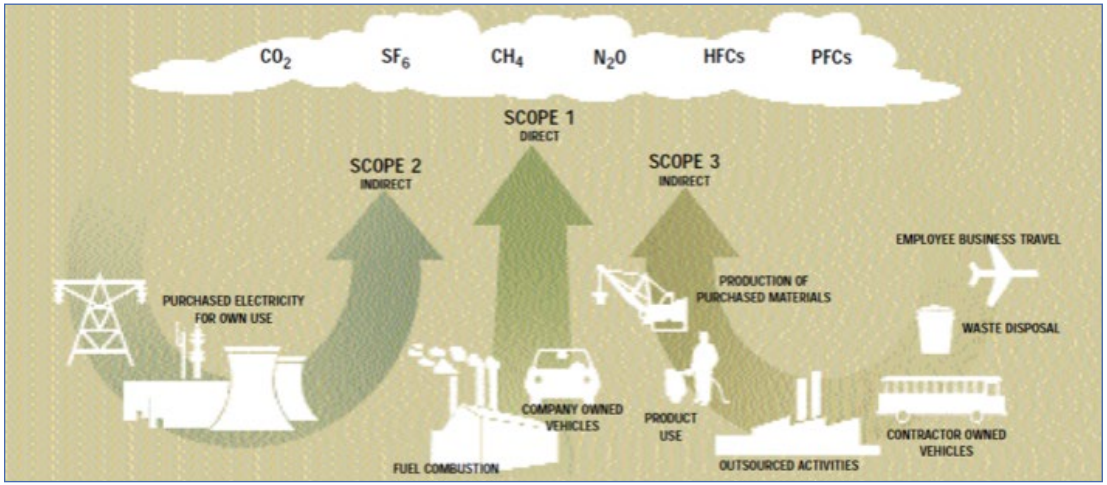
Massachusetts Department of Environmental Protection electricity emission factors[iii] were used along with supplier specific factors in substitute of EPA estimated factors for the New England Region; this represents a more accurate estimate of emissions from electricity purchases in Massachusetts.

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 MA DEP 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 to 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

MWRA uses electric vehicles in and around its large treatment facilities

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.

Massachusetts-based (MA DEP) 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 MA DEP. 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 2014

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

Diesel (Stationary) - Distillate Fuel #2	CO2	CH4	N2O
	kg CO2 / gallon	g CH4 / gallon	g N2O / gallon
	10.21	0.41	0.08
	kg CO2 / gallon	kg CH4 / gallon	kg N2O / gallon
	10.21	0.00041	0.00008

Diesel	CO2	CH4	N2O
	kg CO2 / MMBtu	kg CH4 / mmBtu	kg N2O / mmBtu
	73.96	0.003	0.0006

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 2014

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 2014

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 2014

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**
lbs CO2e / kWh	**0.977**	**1.005**	**0.906**	**0.838**	**0.846**	**0.701**	**0.638**	**0.649**	**0.615**	**0.697**	**0.642**

Source: TransCanada, MA DEP website

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

The Oakdale Hydroelectric Generation facility captures energy as water enters the Wachusett Reservoir from the Quabbin Reservoir.

Hydroelectric generators at the Cosgrove Intake capture energy as water leaves the Wachusett Reservoir headed toward metropolitan Boston area.

Appendix C: Emissions Tables (including Biogenic)

Emissions by Scope:

MWRA's contributions to greenhouse gas emissions, in metric tons of CO_2e[14] 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 2: GHG Emissions by Scope – 2006 through 2016[15]

Metric tons CO_2e by type	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Scope 1 (direct)											
Stationary	36,523	33,356	27,597	27,932	40,774	28,196	27,787	27,959	28,771	29,011	31,449
Mobile	2,137	2,173	2,125	2,082	2,155	2,131	2,083	2,099	2,081	2,142	1,966
Process	6,726	6,655	7,498	5,263	5,599	7,777	6,082	5,780	8,115	7,253	7,877
Fugitive	11,664	11,066	10,993	11,548	11,001	11,544	11,227	11,671	11,458	9,836	10,913
Total Scope 1	57,049	53,250	48,213	46,824	59,529	49,649	47,179	47,508	50,425	48,242	52,204
Scope 2 (indirect)											
Electricity (MA DEP/supplier specific)	86,382	89,025	81,050	70,653	66,957	58,700	49,014	50,971	47,384	51,736	51,736
Total (metric tons CO_2e) Scope 1 & 2	***143,431***	***142,275***	***129,263***	***117,477***	***126,486***	***108,349***	***96,193***	***98,479***	***97,809***	***99,978***	***99,978***

[14] *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.*
[15] *Annual data based on Calendar Year (January 1 – December 31).*

As the data in Table 2 shows, MWRA's total GHG emissions have decreased over the last 11 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 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 CO_2 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 3: MWRA Biogenic Emissions

tCO_2e	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Biogenic Biogas Combustion CO_2	51,526	49,342	49,798	51,816	48,774	52,296	50,612	53,003	53,382	50,194	53,474
Biogenic Biogas Flaring CO_2	2,191	1,311	1,025	947	1,854	1,202	1,414	1,324	1,689	998	1,560
Biogenic Ethanol CO_2	57	82	76	70	64	62	61	60	60	57	57
Biogenic Biodiesel CO_2	48	50	51	54	61	62	60	62	60	66	57
Digester Gas Process CO_2	32,875	31,693	31,693	33,311	30,480	33,754	33,039	32,435	32,613	33,276	32,215

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 (CH_4) and nitrous oxide (N_2O) emissions are considered anthropogenic, while carbon dioxide (CO_2) 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 CO_2 from the calcination step in cement manufacturing, CO_2 from 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

SF6: sulfur hexafluoride

T&D: transmission and distribution (electricity)

tCO_2e: 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

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

ii https://www.environment.gov.au/system/files/resources/da7bde5c-1be2-43f7-97d7-d7d85bb9ad6c/files/nger-technical-guidelines-2014.pdf

iii http://www.mass.gov/eea/agencies/massdep/climate-energy/climate/approvals/magreenhouse-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: https://www.epa.gov/sites/production/files/2016-08/documents/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://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_full_report.pdf

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: https://www.epa.gov/statelocalclimate/state-inventory-and-projection-tool