Updated Preliminary 1990 Greenhouse Gas Inventory Baseline and Statewide Greenhouse Gas Inventory for 2007

Technical Support Document

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Prepared for:

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Acronyms and Abbreviations

AFOLU	Agriculture, Forestry, and Other Land Use
BOD	Biochemical oxygen demand
CARB	California Air Resources Board
CH_4	Methane
CO_2	Carbon dioxide
DBEDT	Department of Business, Economic Development, and Tourism
DLNR	Department of Land and Natural Resources
DOH	Department of Health
EPA	Environmental Protection Agency
FOD	First order decay
GHG	Greenhouse gas
GWP	Global warming potential
HFC	Hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
MCF	Methane conversion factor
MMT	million metric tons
MSW	Municipal solid waste
N_2O	Nitrous oxide
NOAA-CCAP	National Oceanic and Atmospheric Administration's Coastal Change Analysis Program
NPDES	National Pollutant Discharge Elimination System
ODS	Ozone Depleting Substance
PFC	Perfluorocarbon
SF_6	Sulfur hexafluoride
SIT	State Inventory Tool
UNFCCC	United Nations Framework Convention on Climate Change
VMT	Vehicle miles traveled
VS	Volatile solids
WMS	Waste management system

Executive Summary

In 2007, Hawaii passed Act 234 to establish the state's policy framework and requirements to address greenhouse gas (GHG) emissions. The law aims to achieve cost-effective GHG emission reductions to achieve emission levels at or below Hawaii's 1990 GHG emissions by January 1, 2020. In 2008, the state of Hawaii developed statewide GHG emission inventories for 1990 and 2007. In an effort to track progress toward achieving the 2020 GHG reduction goal, the state of Hawaii is now updating the 1990 and 2007 estimates, as well as developing estimates for 2010 and 2015. This document provides a summary of statewide GHG emissions and sinks in 1990 and 2007.

To update statewide emission estimates for 1990 and 2007, ICF carefully reviewed and evaluated the data and methods used for each source or sink category in the 2008 inventory report to determine if any updates were needed. In addition, the latest guidance for developing national GHG inventories (e.g., the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories*) were used in order to adhere to national and international standards for GHG accounting. The United States Environmental Protection Agency's (U.S. EPA) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015* and the U.S. EPA's State Inventory Tool were also used as key resources for providing updates to the previous GHG estimates for 1990 and 2007.

The updated 1990 and 2007 GHG estimates in this report include anthropogenic[1] GHG emissions from four sectors, which include Energy; Industrial Processes and Product Use (IPPU); Agriculture, Forestry, and Other Land Use (AFOLU); and Waste. In 1990, Hawaii's total GHG emissions were 21.61 million metric tons (MMT) of CO_2 Eq. In 2007, total GHG emissions were 24.71 MMT CO_2 Eq. Net emissions, which take into account carbon sinks, were 18.76 MMT CO_2 Eq. in 1990 and 21.72 MMT CO_2 Eq. in 2007. Net emissions excluding aviation, which is used for the statewide GHG reduction target, were 14.11 MMT CO_2 Eq. in 1990 and 17.30 MMT CO_2 Eq. in 2007. Table 1 summarizes updated estimates of 1990 and 2007 emissions and sinks by sector.

Table 1: Hawaii GHG Emissions by Sector, 1990 and 2007 (MMT CO_2 Eq.)

Sector	1990	2007
Energy	19.35	21.67
IPPU	0.17	0.54
AFOLU (Sources)	1.34	1.45
AFOLU (Sinks)	(2.85)	(3.00)
Waste	0.75	1.05
Total Emissions (Excluding Sinks)	**21.61**	**24.71**
Net Emissions (Including Sinks)	**18.76**	**21.72**

[1] Anthropogenic greenhouse gas emissions are those that originate from human activity.

Net Emissions (Including Sinks, Excluding Aviation)[a]	**14.11**	**17.30**

[a] Domestic aviation emissions, which are reported under the Energy sector, are excluded from Hawaii's GHG emission reduction goal established in Act 234.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

In both 1990 and 2007, emissions from the Energy sector accounted for the largest portion (more than 85 percent) of total emissions in Hawaii. Figure 1 shows emissions for 1990 and 2007 by sector while Figure 2 shows emissions by gas for 1990 and 2007.

Figure 1: Hawaii GHG Emissions by Sector, 1990 and 2007 (MMT CO_2 Eq.)

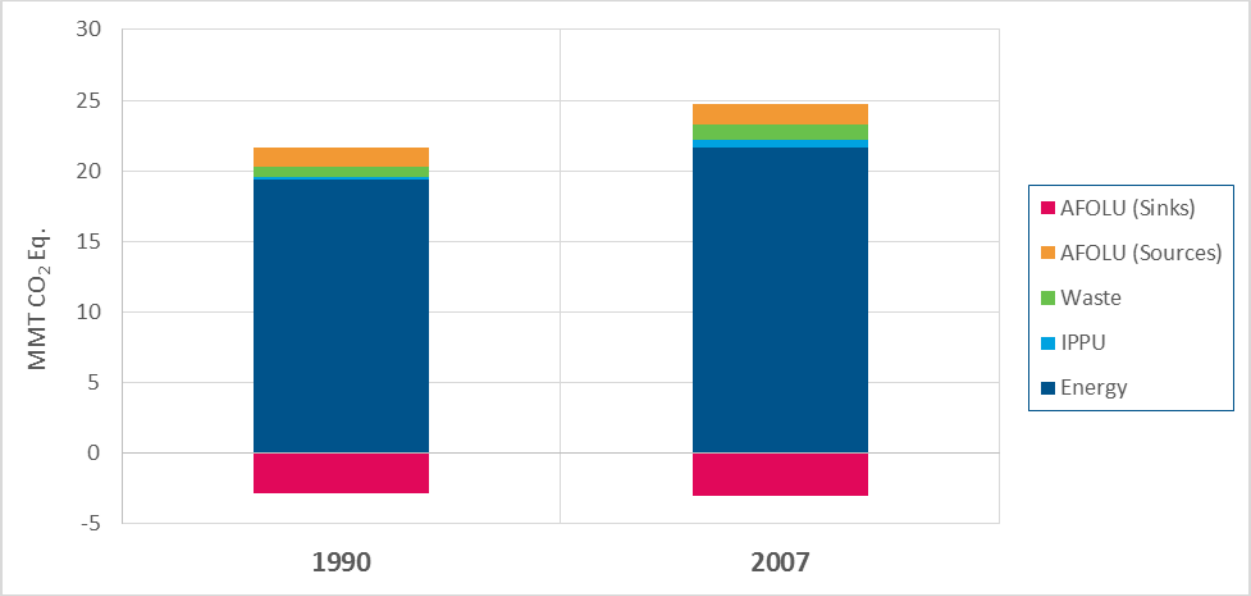
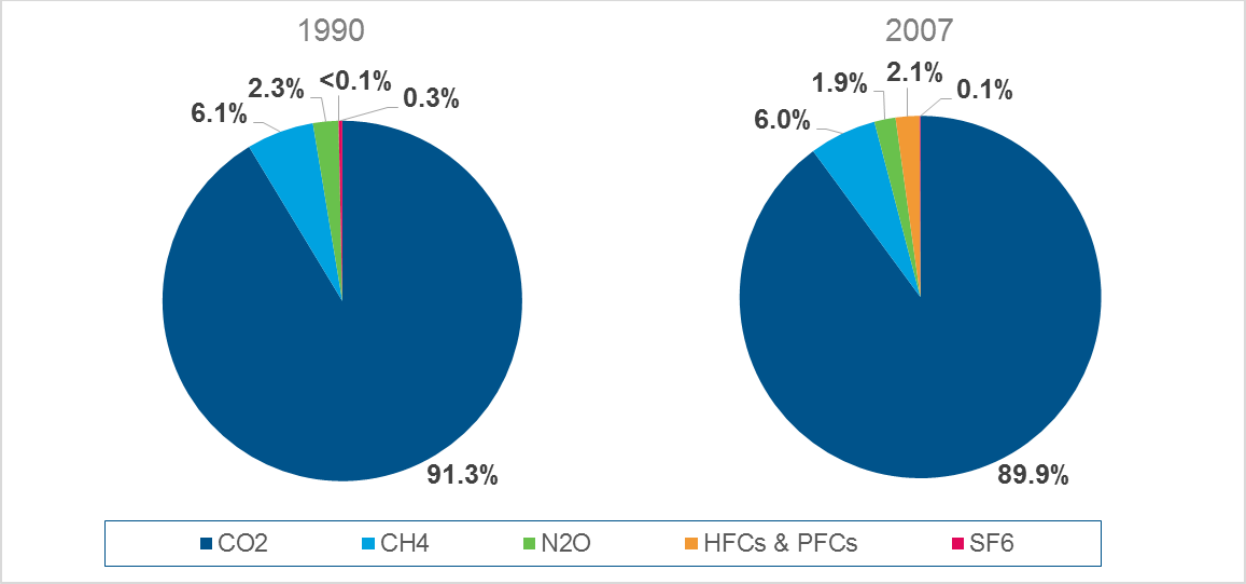


Figure 2: Hawaii GHG Emissions by Gas, 1990 and 2007 (% of total emissions excluding sinks)



1. Introduction

The state of Hawaii is committed to minimizing its contribution to global climate change and has taken efforts to reduce statewide greenhouse gas (GHG) emissions. In 2007, Hawaii passed Act 234 to establish the state's policy framework and requirements to address GHG emissions. The law aims to achieve cost-effective GHG emission reductions at or below Hawaii's 1990 GHG emissions level by January 1, 2020. In 2008, the state of Hawaii developed statewide GHG emission inventories for 1990 and 2007. In an effort to track progress toward achieving the 2020 GHG reduction goal, the state of Hawaii is now updating the 1990 and 2007 emission estimates, as well as developing estimates for 2010 and 2015. This document provides a summary of statewide GHG emissions and sinks in 1990 and 2007, including technical documentation of the activity data, methodologies, and emission factors used.[2]

The updated 1990 and 2007 GHG emission estimates in this report include anthropogenic[3] GHG emissions from the following four IPCC sectors: (1) Energy; (2) Industrial Processes and Product Use (IPPU); (3) Agriculture, Forestry, and Other Land Use (AFOLU); and (4) Waste. Within these four sectors, updated emissions are presented by source or sink category. Emission estimates are included for the following GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

ICF relied on the best available data and methodologies to update the 1990 and 2007 GHG emission estimates presented in this report. For data sources, this involved efforts to re-collect and verify activity data to ensure accuracy and completeness, wherever possible. For methodologies, this involved an in-depth review of previous methods used and identification of available updates. Decisions about the inclusion of source categories, their assignment to particular inventory sectors, and the selection of appropriate methodologies and data reflect a consideration of international GHG accounting guidelines and the U.S. national inventory. A summary of updated 1990 and 2007 emission estimates is presented below, followed by a discussion of data sources and methods used, key changes from the 2008 inventory report, and the significance of these changes in the context of achieving Hawaii's GHG reduction goal.

Summary of Updated 1990 and 2007 Emissions

In 1990, total GHG emissions were 21.61 million metric tons (MMT) of CO_2 Eq. In 2007, total GHG emissions were 24.71 MMT CO_2 Eq., an increase of 14 percent over 1990 levels. Net emissions, which take into account carbon sinks, were 18.76 MMT CO_2 Eq. in 1990 and 21.72 MMT CO_2 Eq. in 2007 (an increase of 16 percent). Net emissions excluding aviation, which is used for the statewide GHG reduction

[2] It is best practice to review GHG estimates for prior years and revise them, as necessary, to take into account updated activity data and improved methodologies or emission factors that reflect advances in the field of GHG accounting.

[3] Anthropogenic greenhouse gas emissions are those that originate from human activity.

target, were 14.11 MMT CO_2 Eq. in 1990 and 17.30 MMT CO_2 Eq. in 2007. Table 2 summarizes 1990 and 2007 emissions and sinks by sector and category.

Table 2: Hawaii GHG Emissions by Sector/Category, 1990 and 2007 (MMT CO_2 Eq.)

Sector/Category	1990	2007
Energy	**19.35**	**21.67**
Fossil Fuel Stationary Combustion	7.91	9.28
Electric Power	*6.80*	*8.78*
Residential	*0.03*	*0.05*
Commercial	*0.38*	*0.26*
Industrial	*0.70*	*0.19*
Transportation	11.27	12.23
Ground	*3.41*	*5.01*
Domestic Marine	*1.82*	*1.79*
Domestic Aviation	*4.66*	*4.42*
Military	*1.38*	*1.02*
Incineration of Waste[a]	0.18	0.15
Oil and Gas Operations	+	0.01
International Bunker Fuels[b]	*2.95*	*1.54*
CO_2 from Wood Biomass and Biofuel Consumption[b]	*NE*	*0.16*
IPPU	**0.17**	**0.54**
Cement Production	0.10	NO
Electrical Transmission and Distribution	0.07	0.02
Substitution of Ozone Depleting Substances	+	0.53
AFOLU (Sources)	**1.34**	**1.45**
Enteric Fermentation	0.38	0.36
Manure Management	0.13	0.05
Agricultural Soil Management	0.18	0.16
Field Burning of Agricultural Residues	0.03	0.01
Urea Application	+	+
Agricultural Soil Carbon	0.22	0.24
Forest Fires	0.38	0.62
AFOLU (Sinks)	**(2.85)**	**(3.00)**
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.04)
Urban Trees	(0.28)	(0.37)
Forest Carbon	(2.45)	(2.59)

Waste	**0.75**	**1.05**
Landfills	0.65	0.92
Composting	+	0.02
Wastewater Treatment	0.10	0.12
Total Emissions (Excluding Sinks)	**21.61**	**24.71**
Net Emissions (Including Sinks)	**18.76**	**21.72**
Net Emissions (Including Sinks, Excluding Aviation)[c]	**14.11**	**17.30**

+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring); NE (emissions are Not Estimated).

[a] Emissions from the incineration of waste are reported under the Energy sector, consistent with the U.S. Inventory (U.S. EPA 2017), since the incineration of waste generally occurs at facilities where energy is recovered.

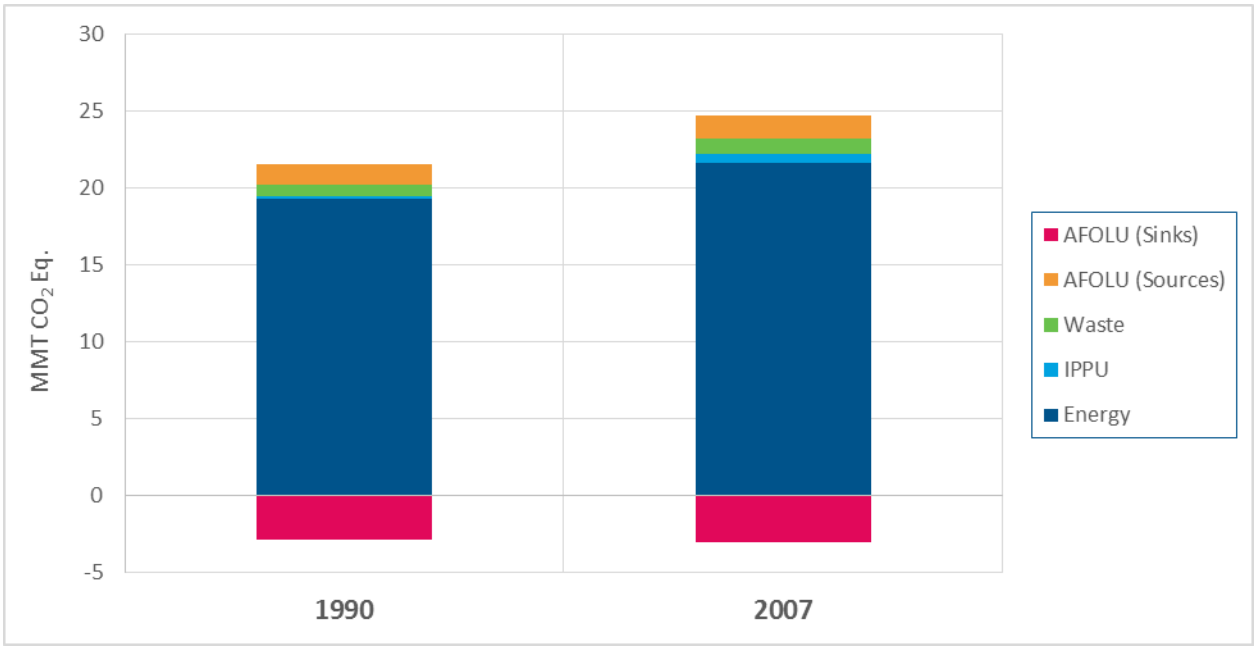
[b] Emissions from International Bunker Fuels and CO_2 from Wood Biomass and Biofuel Consumption are not included in totals.

[c] Domestic aviation emissions, which are reported under the Energy sector, are excluded from Hawaii's GHG emissions reduction goal established in Act 234.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

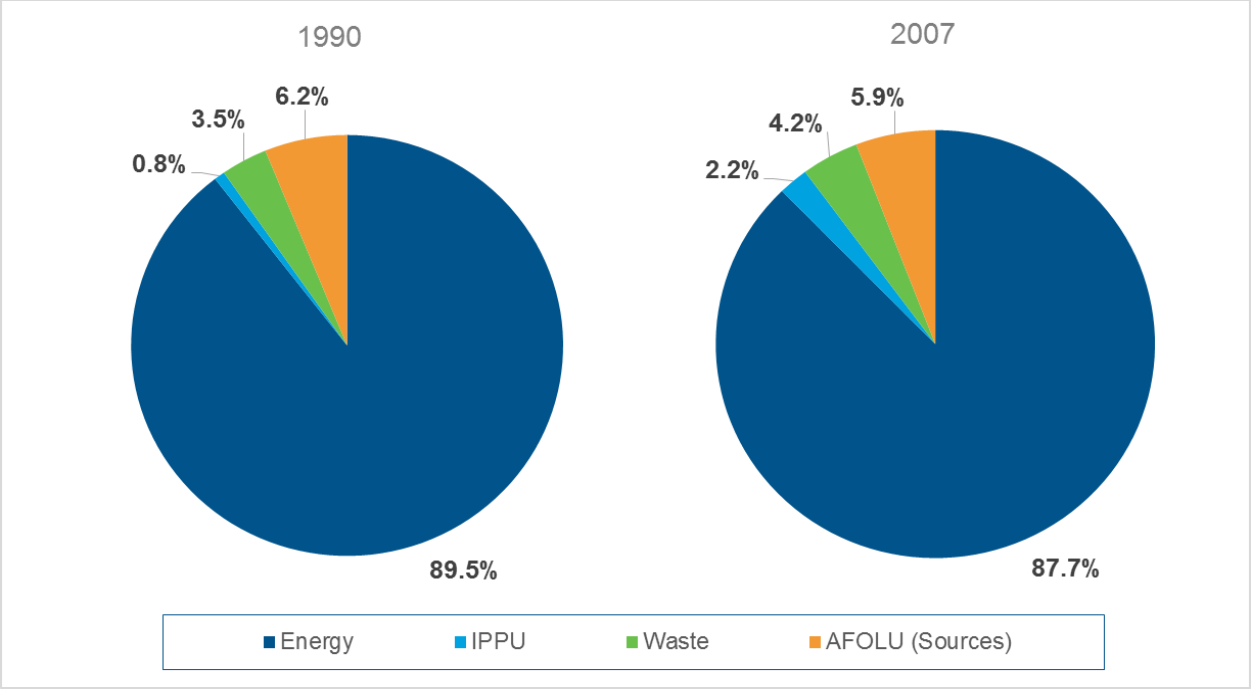
In both 1990 and 2007, emissions from the Energy sector accounted for the largest portion (more than 85 percent) of total emissions in Hawaii, followed by the AFOLU sector, the Waste sector, and the IPPU sector. Figure 3 and Figure 4 show emissions for 1990 and 2007 by sector.[4]

Figure 3: Hawaii GHG Emissions by Sector, 1990 and 2007 (MMT CO_2 Eq.)



[4] Unless otherwise noted, percentages represent a portion of total emissions (excluding sinks, including aviation).

Figure 4: Hawaii GHG Emissions by Sector, 1990 and 2007 (% of total emissions excluding sinks)



Each GHG differs in its global warming potential (GWP); for example, methane (CH_4) has 25 times the warming potential of carbon dioxide (CO_2).[5] As a result, throughout this inventory report the relative contribution of each gas is shown in million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). In both 1990 and 2007, CO_2 was the largest single contributor to statewide emissions, accounting for roughly 90 percent of total emissions. Table 3 shows emission sources and sinks for 1990 and 2007 by gas and category. Figure 5 and Figure 6 show emissions by gas for 1990 and 2007.

Table 3: Hawaii GHG Emissions by Gas and Sector/Category, 1990 and 2007 (MMT CO_2 Eq.)

Gas/Category	1990	2007
CO_2 (Sources)	**19.74**	**22.22**
Transportation	11.02	12.02
Fossil Fuel Stationary Combustion	7.88	9.25
Forest Fires	0.34	0.55
Agricultural Soil Carbon	0.22	0.24
Incineration of Waste	0.17	0.15
Cement Production	0.10	NO
Urea Application	+	+
International Bunker Fuels[a]	*2.92*	*1.53*

[5] This Technical Support Document uses GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007).

CO_2 from Wood Biomass and Biofuel Consumption[a]	*NE*	*0.16*
CO_2 (Sinks)	**(2.85)**	**(3.00)**
Forest Carbon	(2.45)	(2.59)
Urban Trees	(0.28)	(0.37)
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.04)
CH_4	**1.31**	**1.49**
Landfills	0.65	0.92
Enteric Fermentation	0.38	0.36
Manure Management	0.11	0.04
Wastewater Treatment	0.07	0.08
Forest Fires	0.03	0.04
Transportation	0.03	0.02
Field Burning of Agricultural Residues	0.03	0.01
Fossil Fuel Stationary Combustion	0.01	0.01
Oil and Gas Operations	+	0.01
Composting	+	0.01
Incineration of Waste	+	+
International Bunker Fuels[a]	*+*	*+*
N_2O	**0.49**	**0.47**
Transportation	0.21	0.20
Agriculture Soil Management	0.18	0.16
Wastewater Treatment	0.04	0.04
Manure Management	0.02	0.01
Fossil Fuel Stationary Combustion	0.02	0.02
Forest Fires	0.02	0.03
Composting	+	0.01
Field Burning of Agricultural Residues	+	+
Incineration of Waste	+	+
International Bunker Fuels[a]	*0.03*	*0.01*
HFCs/PFCs	**+**	**0.53**
Substitution of Ozone Depleting Substances	+	0.53
SF_6	**0.07**	**0.02**
Electrical Transmission and Distribution	0.07	0.02

+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring); NE (emissions are Not Estimated).

[a] Emissions from International Bunker Fuels and CO_2 from Wood Biomass and Biofuel Consumption are not included in totals.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Figure 5: Hawaii GHG Emissions by Gas, 1990 and 2007 (MMT CO_2 Eq.)

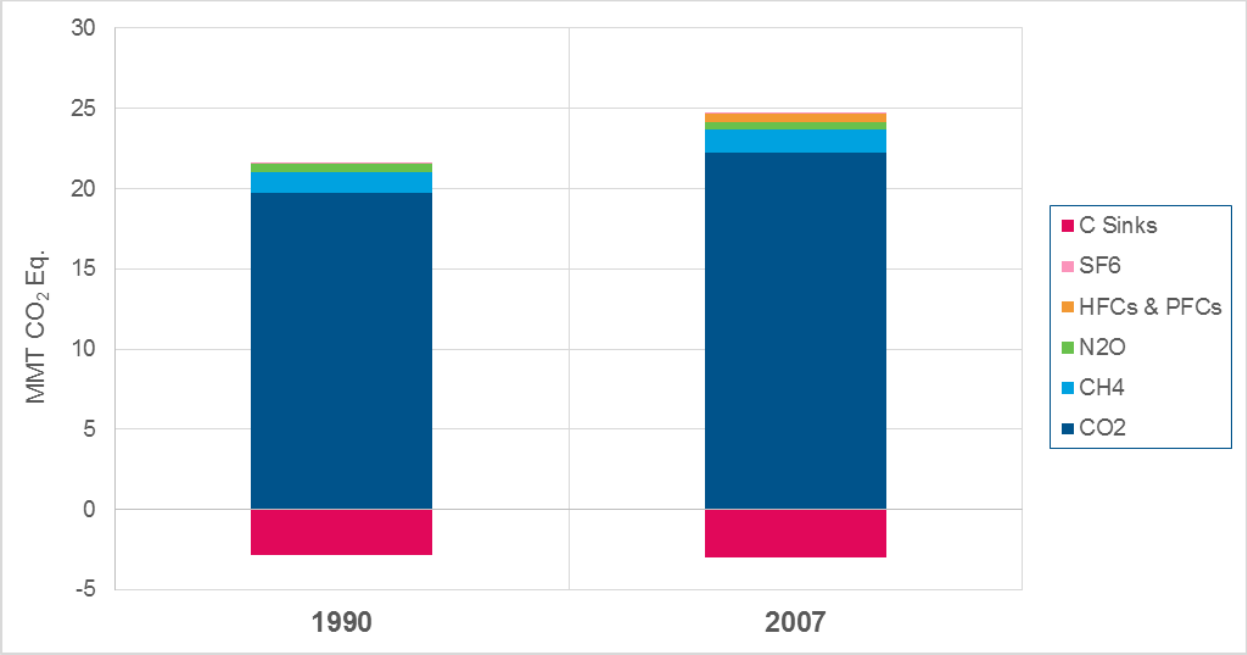
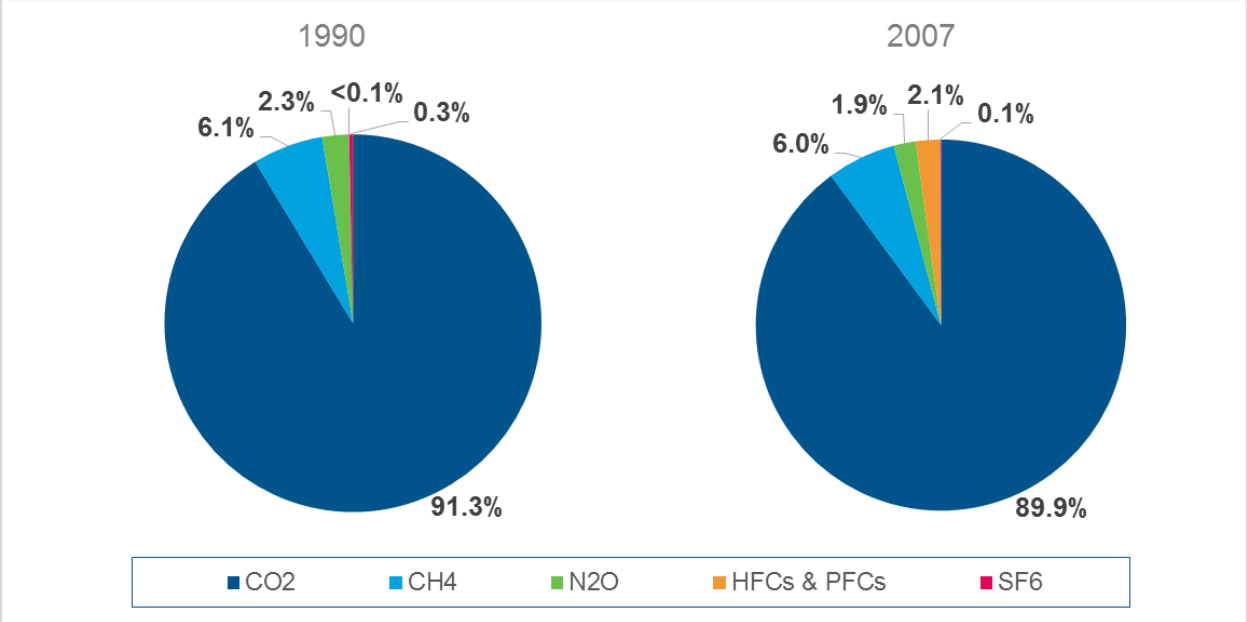


Figure 6: Hawaii GHG Emissions by Gas, 1990 and 2007 (% of total emissions excluding sinks)



Methodology and Data Sources

To update the emission estimates in this inventory report, ICF carefully reviewed and evaluated the data and methods used for each source or sink category in the 2008 inventory report to determine if any updates were needed. In addition, the latest guidance for developing national GHG inventories (e.g., the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas*

Inventories) were used in order to adhere to national and international standards for GHG accounting. The United States Environmental Protection Agency's (U.S. EPA) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015* (hereafter referred to as the U.S. Inventory) and the U.S. EPA's State Inventory Tool (SIT) were also used as key resources for providing updates to the previous 1990 and 2007 estimates.

The *2006 IPCC Guidelines* highlight the standard methodological approaches adopted by the United States and all other Annex 1 (developed) countries that are signatories to the United Nations Framework Convention on Climate Change (UNFCCC). As appropriate and feasible, emissions from source and sink categories included in this report have been estimated using methodologies that are consistent with the *2006 IPCC Guidelines*. The methodologies used to estimate emissions align with the IPCC "Tier" approach, which is a useful framework for addressing the combined challenges of data availability and resources, while maintaining transparency and consistency. For most source categories, the *2006 IPCC Guidelines* suggest three tiers: Tier 1 is the most basic; Tier 2 provides an intermediate approach; and Tier 3 is the most resource-intensive, requiring highly specific activity data inputs. In the methodological discussions that follow, the IPCC Tier approach is referred to on a source-by-source basis.

Estimating Uncertainty

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015* estimated the range of uncertainty for total U.S. emissions estimates to be -1 to +5 percent. Considerable resources are expended at the national level to develop these estimates of uncertainty. Detailed uncertainty estimates were not developed for this Technical Support Document. Since fuel combustion in Hawaii drives about 90 percent of total emissions, uncertainty around this source (which is typically lower than other sources) drives the uncertainty around the inventory totals. Following this report, an uncertainty analysis will be conducted on statewide GHG estimates in order to help identify areas for improvement and prioritize future actions to improve GHG emission estimates for Hawaii.

Some level of uncertainty in GHG estimates is associated with all emission inventories. This uncertainty can be attributed to a number of factors such as incomplete data, uncertainty in the activity data collected, the use of average or default emission factors that may not reflect the specific nature of how emissions are generated from certain sources, the use of national data where state-specific data were unavailable, and uncertainty in scientific understanding of emission pathways. For some sources (e.g., CO_2 emissions from fuel combustion), emissions are relatively well understood and uncertainty is expected to be low and largely dependent on the accuracy of activity data. For other sources (e.g., CH_4 and N_2O emissions from wastewater), emission estimates have greater uncertainty. Overall, it is important to recognize that some level of uncertainty exists with all GHG estimates, and these uncertainties vary between sector, source, and gas.

Specific data sources and methodologies used to develop updated estimates are discussed for each source category in the subsequent sections of this report. In addition, changes from the 2008 report are discussed at the source level, including key differences in source categorization, methods, and data used to develop emission estimates.

Comparison of Updated Inventory Results to Previous Emission Estimates

Relative to the 2008 inventory report, total emissions presented in this inventory report decreased by 7 percent for 1990 and increased by 2 percent for 2007. Total net emissions decreased by 8 percent for 1990 and increased by 1 percent for 2007. Net emissions excluding aviation (used for the Hawaii GHG target) increased by 3 percent for 1990 and 4 percent for 2007. These changes are largely associated with (1) updates to the GWP values, which previously reflected values from the *IPCC Second Assessment Report* and were updated to reflect values from the *IPCC Fourth Assessment Report*,[6] and (2) updates to emission factors. In addition, for the 2008 inventory report, in some cases 2006 data were used as a proxy for 2007 data; for this inventory report, 2007 data, which has since become available, were used instead. Other updates also impacted emission estimates, which are discussed on a source-by-source basis in the subsequent sections of this report. A summary of the change in emission estimates by inventory report is provided in Table 4 below by sector. A more detailed summary of changes by source and sink category can be found in Appendix A.

Table 4: Change in Emissions Relative to the 2008 Inventory Report (MMT CO_2 Eq.)

Sector	1990			2007		
	2008 Report	2017 Report	Percent Change	2008 Report	2017 Report	Percent Change
Energy[a]	21.12	19.35	-8.4%	21.83	21.67	-0.7%
IPPU	0.18	0.17	-3.5%	0.54	0.54	1.4%
AFOLU (Sources)	0.98	1.34	35.7%	0.83	1.45	74.6%
AFOLU (Sinks)	(2.67)	(2.85)	6.8%	(2.75)	(3.00)	8.9%
Waste[a]	0.85	0.75	-11.2%	1.07	1.05	-1.8%
Total Emissions (Excluding Sinks)	**23.13**	**21.61**	**-6.6%**	**24.27**	**24.71**	**1.8%**
Net Emissions (Including Sinks)	**20.46**	**18.76**	**-8.3%**	**21.52**	**21.72**	**1.0%**
Net Emissions (Including Sinks, Excluding Aviation)[b]	**13.66**	**14.11**	**3.3%**	**16.69**	**17.30**	**3.6%**

[a] In the 2008 inventory report, emissions from incineration of waste were categorized under the Waste sector. In this inventory report, the emissions are categorized under the Energy sector, consistent with the U.S. Inventory.
[b] Domestic aviation emissions, which are reported under the Energy sector, are excluded from Hawaii's GHG emissions reduction goal established in Act 234.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Progress towards Achieving Hawaii's GHG Emissions Reduction Goal

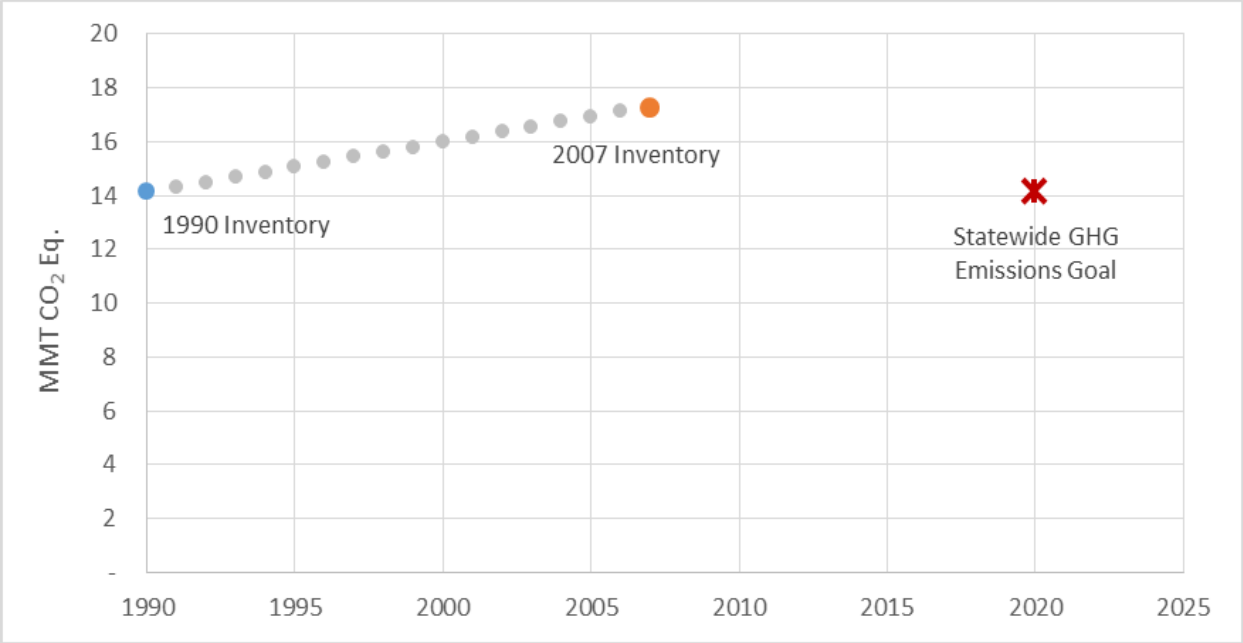
Act 234, Session Laws of Hawaii 2007, establishes as state policy statewide GHG emission limits at or below the statewide GHG emissions levels in 1990 to be achieved by January 1, 2020. While aviation

[6] Key changes to the GWP values, assuming a 100-year time horizon, include the value for CH_4 increasing from 21 to 25 and the value for N_2O decreasing from 310 to 298.

emissions are included in the inventory totals presented in this report, Act 234 specifies that they shall not be included in Hawaii's GHG target. In 1990, domestic aviation emissions accounted for 4.66 MMT CO_2 Eq. or 22 percent of total emissions. In 2007, domestic aviation emissions accounted for 4.42 MMT CO_2 Eq. or 18 percent of total emissions.

With aviation emissions excluded, 1990 statewide emissions were 14.11 MMT CO_2 Eq., which represents the 2020 emission reduction target. This target could change with any future updates to the 1990 emission estimates, but it is not likely to change significantly.[7] Figure 7 shows the trend in emissions in Hawaii from 1990 to 2007 (excluding aviation) and the 2020 statewide target, which is equal to 1990 emission levels (excluding aviation). A detailed assessment of statewide GHG emissions relative to the statewide GHG emissions limit will be presented in a subsequent technical support document prepared by ICF.

Figure 7: Hawaii GHG Emissions Trend in Meeting 2020 Statewide Goal (including sinks, excluding aviation)*



* The gray data points between the 1990 inventory and 2007 inventory estimates show a linear trend line for the reader's benefit; they do not reflect actual inventory estimates.

[7] The state of Hawaii may update 1990 emission estimates, as necessary, in future inventories.

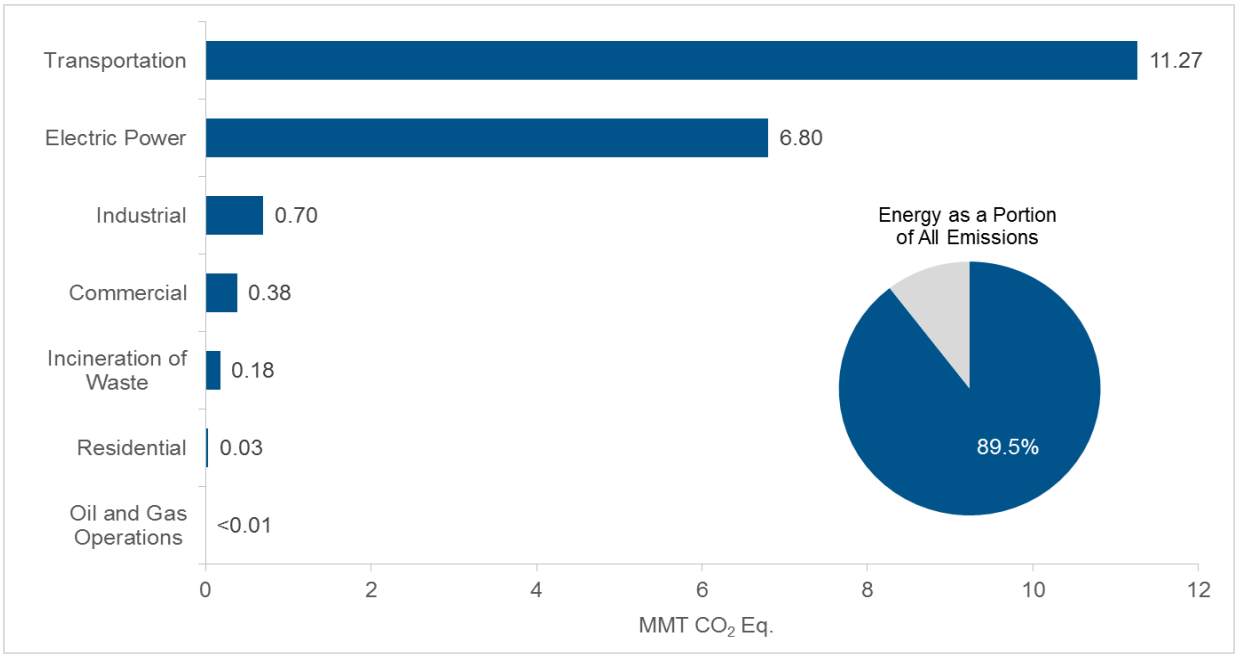
2. Energy

This chapter presents GHG emissions that occur from stationary and mobile energy combustion activities. For the state of Hawaii, energy sector emissions are estimated from the following sources[8] and gases:

- Fossil Fuel Stationary Combustion (IPCC Source Categories 1A1, 1A2, 1A4, 1A5): CO_2, CH_4, N_2O
- Transportation (IPCC Source Category 1A3): CO_2, CH_4, N_2O
- Incineration of Waste (IPCC Source Category 1A1a): CO_2, N_2O
- Oil and Gas (IPCC Source Category 1B2c): CH_4
- International Bunker Fuels (IPCC Source Category 1: Memo Items): CO_2, CH_4, N_2O
- Wood Biomass and Biofuel Consumption (IPCC Source Categories 1A1, 1A2, 1A3, 1A4, 1A5): CO_2

Emissions from the energy sector were 19.35 MMT CO_2 Eq. in 1990 and 21.67 MMT CO_2 Eq. in 2007, accounting for 90 percent and 88 percent of total Hawaii emissions, respectively. While emissions from international bunker fuels and wood biomass and biofuel consumption are estimated as part of this analysis, these emissions are not included in the totals, consistent with IPCC (2006) guidelines. Figure 8 and Figure 9 show energy emissions by source for 1990 and 2007. Emissions by source and year are summarized in Table 5.

Figure 8: 1990 Energy Emissions by Source (MMT CO_2 Eq.)



[8] IPCC Source Categories for which emissions were not estimated for the state of Hawaii include: Fugitive emissions from Solid Fuels (1B1), Oil and Gas Production emissions (1B2a and 1B2b), and CO_2 Transport and Storage (1C). Appendix B provides information on why emissions were not estimated for these IPCC Source Categories.

Figure 9: 2007 Energy Emissions by Source (MMT CO_2 Eq.)

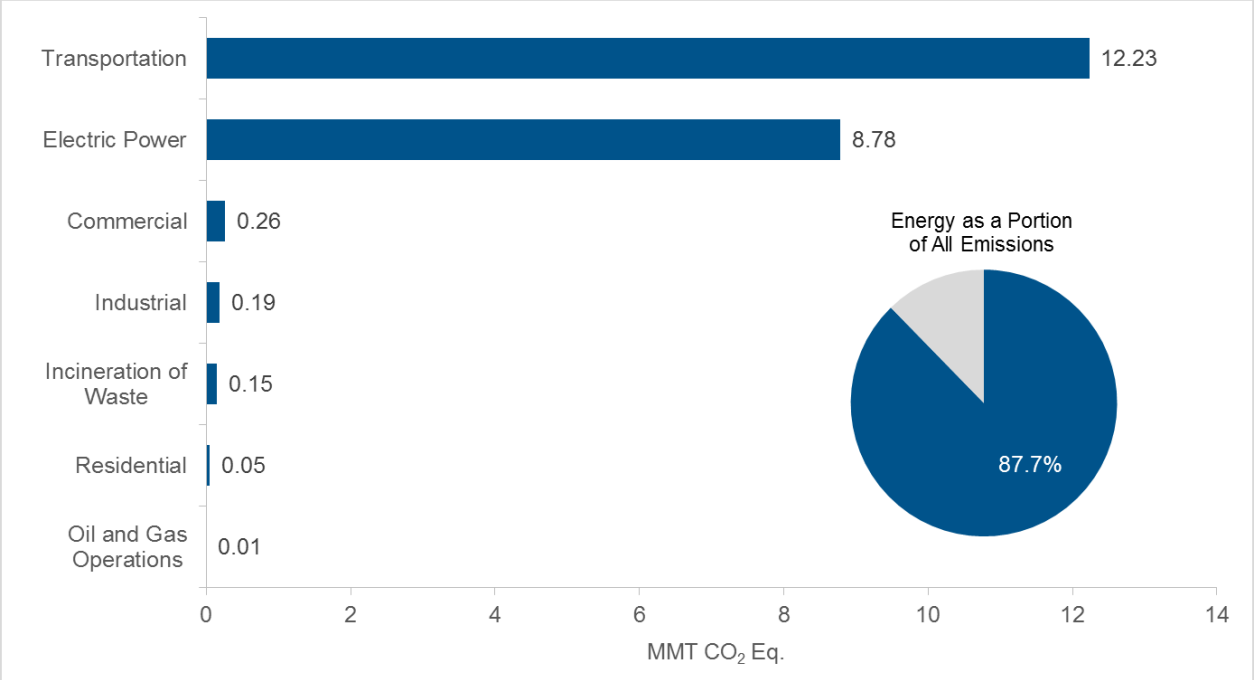


Table 5: GHG Emissions from the Energy Sector by Source (MMT CO_2 Eq.)

Source	1990	2007
Fossil Fuel Stationary Combustion	**7.91**	**9.28**
Electric Power	6.80	8.78
Residential	0.03	0.05
Commercial	0.38	0.26
Industrial	0.70	0.19
Transportation	**11.27**	**12.23**
Ground	3.41	5.01
Domestic Marine	1.82	1.79
Domestic Aviation	4.66	4.42
Military	1.38	1.02
Incineration of Waste	**0.18**	**0.15**
Oil and Gas Operations	**+**	**0.01**
International Bunker Fuels[a]	*2.95*	*1.54*
CO_2 from Wood Biomass and Biofuel Consumption[a]	*NE*	*0.16*
Total	**19.35**	**21.67**

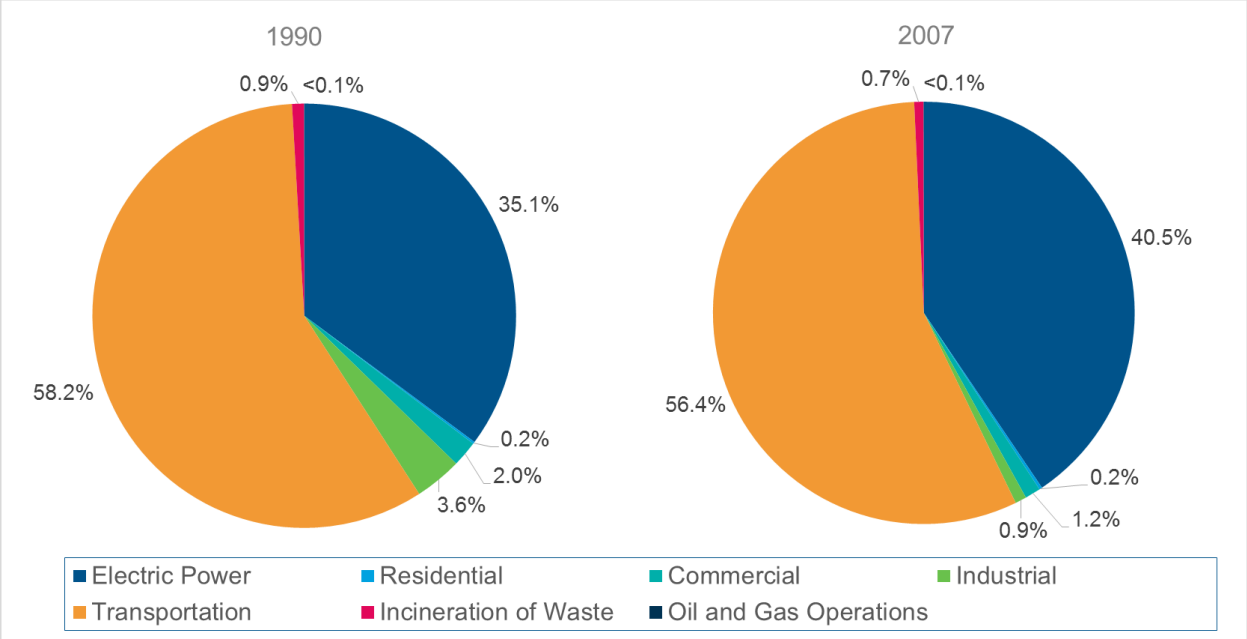
[a] Emissions from International Bunker Fuels and Wood Biomass and Biofuel Consumption are not included in totals.

+ Does not exceed 0.005 MMT CO_2 Eq.; NE (emissions are Not Estimated).

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

In both 1990 and 2007, the transportation sector accounted for the largest share of emissions, representing 58 percent and 56 percent of energy sector emissions, respectively. Emissions from electric power plants accounted for the second largest share of emissions, representing 35 percent and 41 percent of 1990 and 2007 emissions, respectively. Industrial, commercial, residential, waste incineration and oil and gas operations comprised a relatively small portion of emissions (less than 7 percent) in both years. Figure 10 presents the breakout of GHG emissions by source within the energy sector for both 1990 and 2007.

Figure 10: Energy Emissions by Source, 1990 and 2007 (% of energy sector emissions)



2.1. Fossil Fuel Stationary Combustion (IPCC Source Categories 1A1, 1A2, 1A4, 1A5)

Fossil fuels are burned to generate energy from a variety stationary sources, including electric power plants, industrial facilities, commercial businesses, and homes. When fossil fuels are combusted, they release CO_2, CH_4, and N_2O emissions. Stationary combustion emissions can be broken out by economic sector (i.e., electric power, residential, commercial, and industrial), which is based on where the fuel is combusted. Table 6 summarizes emissions from fossil fuel stationary combustion in Hawaii by economic sector for 1990 and 2007. As shown, the vast majority of emissions from stationary combustion are from the electric power sector, as the majority of fossil fuels used for stationary combustion are combusted at electric power plants.

Table 6: Fossil Fuel Stationary Combustion Emissions by Gas (MMT CO_2 Eq.)

Economic Sector	1990				2007			
	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total
Electric Power	6.78	0.01	0.02	**6.80**	8.75	0.01	0.02	**8.78**
Residential	0.03	+	+	**0.03**	0.05	+	+	**0.05**
Commercial	0.38	+	+	**0.38**	0.26	+	+	**0.26**
Industrial	0.69	+	+	**0.70**	0.19	+	+	**0.19**
Total	**7.88**	**0.01**	**0.02**	**7.91**	**9.25**	**0.01**	**0.02**	**9.28**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

Carbon dioxide emissions from fossil fuel stationary combustion were calculated using an IPCC (2006) Tier 2 methodology. Emissions were calculated using the following equation:

$$CO_2 \text{ Emissions} = \text{Fuel Consumption} \times \text{Carbon Content Coefficient}$$

Methane and N_2O emissions were calculated using an IPCC (2006) Tier 1 methodology. Emissions were calculated using the following equation:

$$CH_4 \text{ and } N_2O \text{ Emissions} = \text{Fuel Consumption} \times \text{Fuel Emission Factor}$$

Data Sources

Fuel consumption data by fuel type for both 1990 and 2007 were largely provided by DBEDT (2008a) in energy units (Btu). DBEDT categorized the data into residential, commercial, industrial, and electric power sectors, based on the consumption activity of each fuel type. Refer to Appendix C for a detailed breakout of energy consumption by fuel type and sub-sector.

Carbon content coefficients for estimating CO_2 emissions, which are specific to each fuel type, were taken from the U.S. Inventory (U.S. EPA 2017a). Methane and N_2O emission factors were obtained from the *2006 IPCC Guidelines* (IPCC 2006).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from fossil fuel stationary combustion have increased by less than 0.1 percent and 0.3 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Additionally, all emission factors obtained from the U.S. Inventory were updated based on the most recent version of the report (U.S. EPA 2017a).

2.2. Transportation (IPCC Source Category 1A3)

Emissions result from the combustion of fuel during the operation of highway and non-highway (i.e., off-road) vehicles. Highway vehicles—which are a source of ground transportation emissions—include passenger cars, light trucks, motorcycles, and heavy-duty vehicles (i.e., trucks and buses). Non-highway vehicles—which include ground, marine, aviation, and military sources—consist of construction equipment, agricultural vehicles, planes, and military vehicles. Table 7 summarizes emissions from transportation in Hawaii for 1990 and 2007.

Table 7: Transportation Emissions by Gas (MMT CO_2 Eq.)

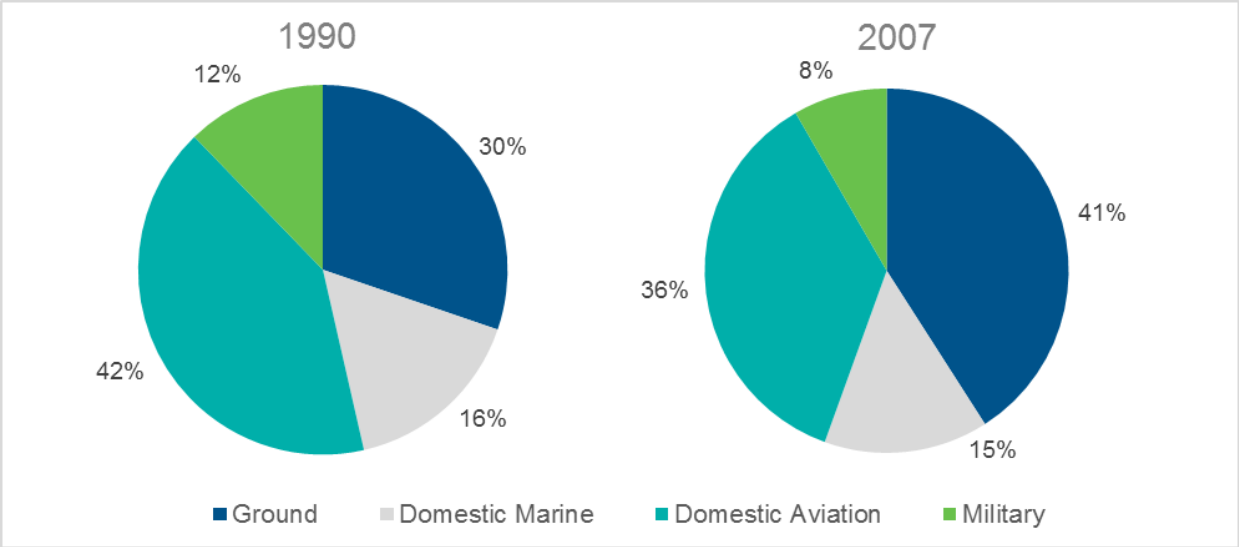
Source	1990				2007			
	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total
Ground	3.23	0.03	0.14	**3.41**	4.86	0.01	0.13	**5.01**
Domestic Marine	1.81	+	0.01	**1.82**	1.77	+	0.01	**1.79**
Domestic Aviation	4.61	+	0.04	**4.66**	4.38	+	0.04	**4.42**
Military	1.37	+	0.01	**1.38**	1.01	+	0.01	**1.02**
Total	**11.02**	**0.03**	**0.21**	**11.27**	**12.02**	**0.02**	**0.19**	**12.23**

+ Does not exceed 0.005 MMT CO_2 Eq.

Notes: Totals may not sum due to independent rounding.

In 1990, domestic aviation accounted for the largest portion of transportation emissions (42 percent) followed by ground, domestic marine, and military transportation. In 2007, ground transportation accounted for the largest portion of transportation emissions (41 percent) followed by domestic aviation (36 percent), domestic marine (15 percent), and military (8 percent). Figure 11 shows the breakout of transportation emissions by source for 1990 and 2007.

Figure 11: Transportation Emissions by Source, 1990 and 2007 (% of transportation sector emissions)



Methodology

Carbon dioxide emissions were estimated using the following equation, consistent with IPCC (2006):

CO_2 Emissions = [Fuel Consumption (by fuel type) – International Bunker Fuel Consumption (by fuel type)] x Carbon Content Coefficient

Methane and N_2O emissions from highway vehicles are dependent on numerous factors, such as engine type and emissions control technology. Consistent with the IPCC (2006) Tier 2 methodology, the following equation was used to calculate CH_4 and N_2O emissions from highway vehicles:

CH_4 and N_2O Emissions = VMT (by vehicle, fuel, model year, and control technology) x Control Technology Emission Factor

Methane and N_2O emissions from non-highway vehicles were estimated using the following equation, consistent with the IPCC (2006) Tier 1 methodology:

CH_4 and N_2O Emissions = [Non-Highway Vehicle Fuel Consumption (by fuel type) – International Bunker Fuel Consumption (by fuel type)] x Emission Factor

Data Sources

Fuel consumption data by fuel type for both 1990 and 2007 were provided by DBEDT (2008a). DBEDT categorized the data into ground, aviation, marine, and military transportation sources, based on the consumption activity of each fuel type. Aviation and marine fuel consumption were then further apportioned into domestic and international consumption, which is discussed in Section 2.5: International Bunker Fuels. Refer to Appendix C for a detailed breakout of energy consumption by fuel type and sector.

Vehicle miles traveled (VMT) estimates by vehicle type for 1990 and 2007 were provided by the Hawaii Department of Transportation (Hawaii DOT 2008). Vehicle age distribution by model year, as well as control technologies and emission factors by vehicle type, were obtained from the U.S. Inventory (U.S. EPA 2017a). Default emission factors for estimating emissions from off-road vehicles were obtained from the *1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997).

Accounting for Emissions from Domestic vs. International Aviation and Marine Fuel Consumption

Consistent with IPCC (2006), the following approach is used to determine emissions from the transportation sector:

- **Included in Hawaii Inventory Totals:** All transportation activities that occur within Hawaii (e.g., flights from Oahu to Maui) and domestic interstate activities originating in Hawaii (e.g., flights from Honolulu to Los Angeles).
- **Estimated but Excluded from Hawaii Inventory Totals:** Any fuel combustion used for international flights and marine voyages that originate in Hawaii (e.g., flights from Honolulu to Hong Kong).
- **Not Estimated:** All transportation activities that originate outside Hawaii (e.g., travel from New York City to Honolulu, travel from Tokyo to Honolulu).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 emission estimates for transportation decreased by 15 percent, and 2007 emission estimates decreased by 3 percent. The primary reason for the 15 percent decrease in 1990 emissions was due to higher estimates of the proportion of jet fuel used for international bunker fuels, which reduced the estimate for domestic aviation.[9] Updates to international bunker fuel consumption estimates are described in detail in to Section 2.5; these estimates impacted domestic marine and domestic aviation consumption totals. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). All emission factors obtained from the U.S. Inventory were also updated based on the most recent version of the report (U.S. EPA 2017a). Additionally, transportation emissions previously categorized as Other were disaggregated into Military, Ground, and Domestic Marine. Because of this change, Military is now listed as a separate sub-category. Finally, highway diesel for 2007 was reclassified as Ground transportation from Domestic Marine transportation after a time-series analysis was performed to confirm the reclassification.

2.3. Incineration of Waste (IPCC Source Category 1A1a)

Municipal solid waste (MSW) releases CO_2, CH_4, and N_2O emissions when combusted. In 1990, MSW was combusted in Hawaii at two facilities: the H-POWER plant and the Waipahu Incinerator. The Waipahu Incinerator ceased operations in the early 1990s, while the H-POWER plant was operational in 2007. Consistent with the U.S. Inventory (U.S. EPA 2017a), all waste incineration in Hawaii is reported under the Energy sector. This is because in Hawaii the incineration of waste generally occurs at facilities where energy is recovered. Table 8 summarizes emissions from the incineration of waste in Hawaii for 1990 and 2007.

Table 8: Incineration of Waste Emissions by Gas (MMT CO_2 Eq.)

Source	1990				2007			
	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total
Incineration of Waste	0.17	+	+	**0.18**	0.15	+	+	**0.15**

+ Does not exceed 0.005 MMT CO_2 Eq.

Methodology

For the Waipahu Incinerator, CO_2, CH_4, and N_2O emissions were calculated using the IPCC (2006) Tier 1 methodology. For CO_2 emissions, this approach uses waste composition data (i.e., the percent of plastics and synthetic materials) and their respective carbon content to determine emissions from the combustion of these materials, as described in the following equation:

[9] Note that while this change affects total statewide emissions, it does not affect the 1990 statewide baseline, as aviation emissions are excluded.

$$CO_2\ Emissions = MSW\ x \sum_i (WF_i\ x\ dm_i\ x\ CF_i\ x\ FCF_i\ x\ OF_i)$$

where,

CO_2 Emissions	= CO_2 emissions in the inventory year
MSW	= total amount of MSW incinerated
WF_i	= fraction of waste type/material of component i in the MSW
dm_i	= dry matter content in the waste incinerated
CF_i	= fraction of carbon in the dry matter (total carbon content)
FCF_i	= fraction of fossil carbon in the total carbon
OF_i	= oxidation factor
i	= type of waste incinerated

For CH_4 emissions, this Tier 1 approach uses the waste input to the incinerator and a default emission factor, as described in the following equation:

$$CH_4\ Emissions = IW\ x\ EF$$

where,

CH_4 Emissions	= CH_4 emissions in the inventory year
IW	= amount of incinerated waste
EF	= CH_4 emission factor

For N_2O emissions, this Tier 1 approach uses the waste input to the incinerator and a default emission factor, as described in the following equation:

$$N_2O\ Emissions = IW\ x\ EF$$

where,

N_2O Emissions	= N_2O emissions in the inventory year
IW	= amount of incinerated waste
EF	= N_2O emission factor

For the H-POWER plant, emissions were calculated using a Tier 3 methodology consistent with California Air Resources Board (CARB) guidance for Mandatory GHG Emissions Reporting (Hahn 2008). This methodology is believed to be more accurate than the IPCC methodology and attributes a specific ratio of carbon emissions to account for biogenic and anthropogenic sources based on carbon isotope measurements at the facility. This approach utilizes facility-specific steam output data from HPOWER to estimate CO_2, CH_4, and N_2O emissions from the combustion of refuse-derived fuel which is processed from MSW, as described in the following equation:

$$Emissions = \sum_i Heat\ x\ EF_i$$

where,

Emissions	= GHG emissions in the inventory year
Heat	= heat output at a given facility
EF_i	= default emission factor for GHG i
i	= type of GHG emitted (CO_2, CH_4, and N_2O)

Data Sources

Data on the quantity of waste combusted in 1990 at the Waipahu Incinerator was provided by Steve Serikaku, Honolulu County Refuse Division (Serikaku 2008). Emission factors and the proportion of plastics, synthetic rubber, and synthetic fibers in the waste stream used for calculating emissions from the Waipahu Incinerator were taken from the U.S. EPA's State Inventory Tools – Solid Waste Module (U.S. EPA 2017b).

Facility-specific information for the H-POWER plant was obtained directly from Convanta Energy, which operated the H-POWER facility. This data included steam generation, RDF composition, biogenic carbon ratios, fuel consumption data, and CO_2 and N_2O emissions (Hahn 2008).

Changes in Estimates since the 2008 Inventory Report

In the 2008 inventory report, this emission source was included in the Waste sector; this inventory report moves this category to the Energy sector.[10] 1990 and 2007 emission estimates from the incineration of waste increased by less than 0.01 percent. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Additionally, revised data on the proportion of plastics, synthetic rubber, and synthetic fibers in the waste stream in 1990 and 2007 was used based on updated figures from the U.S. EPA State Inventory Tools – Solid Waste Module (U.S. EPA 2017b). Finally, an updated emission factor for N_2O emissions from MSW combustion was used based on the revised methodology in the U.S. EPA's State Inventory Tools – Solid Waste Module (EPA 2017b).

2.4. Oil and Gas Operations (IPCC Source Category 1B2c)

Refinery activities release CH_4 to the atmosphere as fugitive emissions, vented emissions, emissions from operational upsets, and emissions from fuel combustion. In 1990 and 2007, two refineries were in operation in Hawaii (EIA 2017). Table 9 summarizes emissions from oil and gas operations in Hawaii for 1990 and 2007.

[10] Emissions from the incineration of waste were moved under the Energy sector to be consistent with the U.S. Inventory (U.S. EPA 2017) and because in Hawaii the incineration of waste generally occurs at facilities where energy is recovered.

Table 9: CH_4 Emissions from Oil and Gas Operations (MMT CO_2 Eq.)

Source	1990	2007
Oil and Gas Operations	+	0.01

+ Does not exceed 0.005 MMT CO_2 Eq.

Methodology

The following equation was used to estimate CH_4 emissions from oil and gas operations, consistent with the methodology presented in the U.S. Inventory (U.S. EPA 2017a):

$$CH_4 \text{ Emissions} = \text{Crude Oil Refined} \times \text{Emission Factor (by Refinery Activity)}$$

Data Sources

Data on the amount of crude oil refined was obtained from correspondence with the owners of each refinery for both 1990 and 2007 estimates (DBEDT 2008b).[11] Emission factors were obtained from the U.S. Inventory (U.S. EPA 2017a).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from oil and gas operations have increased by roughly 10,000 percent and 5,000 percent, respectively. The change in emission factors resulted in a large percentage change in emissions from this source; however, these emissions still comprise less than 0.1 percent of total energy sector emissions. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Additionally, all emission factors obtained from the U.S. Inventory were updated based on the most recent version of the report (U.S. EPA 2017a).

2.5. International Bunker Fuels (IPCC Source Category 1: Memo Items)

International bunker fuels are defined as marine and aviation travel originating in Hawaii and ending in a foreign country. According to IPCC (2006), emissions from the combustion of fuels used for international transport activities, or international bunker fuels, should not be included in emission totals, but instead should be reported separately. International bunker fuel combustion produces CO_2, CH_4, and N_2O emissions from both marine and aviation fuels. Table 10 summarizes emissions from international bunker fuels in Hawaii for 1990 and 2007.

[11] Data for the Chevron refinery (now owned by Island Energy Services) were unable to be obtained for 1990 and thus were not included in estimates. It is expected that emissions from this source would likely contribute less than 0.005 MMT CO_2 Eq. based on the refinery's 2007 contribution to emissions.

Table 10: International Bunker Fuel Emissions by Gas (MMT CO_2 Eq.)

Source	1990				2007			
	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total
Marine	0.12	+	+	**0.12**	0.05	+	+	**0.05**
Aviation	2.80	+	0.03	**2.83**	1.48	+	0.01	**1.49**
Total	**2.92**	**+**	**0.03**	**2.95**	**1.53**	**+**	**0.01**	**1.54**

+ Does not exceed 0.005 MMT CO_2 Eq.

Notes: Totals may not sum due to independent rounding.

Methodology

Aviation bunker fuel CO_2, CH_4, and N_2O emissions were calculated by first estimating the amount of jet fuel used for international trips. The portion of jet fuel used for international trips was estimated by using the ratio of international flight mileage divided by the total flight mileage originating in Hawaii. That percentage was multiplied by overall jet fuel consumption to obtain aviation bunker fuel consumption. The aviation bunker fuel consumption was then multiplied by CO_2, CH_4, and N_2O emission factors to calculate GHG emissions.

Marine bunker fuel CO_2, CH_4, and N_2O emissions were calculated by multiplying diesel and residual fuel consumption for international trips by their respective emission factors.

Data Sources

Total jet fuel consumption was obtained from DBEDT (2008a). International and domestic flight mileage data were obtained from the U.S. Department of Transportation's Bureau of Transportation Statistics Transtats database (U.S. DOT 2017).

Because marine bunker fuel consumption was not available for 1990, fuel consumption for 1990 was calculated by assuming Hawaii represented the same proportion of the total U.S. consumption in 1990 as in 2006 (the latest available year for Hawaii marine bunker fuel). Marine bunker fuel consumption for Hawaii was obtained from the Census Bureau (U.S. DOC 2008), and national marine bunker fuel consumption was obtained from the U.S. Inventory (U.S. EPA 2017a).

Carbon dioxide emission factors were obtained from the U.S. Inventory (U.S. EPA 2017a), while CH_4 and N_2O emission factors were obtained from IPCC (2006).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from international bunker fuel combustion have increased by roughly 193 percent and 17 percent, respectively.

In the previous inventory, flight mileage data were downloaded from the BTS Transtats database to apportion jet fuel consumption to the International Bunker Fuels source category. For this inventory, flight mileage data were re-downloaded from the BTS Transtats database for 1990 and 2007. While domestic flight mileage did not change, international mileage was significantly higher in both 1990 and

2007, resulting in a higher percentage of international miles relative to total miles. Since total jet fuel consumption did not change, this reallocation of jet fuel resulted in an increase in emissions for International Bunker Fuels, and a decrease in emissions for omestic Aviation compared to the 2008 inventory report. While this reallocation resulted in lower emissions from the Energy sector in Hawaii and higher emissions from International Bunker Fuels for both 1990 and 2007, the sum total of these two sources do not change significantly.

Additionally, 2007 marine bunker fuel data were available for this inventory report, whereas the 2008 inventory report used 2006 data, the latest year available, as a proxy for 2007. This updated data resulted in a decrease in marine bunker fuel emissions estimates in 2007, as fuel use was lower in 2007 relative to 2006. Corrected calculations for converting marine bunker fuels from volume to energy units in both 1990 and 2007 also resulted in lower bunker fuel estimates, and accordingly resulted in higher emissions from the transportation sector, as fewer bunker fuels were deducted from consumption totals.

Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Additionally, all emission factors obtained from the U.S. Inventory were updated based on the most recent version of the report (U.S. EPA 2017a).

2.6. CO_2 from Wood Biomass and Biofuel Consumption (IPCC Source Categories 1A1, 1A2, 1A3, 1A4, 1A5)

Combustion of ethanol,[12] which is blended into motor gasoline at oil refineries, generates CO_2 emissions.[13,14] Hawaii began blending ethanol into its motor gasoline supply in 2006. According to IPCC (2006), since these emissions are biogenic, CO_2 emissions from biomass combustion should be estimated separately from fossil fuel CO_2 emissions and should not be included in Energy sector emission totals. This is to avoid double-counting of biogenic CO_2 emissions from the AFOLU sector. Table 11 summarizes CO_2 emissions from wood biomass and biofuel consumption in Hawaii for 1990 and 2007.

Table 11: CO_2 Emissions from Wood Biomass and Biofuel Consumption (MMT CO_2 Eq.)

Source	1990	2007
CO_2 from Wood Biomass and Biofuel Consumption	NE	0.16

NE (emissions are Not Estimated).

[12] Combustion of biodiesel and wood biomass also generate GHG emissions but were not estimated for this inventory report due to a lack of available data.
[13] In addition to CO_2, small amounts of CH_4 are also emitted from ethanol. Unlike CO_2 emissions from biomass, these CH_4 emissions are not accounted for in a separate process, and thus are apportioned to the ground transportation sector and are counted towards total net emissions.
[14] The IPCC emission factor for N_2O for this source is 0, therefore N_2O emissions are not estimated.

Methodology

Carbon dioxide emissions from biomass combustion are calculated using the following equation:

$$CO_2 \text{ Emissions} = \text{Ethanol Consumption} \times \text{Energy Conversion Factor} \times \text{Emission Factor}$$

Data Sources

Ethanol consumption data, in barrels, were obtained from DBEDT (2017a). Ethanol consumption data were converted to energy units using the lower heating value obtained from the U.S. DOE (2014). Ethanol CO_2 combustion emission factors were obtained from the U.S. Inventory (U.S. EPA 2017a).

Changes in Estimates since the 2008 Inventory Report

This category is newly quantified for this inventory report.

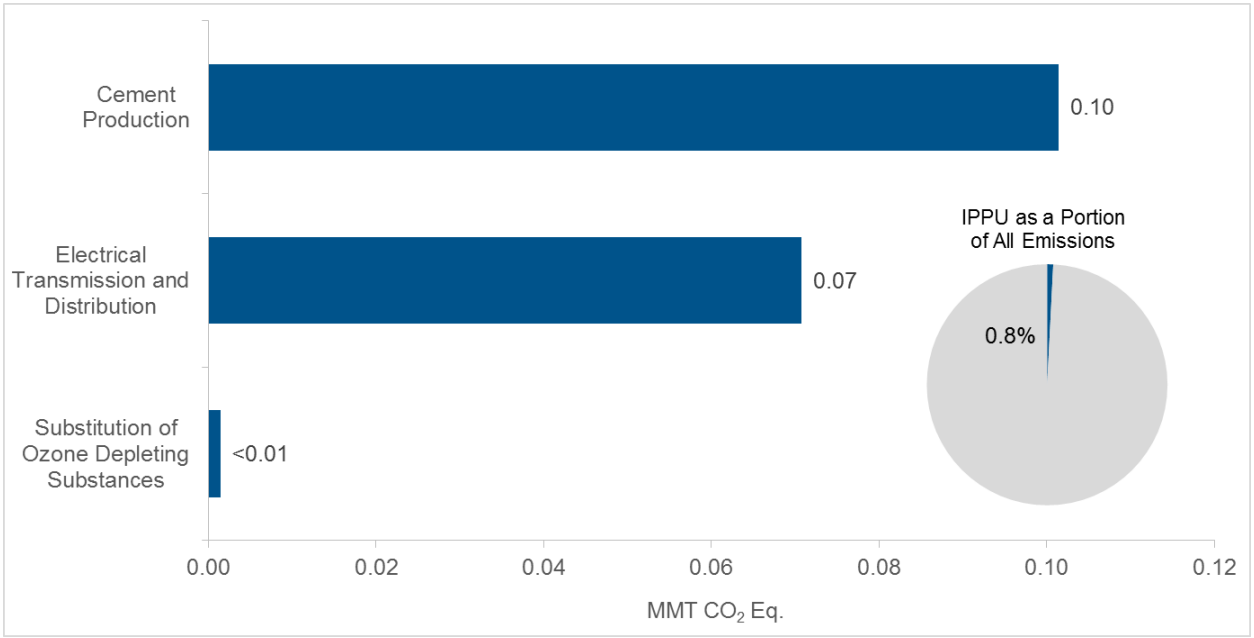
3. Industrial Processes and Product Use (IPPU)

This chapter presents GHG emissions occurring from industrial processes and from the use of GHGs in products. For the state of Hawaii, industrial processes and product use (IPPU) sector emissions are estimated from the following sources[15] and gases:

- Cement Production (IPCC Source Category 2A1): CO_2
- Electrical Transmission and Distribution (IPCC Source Category 2G1): SF_6
- Substitution of Ozone Depleting Substances (IPCC Source Category 2F): HFCs, PFCs

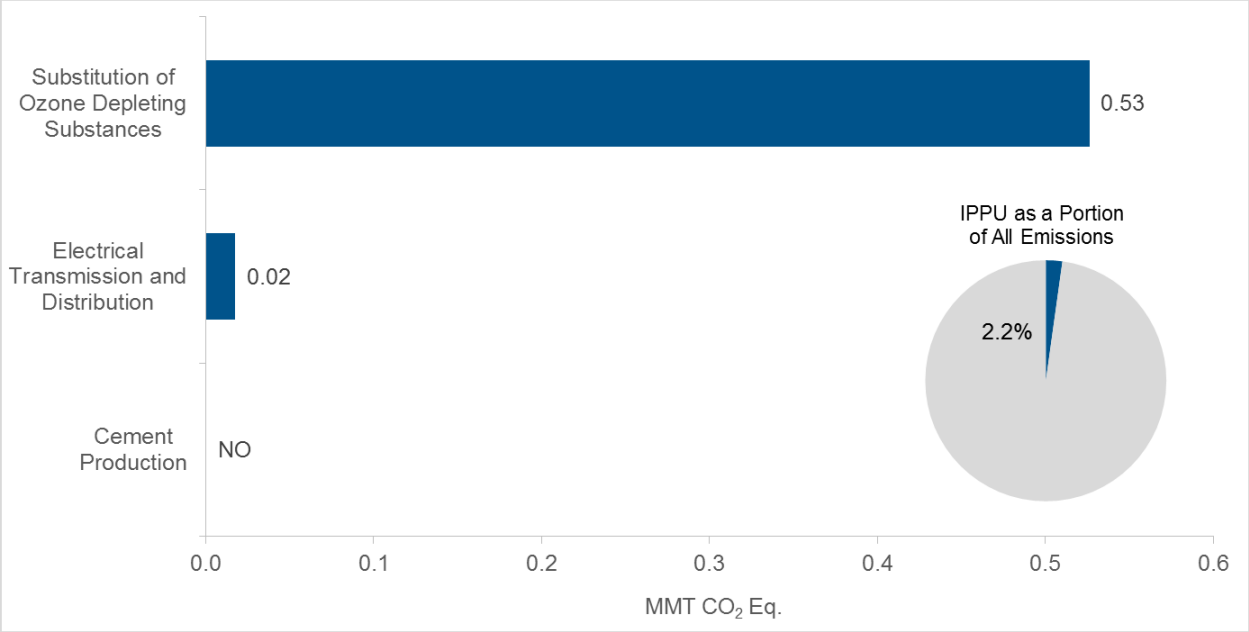
Emissions from the IPPU sector were 0.17 MMT CO_2 Eq. in 1990 and 0.54 MMT CO_2 Eq. in 2007, accounting for 1 percent and 2 percent of total Hawaii emissions, respectively. Figure 12 and Figure 13 show IPPU emissions by source for 1990 and 2007. Emissions by source and year are summarized in Table 12.

Figure 12: 1990 IPPU Emissions by Source (MMT CO_2 Eq.)



[15] IPCC Source Categories for which emissions do not occur and therefore were not estimated for the state of Hawaii include: Lime Production (IPCC Source Category 2A2), Glass Production (IPCC Source Category 2A3), Other Process Uses of Carbonates, (IPCC Source Category 2A4), Chemical Industry (IPCC Source Category 2B), Metal Industry (IPCC Source Category 2C), Non-Energy Products from Fuels and Solvent Use (IPCC Source Category 2D), Electronics Industry (IPCC Source Category 2E), SF_6 and PFCs from Other Product Uses (IPCC Source Category 2G2), and N_2O from Product Uses (IPCC Source Category 2G3). Appendix B provides information on why emissions were not estimated for these IPCC Source Categories.

Figure 13: 2007 IPPU Emissions by Source (MMT CO_2 Eq.)



NO (emissions are Not Occurring)

Table 12: GHG Emissions from the IPPU Sector by Source (MMT CO_2 Eq.)

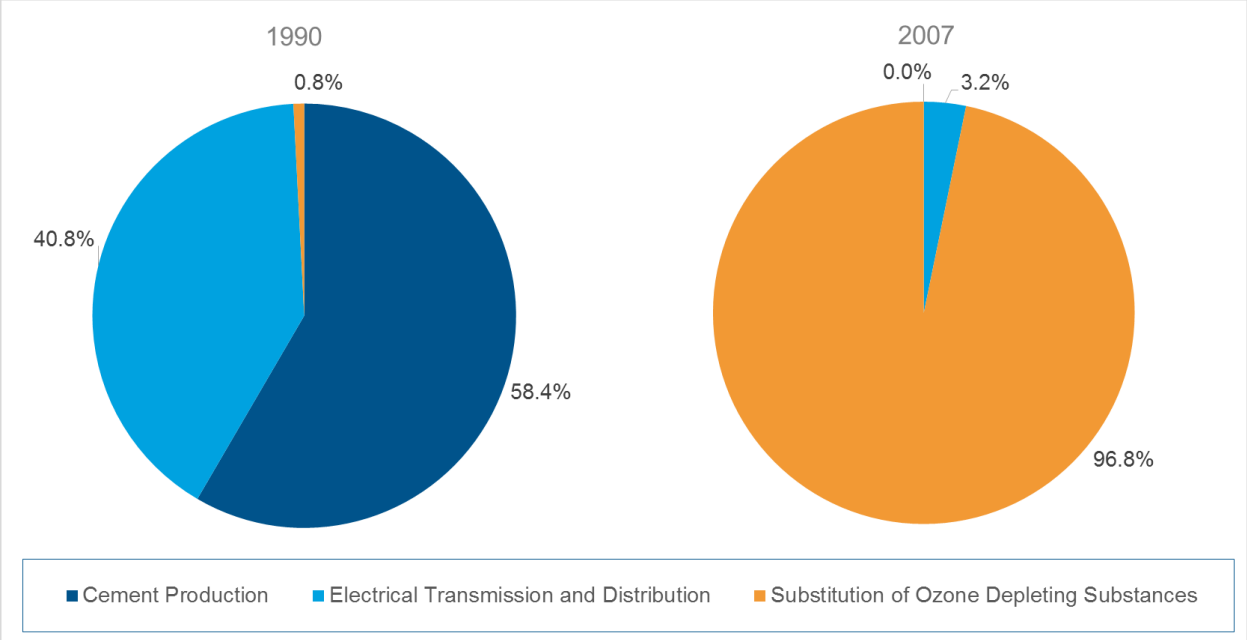
Source	1990	2007
Cement Production	0.10	NO
Electrical Transmission and Distribution	0.07	0.02
Substitution of Ozone Depleting Substances	+	0.53
Total	**0.17**	**0.54**

+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring).

Note: Totals may not sum due to independent rounding.

In 1990, cement production accounted for the largest share of IPPU emissions in Hawaii. Clinker production in Hawaii ceased in 1996 and, as a result, emissions from cement production in 2007 were zero. Emissions from electrical transmission and distribution have similarly decreased between 1990 and 2007. In contrast, emissions from the substitution of ozone depleting substances were less than 0.005 MMT CO_2 Eq. in 1990 but increased significantly to 0.53 MMT CO_2 Eq., accounting for roughly 97 percent of IPPU emissions in 2007. Figure 14 presents the breakout of GHG emissions by source within the IPPU sector for both 1990 and 2007.

Figure 14: IPPU Emissions by Source, 1990 and 2007 (MMT CO_2 Eq.)



3.1. Cement Production (IPCC Source Category 2A1)

Carbon dioxide emissions are released as a by-product of the clinker production process, an intermediate product used primarily to make portland cement. In Hawaii, clinker was produced on-site in Oahu until production ceased in 1996, after which clinker was imported (Wurlitzer 2008). Table 13 summarizes emissions from cement production in Hawaii for 1990 and 2007.

Table 13: CO_2 Emissions from Cement Production (MMT CO_2 Eq.)

Source	1990	2007
Cement Production	0.10	NO

NO (emissions are Not Occurring).

Methodology

Process-related CO_2 emissions from cement production were estimated using IPCC (2006) Tier 2 methodology, plant-specific clinker production, and default factors for calcium oxide content and cement kiln dust. Emissions were calculated using the following equation:

$$CO_2 \text{ Emissions} = M_{clinker} \times EF_{clinker} \times CF_{cement\ kiln\ dust}$$

where:

$M_{clinker}$ = weight (mass) of clinker produced, tonnes
$EF_{clinker}$ = emission factor for clinker, 0.51 tonnes CO_2/tonne clinker
$CF_{cement\ kiln\ dust}$ = emissions correction factor for cement kiln dust, 1.02

Data Sources

Clinker production data were provided by Hawaiian Cement (Wurlitzer 2008). The emission factor for clinker production and CKD correction factor were obtained from the *2006 IPCC Guidelines* (IPCC 2006).

Changes in Estimates since the 2008 Inventory Report

No changes were made to the 1990 and 2007 emission estimates from cement production relative to the 2008 inventory report as no changes were made to the methodology, GWP values, emission factors, or activity data.

3.2. Electrical Transmission and Distribution (IPCC Source Category 2G1)

Sulfur hexafluoride (SF_6) emissions from electrical transmission and distribution systems result from leaks in transmission equipment. Nationally, these emissions have decreased over time due to a sharp increase in the price of SF_6 during the 1990s and a growing awareness of the environmental impact of SF_6 emissions (U.S. EPA 2017a). Table 14 summarizes emissions from electrical transmission and distribution systems in Hawaii for 1990 and 2007.

Table 14: SF_6 Emissions from Electrical Transmission and Distribution (MMT CO_2 Eq.)

Source	1990	2007
Electrical Transmission and Distribution	0.07	0.02

Methodology

Emissions were calculated by apportioning U.S. emissions from this source to Hawaii based on the ratio of Hawaii electricity sales to U.S. electricity sales. The apportionment method was used instead of the IPCC methodology because data on SF_6 purchases and emissions for Hawaiian utilities are not available for 1990 or 2007.

Data Sources

Estimates of national SF_6 emissions data were taken from the U.S. Inventory (U.S. EPA 2017a). National electricity sales data come from the U.S. Department of Energy, Energy Information Administration (EIA 2016). Hawaii electricity sales data come from the State of Hawaii Data Warehouse (DBEDT 2017b).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from electrical transmission and distribution systems decreased by 10 percent and 54 percent, respectively. This change is due to three factors: (1) Hawaii electricity sales data were updated using the most recent State of Hawaii Data Warehouse; (2) U.S. electricity sales data were updated using the most recent time series from the EIA Detailed State Data tables; and (3) U.S. SF_6 emissions from electrical transmission and distribution

systems were updated based on the most recent version of the U.S. Inventory (U.S. EPA 2017a), which uses GWP values from the *IPCC Fourth Assessment Report* (IPCC 2007).

3.3. Substitution of Ozone Depleting Substances (IPCC Source Category 2F)

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are used as alternatives to ozone depleting substances (ODS) that are being phased out under the Montreal Protocol and the Clean Air Act Amendments of 1990. These chemicals are most commonly used in refrigeration and air conditioning equipment, solvent cleaning, foam production, fire extinguishing, and aerosols. Nationally, emissions from ODS substitutes have risen dramatically since 1990, and now constitute one of the largest industrial sources of GHG emissions. Table 15 summarizes emissions from HFCs and PFCs that are used as substitutes of ODS in Hawaii for 1990 and 2007.

Table 15: HFC/PFC Emissions from Substitutes of ODS (MMT CO_2 Eq.)

Source	1990	2007
Substitution of Ozone Depleting Substances	+	0.53

+ Does not exceed 0.005 MMT CO_2 Eq.

Methodology

In contrast to source categories in which emissions are calculated based on production data or are directly monitored at a small number of point sources, emissions of HFCs and PFCs can occur from thousands of types of equipment from millions of sources, including refrigeration and air-conditioning units, aerosols, and solvents. At the national level, these emissions are estimated using the U.S. EPA's Vintaging Model, which tracks the use characteristics of equipment currently in use for more than 50 different end-use categories, and applies HFC and PFC leak rates to estimate annual emissions.

Hawaii emission estimates were calculated for the following sub-categories:

- Mobile air-conditioning
- Other refrigeration and air-conditioning
- Aerosols
- Foams
- Solvents
- Fire extinguishing

Emissions from mobile air-conditioning systems were estimated by apportioning national emissions to Hawaii based on the ratio of Hawaii vehicle registrations to U.S. vehicle registrations. For the remaining sub-categories, national emissions were apportioned to the Hawaii based on the ratio of Hawaii population to U.S. population since emissions are believed to strongly correlate with population.

Data Sources

Estimates of national emissions data were obtained from the U.S. Inventory (U.S. EPA 2017a). National population numbers were obtained from the U.S. Census Bureau (2001, 2011). National vehicle registration data were obtained from the U.S. Department of Transportation, Federal Highway Administration (FHWA 2016). Hawaii vehicle registration and population data were obtained from the State of Hawaii Data Warehouse (DBEDT 2017b).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 emission estimates from substitutes of ODS have increased to 0.001 MMT CO_2 Eq. relative to the previous estimate of zero. This change is due to updated data obtained from the U.S. Inventory (U.S. EPA 2017a), which previously indicated that there were zero emissions from ODS substitutes in 1990. 2007 emission estimates increased by 5.6 percent. The change in 2007 emissions is due to the following four reasons: (1) Hawaii vehicle registration data were updated using the most recent time series for the State of Hawaii Data Warehouse; (2) U.S. emissions from Substitutes for ODS were updated based on the U.S. Inventory (U.S. EPA 2017a), which uses GWP values from the *IPCC Fourth Assessment Report* (IPCC 2007); (3) U.S. vehicle registrations were updated using the most recent FHWA Highway Statistics; and (4) U.S. population data were updated with the most recent data from the U.S. Census Bureau.

4. Agriculture, Forestry and Other Land Uses (AFOLU)

This chapter presents GHG emissions from agricultural activities, land use, changes in land use, and land management practices. For the state of Hawaii, emissions from agriculture, forestry, and other land uses (AFOLU) are estimated from the following sources[16] and gases:

- Agriculture
  - Enteric Fermentation (IPCC Source Category 3A1): CH_4
  - Manure Management (IPCC Source Category 3A2): CH_4, N_2O
  - Agricultural Soil Management (IPCC Source Categories 3C4 and 3C5): N_2O
  - Field Burning of Agricultural Residues (IPCC Source Category 3C1b): CH_4, N_2O
  - Urea Application (IPCC Source Category 3C3): CO_2
- Land Use, Land-Use Change, and Forestry
  - Agricultural Soil Carbon (IPCC Source Categories 3B2 and 3B3): CO_2
  - Forest Fires (IPCC Source Category 3C1a): CO_2, CH_4, N_2O
  - Landfilled Yard Trimmings and Food Scraps (IPCC Source Category 3B5a): CO_2
  - Urban Trees (IPCC Source Category 3B5a): CO_2
  - Forest Carbon (IPCC Source Category 3B1a): CO_2

Agricultural activities are categorized as GHG "sources," which emit GHGs into the atmosphere. Land use, changes in land use, and land management practices may either be "sources" of GHGs or "sinks" of GHGs (sinks remove CO_2 from the atmosphere). In Hawaii, Landfilled Yard Trimmings and Food Scraps, Urban Trees, and Forest Carbon are CO_2 sinks. The remaining AFOLU categories presented in this chapter are sources of GHGs.

Total emissions (excluding sinks) from the AFOLU sector were 1.34 MMT CO_2 Eq. in 1990 and 1.45 MMT CO_2 Eq. in 2007, accounting for 6 percent of total Hawaii emissions in both inventory years. Carbon sinks were -2.85 MMT CO_2 Eq. in 1990 and -3.00 MMT CO_2 Eq. in 2007, while net emissions were -1.52 MMT CO_2 Eq. in 1990 and -1.55 MMT CO_2 Eq. in 2007. Therefore, the AFOLU sector is a net sink of GHG emissions in Hawaii in both years. Figure 15 and Figure 16 show AFOLU emissions by source for 1990 and 2007. Emission sources and sinks by category and year are summarized in Table 16.

[16] IPCC Source Categories for which emissions were not estimated for the state of Hawaii include: Land Converted to Forest Land (3B1b), Biomass Burning in Grassland (3C1c), Biomass Burning in All Other Land (3C1d), Wetlands (3B4), Other Land (3B6), Liming (3C2), and Harvested Wood Products (3D1). Appendix B provides information on why emissions were not estimated for these IPCC source categories.

Figure 15: 1990 AFOLU Emissions by Source (MMT CO_2 Eq.)

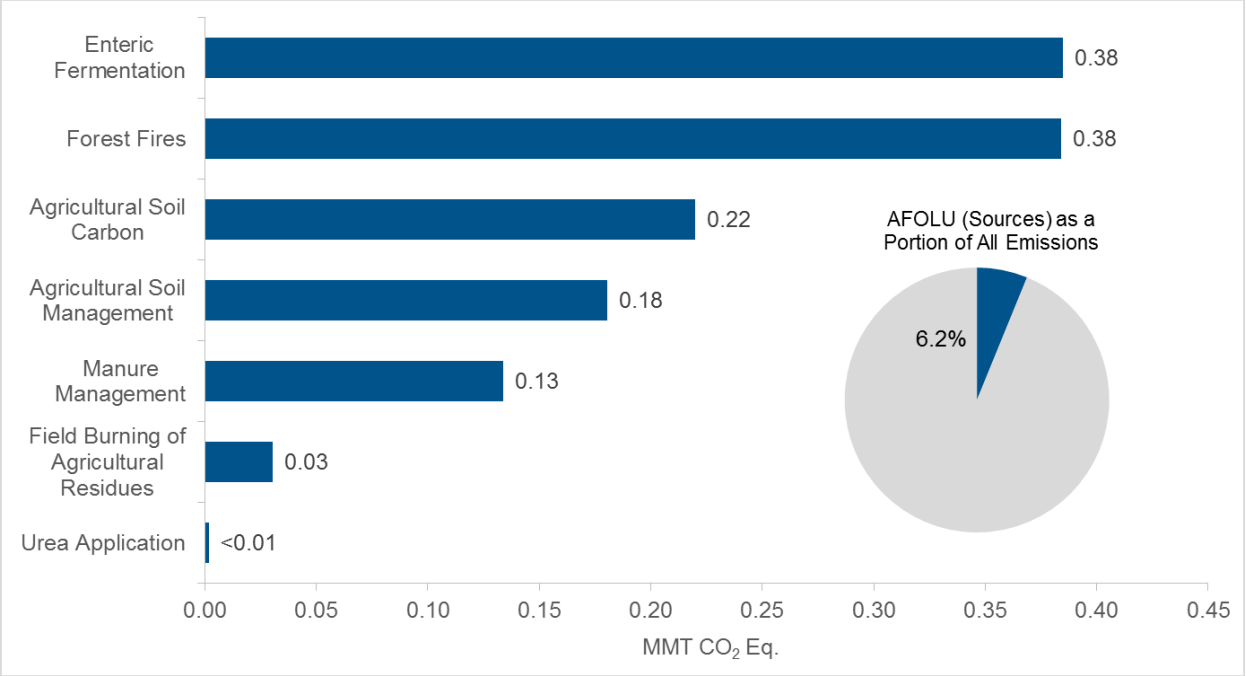


Figure 16: 2007 AFOLU Emissions by Source (MMT CO_2 Eq.)

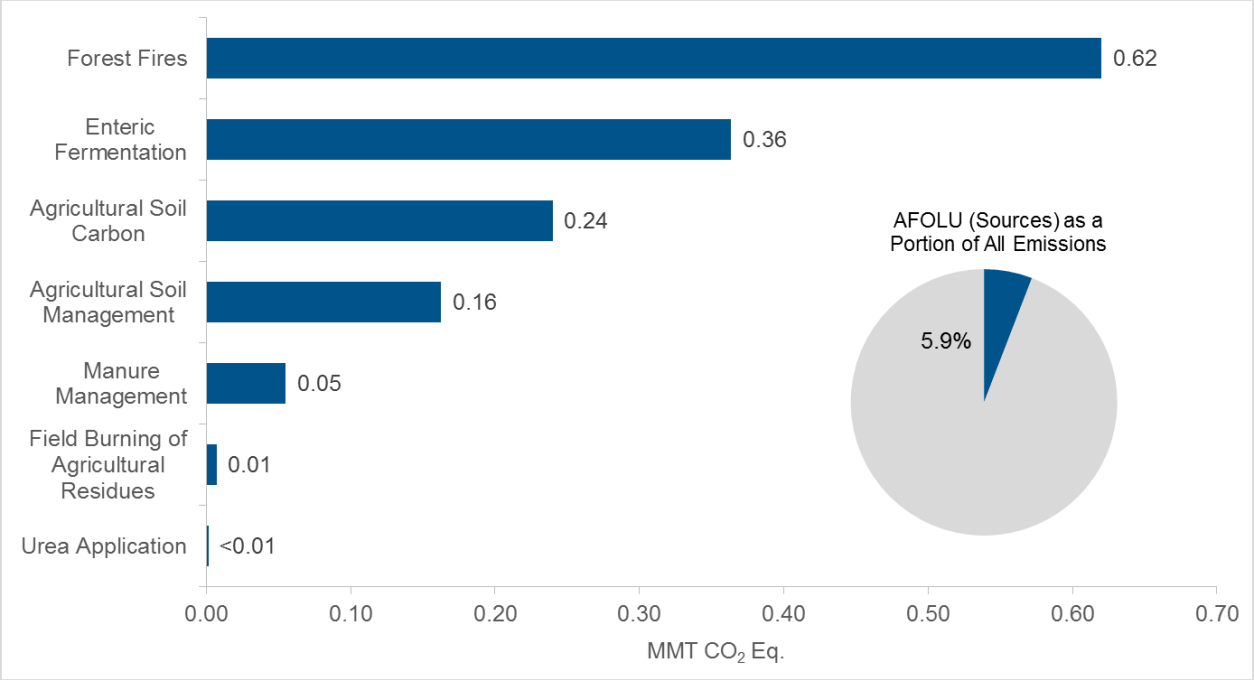


Table 16: GHG Emissions from the AFOLU Sector by Category (MMT CO_2 Eq.)

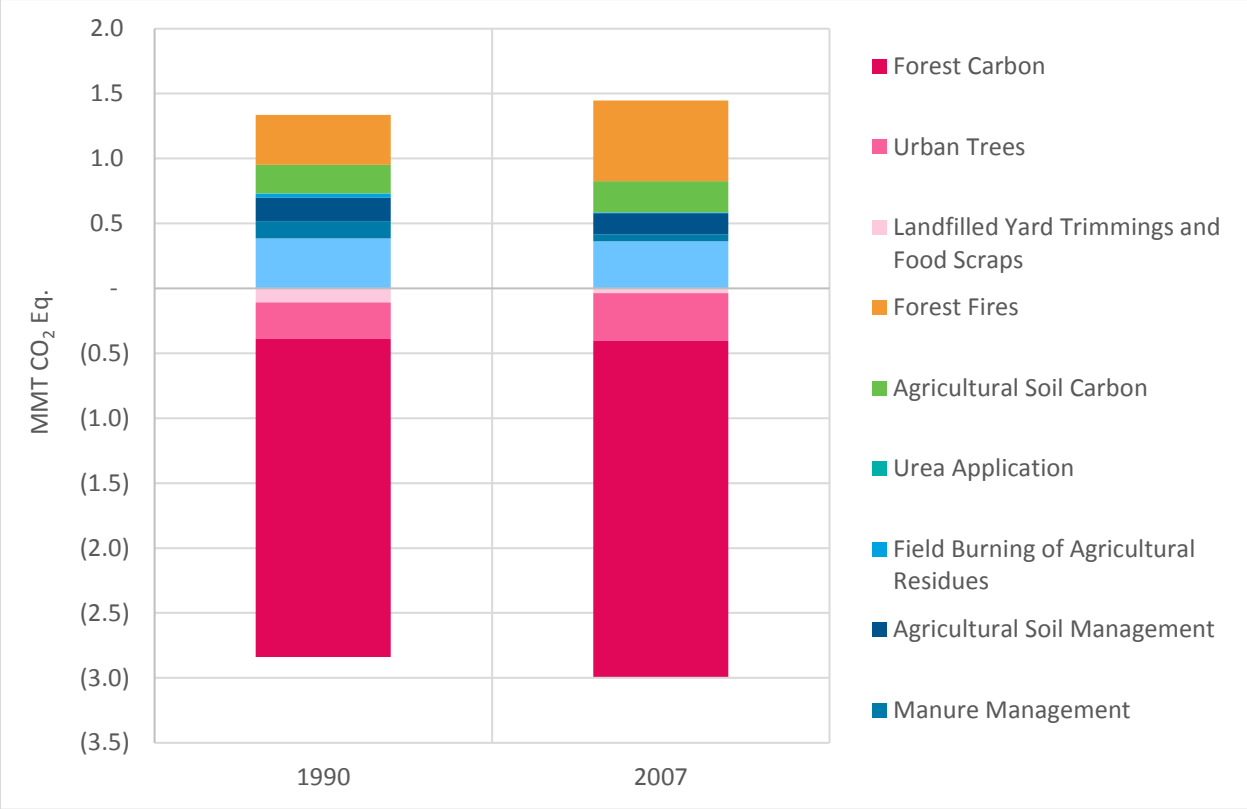
Category	1990	2007
Agriculture	**0.73**	**0.59**
Enteric Fermentation	0.38	0.36
Manure Management	0.13	0.05
Agricultural Soil Management	0.18	0.16
Field Burning of Agricultural Residues	0.03	0.01
Urea Application	+	+
Land Use, Land-Use Change, and Forestry	**(2.25)**	**(2.14)**
Agricultural Soil Carbon	0.22	0.24
Forest Fires	0.38	0.62
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.04)
Urban Trees	(0.28)	(0.37)
Forest Carbon	(2.45)	(2.59)
Total (Sources)	**1.34**	**1.45**
Total (Sinks)	**(2.85)**	**(3.00)**

+ Does not exceed 0.005 MMT CO_2 Eq.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Forest fires and enteric fermentation account for the largest share of AFOLU emissions in both 1990 and 2007, followed by agricultural soil management, agricultural soil carbon, manure management, field burning of agricultural residues, and urea application. Forest carbon accounts for the largest carbon sink, followed by urban trees and landfilled yard trimmings and food scraps. Figure 17 presents AFOLU emissions by source and sink in Hawaii for 1990 and 2007.

Figure 17: AFOLU Emissions by Source and Sink Category, 1990 and 2007 (MMT CO_2 Eq.)



4.1. Enteric Fermentation (IPCC Source Category 3A1)

Methane is produced as part of the digestive processes in animals, a microbial fermentation process referred to as enteric fermentation. The amount of CH_4 emitted by an animal depends upon the animal's digestive system, and the amount and type of feed it consumes (U.S. EPA 2017a). This source includes CH_4 emissions from dairy and beef cattle, sheep, goats, swine, and horses. Table 17 summarizes emissions from enteric fermentation in Hawaii for 1990 and 2007.

Table 17: CH_4 Emissions from Enteric Fermentation (MMT CO_2 Eq.)

Source	1990	2007
Enteric Fermentation	0.38	0.36

Methodology

The IPCC (2006) Tier 1 methodology was used to estimate emissions of CH_4 from enteric fermentation. Emissions were calculated using the following equation:

CH_4 emissions = Σ (for each animal type) animal population x animal-specific emission factor for CH_4 from cattle, sheep, goats, swine and horses (kg CH_4 per head per year)

Data Sources

Animal population data were obtained from the U.S. Department of Agriculture's (USDA) National Agriculture Statistics Service (NASS) (USDA 2017a, USDA 2017b). NASS reported annual population data for cattle and swine for 1990 and 2007. Population data for sheep, goats, and horses were obtained from the USDA Census of Agriculture, which is compiled every five years. The USDA's 2007 Census of Agriculture (USDA 2009) provided population data for sheep, goats, and horses for 2007. Population data for sheep, goats, and horses for 1990 were interpolated based on population data for 1987 and 1992 from the 1992 USDA Census of Agriculture (USDA 1994).

Yearly emission factors for the several cattle types available for the state of Hawaii for 1990 and 2007 were obtained from the EPA's State Inventory Tool (U.S. EPA 2017a).[17] Emission factors for bulls, sheep, goats, horses, and swine were obtained from the U.S. Inventory (U.S. EPA 2017a).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from enteric fermentation have increased by 44 percent and 46 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Emission factors obtained from the EPA's State Inventory Tool (U.S. EPA 2017a) were higher for most cattle types. Animal population data for sheep, goats, and horses for 2007, which was estimated in the 2008 inventory report, increased based on the 2007 USDA Census of Agriculture (USDA 2009). Population data for cattle and swine remained unchanged. Emission factors for sheep, goats, horses, and swine remained unchanged, while the emission factor for bulls increased.

4.2. Manure Management (IPCC Source Category 3A2)

The main GHGs emitted by the treatment, storage, and transportation of livestock manure are CH_4 and N_2O. Methane is produced by the anaerobic decomposition of manure. Direct N_2O emissions are produced through the nitrification and denitrification of the organic nitrogen (N) in livestock dung and urine. Indirect N_2O emissions result from the volatilization of N in manure and the runoff and leaching of N from manure into water (U.S. EPA 2017a). This category includes CH_4 and N_2O emissions from dairy and beef cattle, sheep, goats, swine, horses, and chickens. Table 18 summarizes emissions from manure management in Hawaii for 1990 and 2007.

Table 18: Manure Management Emissions by Gas (MMT CO_2 Eq.)

Source	1990			2007		
	CH_4	N_2O	Total	CH_4	N_2O	Total
Manure Management	0.11	0.02	**0.13**	0.04	0.01	**0.05**

Note: Totals may not sum due to independent rounding.

[17] The State Inventory Tool includes yearly emission factors for the following cattle types: dairy cows, beef cows, dairy replacement heifers, other dairy heifers, beef replacement heifers, other beef heifers, steers, and weanlings.

Methodology

The IPCC (2006) Tier 2 method was employed to estimate emissions of both CH_4 and N_2O using the following equations:

CH_4 emissions = animal population × typical animal mass × volatile solids excretion per kilogram animal mass × maximum potential emissions × weighted methane conversion factor

N_2O emissions = [Σ (for each waste management system) typical animal mass × N excretion per kg animal mass per day × 365 × (1 - percent N volatilized) × % of manure managed in that system × emission factor for that system] × conversion from N_2O-N to N_2O, 44/28

Data Sources

Animal population data for cattle, swine, and chickens were obtained from the USDA NASS (USDA 2017a, USDA 2017b, USDA 2017c). Population data for sheep, goats, and horses were obtained from the USDA Census of Agriculture, with year 2007 data obtained directly from the 2007 USDA Census of Agriculture (USDA 2009) and year 1990 data interpolated from data available for 1987 and 1992 in the 1992 USDA Census of Agriculture (USDA 1994).

To develop CH_4 emissions from manure management, typical animal mass, maximum potential emissions by animal, Hawaii-specific values for volatile solids (VS) excretion rates and weighted methane conversion factors (MCFs) were all obtained from the EPA's State Inventory Tool (U.S. EPA 2017c).

To develop N_2O emissions from manure management, nitrogen (N) excretion rates by animal type were also obtained from the EPA's State Inventory Tool (U.S. EPA 2017c). The distributions of waste by animal in different waste management systems (WMS) were obtained from the U.S. Inventory (U.S. EPA 2017a). Weighted MCFs take into account the percent of manure for each animal type managed in different WMS. Emission factors for the different WMS were obtained from the *2006 IPCC Guidelines* (IPCC 2006).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from manure management have increased by 9 percent and 10 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Volatile solids excretion rates were updated to reflect Hawaii-specific values rather than values for the U.S. "West" region. The typical animal mass for sheep and assumed distribution of manure among manure management system types for sheep, goats, swine, and horses were updated based on EPA's State Inventory Tool (U.S. EPA 2017c). Animal population data for sheep, goats, and horses for 2007, which were estimated in the 2008 inventory report based on 1992 and 1997 USDA Census of Agriculture data, increased based on the 2007 USDA Census of Agriculture (USDA 2009). Population data for cattle, swine, and chicken remained unchanged.

4.3. Agricultural Soil Management (IPCC Source Categories 3C4 and 3C5)

Nitrous oxide is produced naturally in soils through the nitrogen (N) cycle. Many agricultural activities, such as the application of N fertilizers, increase the availability of mineral N in soils that lead to direct N_2O emissions from nitrification and denitrification (U.S. EPA 2017a). This category includes N_2O emissions from synthetic fertilizer, organic fertilizer, manure N, as well as crop residue inputs from sugarcane, pineapples, sweet potatoes, ginger root, taro and corn for grain. Table 19 summarizes emissions from agricultural soil management in Hawaii for 1990 and 2007.

Table 19: N_2O Emissions from Agricultural Soil Management (MMT CO_2 Eq.)

Source	1990	2007
Agricultural Soil Management	0.18	0.16

Methodology

The IPCC (2006) Tier 1 approach was used to calculate N_2O emissions from agricultural soil management. The overall equation for calculating emissions is as follows:

$$N_2O \text{ emissions} = \text{direct } N_2O \text{ emissions} + \text{indirect } N_2O \text{ emissions}$$

The following equations were used to calculate direct emissions:

$$\text{Direct } N_2O \text{ emissions} = [(N_F \times EF_F) + (N_O \times EF_F) + (N_{CR} \times EF_F) + (N_{PRP1} \times EF_{PRP1}) + (N_{PRP2} \times EF_{PRP2})] \times 44/28$$

where,

N_F = N inputs to agricultural soils from synthetic fertilizers

N_O = N inputs to agricultural soils from organic fertilizers

N_{CR} = N inputs to agricultural soils from crop residues

N_{PRP1} = N inputs to agricultural soils from pasture, range, and paddock manure from cattle, swine, and poultry

N_{PRP2} = N inputs to agricultural soils from pasture, range, and paddock manure from sheep, goats, and horses

EF_F = emission factor for direct N_2O emissions from synthetic and organic fertilizers and crop residues (0.01 kg N_2O-N/kg N input)

EF_{PRP1} = emission factor for direct N_2O emissions from pasture, range, and paddock manure from cattle, swine, and poultry (0.02 kg N_2O-N/kg N input)

EF_{PRP2} = emission factor for direct N_2O emissions from pasture, range, and paddock manure from sheep, goats, and horses (0.01 kg N_2O-N/kg N input)

44/28 = conversion from N_2O-N to N_2O

N inputs to agricultural soils from crop residues (N_{CR}) = above-ground residue dry matter × crop area × [N content of aboveground residues + ratio of belowground residues to harvested yield for crop × N content of belowground residues]

Above-ground residue dry matter = Fresh weight yield (kg fresh weight harvested/ha) × dry matter fraction of harvested crop × slope + intercept

The following equations were used to calculate indirect emissions:

Indirect N_2O emissions = indirect emissions from volatilization + indirect emissions from leaching/runoff

$$\text{Indirect emissions from volatilization} = [(N_F \times L_{vol\text{-}F}) + (N_O \times L_{vol\text{-}O}) + (N_{PRP} \times L_{vol\text{-}O})] \times E_{Fvol} \times 44/28$$

$$\text{Indirect emissions from leaching/runoff} = (N_F + N_O + N_{CR} + N_{PRP}) \times L_{leach} \times EF_{leach} \times 44/28$$

where,

N_F	= N inputs to agricultural soils from synthetic fertilizers
N_O	= N inputs to agricultural soils from organic fertilizers
N_{CR}	= N inputs to agricultural soils from crop residues
N_{PRP}	= N inputs to agricultural soils from pasture, range, and paddock manure from all animals
$L_{vol\text{-}F}$	= fraction N lost through volatilization from synthetic fertilizer inputs (0.10)
$L_{vol\text{-}O}$	= fraction N lost through volatilization from organic fertilizer and manure inputs (0.20)
L_{leach}	= fraction N lost through leaching/runoff from all N inputs (0.30)
EF_{vol}	= emission factor for indirect N_2O emissions from N volatilization (0.010 kg N_2O-N / kg NH_3–N + NOX–N volatilized)
EF_{leach}	= emission factor for N_2O emissions from pasture, range, and paddock manure from cattle, swine, and poultry (+75 kg N_2O-N / kg N leached/runoff)
44/28	= conversion from N_2O-N to N_2O

Data Sources

Annual sugarcane area and production estimates used to estimate emissions from crop residue N additions were obtained from NASS (USDA 2017d). For other crops (i.e., pineapples, sweet potatoes, ginger root, taro, and corn for grain), data for 2007 were obtained from the 2007 Census of Agriculture (USDA 2009) and data for 1990 were estimated based on interpolations between data for 1987 and 1992 from the 1992 USDA Census of Agriculture (USDA 1994). Percent distribution of waste to various

animal waste management systems, used to estimate manure N additions to pasture, range, and paddock soils, were obtained from the U.S. Inventory (U.S. EPA 2017a).

Synthetic and organic fertilizer N application data were obtained from the annual publication of Association of American Plant Food Control Officials (AAPFCO 1995-2013, TVA 1991-1994). According to these data sources, commercial organic fertilizer is not applied in Hawaii.

Crop residue factors for corn were obtained from the *2006 IPCC Guidelines* (IPCC 2006). Crop residue factors for tubers were used for sweet potatoes, ginger root, and taro. No residue factors nor adequate proxy factors were available for pineapples or sugarcane, so crop residue N inputs from these crops were not included. However, as nearly 100 percent of aboveground sugarcane residues are burned in Hawaii, there is little crop residue N input from sugarcane. All emission and other factors are IPCC (2006) defaults.

Animal population data are used to calculate the N inputs to agricultural soils from pasture, range, and paddock manure from all animals. Animal population data for cattle, swine and chickens were obtained from the USDA NASS (USDA 2017a, USDA 2017b, USDA 2017c, USDA 2017d). Population data for sheep, goats, and horses were obtained from the USDA Census of Agriculture, with year 2007 data obtained directly from the 2007 USDA Census of Agriculture (USDA 2009) and year 1990 data interpolated from data available for 1987 and 1992 in the 1992 USDA Census of Agriculture (USDA 1994).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from agricultural soil management have decreased by 3 percent and 2 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Crop production data for 2007 for pineapples, sweet potatoes, ginger root, taro and corn for grain were updated based on the 2007 Census of Agriculture (USDA 2009). In addition, the typical animal mass for sheep and assumed distribution of manure among manure management system types for sheep, goats, swine, and horses were updated. Also, animal population data, used to calculate N inputs to agricultural soils from manure from sheep, goats, and horses for 2007 increased based on the 2007 USDA Census of Agriculture (USDA 2009).

4.4. Field Burning of Agricultural Residues (IPCC Source Category 3C1b)

Field burning is a method that farmers use to manage the vast amounts of agricultural crop residues that can be created during crop production. Crop residue burning is a net source of CH_4 and N_2O, which are released during combustion (U.S. EPA 2017a). This source includes CH_4 and N_2O emissions from sugarcane burning, which is the only major crop in Hawaii whose residues are regularly burned (Hudson 2008). Table 20 summarizes emissions from field burning of agricultural residues in Hawaii for 1990 and 2007.

Table 20: Field Burning of Agricultural Residues Emissions by Gas (MMT CO_2 Eq.)

Source	1990			2007		
	CH_4	N_2O	Total	CH_4	N_2O	Total
Field Burning of Agricultural Residues	0.03	+	**0.03**	0.01	+	**0.01**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

The IPCC/UNEP/OECD/IEA (1997) Tier 1 approach was used to calculate CH_4 and N_2O emissions from field burning of agricultural residues. Compared to the IPCC (2006) approach, the IPCC/UNEP/OECD/IEA (1997) method is considered more appropriate for conditions in the United States because it is more flexible for incorporating country-specific data (U.S. EPA 2017a). Emissions were calculated using the following equation:

CH_4 and N_2O Emissions = crop production × residue-crop ratio × dry matter fraction × fraction of crop residue burned × burning efficiency × combustion efficiency × C or N content of residue × emissions ratio × conversion factor

where,

Crop production	= annual weight of crop produced
Residue-crop ratio	= amount of residue produced per unit of crop production (0.19)
Fraction of crop residue burned	= amount of residue which is burned per unit of total residue (95%)
Dry matter fraction	= amount of dry matter per unit of biomass (62%)
C or N content of residue	= amount of C or N per unit of dry matter (42.4% and 0.4%, respectively)
Burning efficiency	= the proportion of prefire fuel biomass consumed (0.81)
Combustion efficiency	= the proportion of C or N released with respect to the total amount of C or N available in the burned material, respectively (0.68)
Emissions ratio	= g CH_4-C/g C released or g N_2O-N/g N release (+5 and +7, respectively)
Conversion factor	= conversion of CH_4-C to C or N_2O-N to N (16/12 and 44/28, respectively)

Data Sources

Annual sugarcane area and production estimates used to estimate emissions from crop residue N additions were obtained from USDA NASS (USDA 2017d). The residue/crop ratio and burning efficiency were taken from Kinoshita (1988). Dry matter fraction, fraction of carbon and N, and combustion

efficiency were taken from Turn et al. (1997). Fraction of residue burned was taken from Ashman (2008).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from field burning of agricultural residues have increased by 15 percent for both inventory years. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007).

4.5. Urea Application (IPCC Source Category 3C3)

Urea ($CO(NH_2)_2$) is a nitrogen fertilizer that is often applied to agricultural soils. When urea is added to soils, bicarbonate forms and evolves into CO_2 and water (IPCC 2006). Table 21 summarizes emissions from urea application in Hawaii for 1990 and 2007.

Table 21: CO_2 Emissions from Urea Application (MMT CO_2 Eq.)

Source	1990	2007
Urea Application	+	+

+ Does not exceed 0.005 MMT CO_2 Eq.

Methodology

The IPCC (2006) Tier 1 methodology was used to estimate emissions from urea application. Emissions were calculated using the following equation:

$$CO_2 \text{ Emissions} = M \times EF \times CO_2\text{-}C$$

where:

M = annual amount of urea fertilization, tonnes
EF = emission factor, 0.2 tonnes C/ton urea
CO_2-C = conversion of carbon to CO_2, 44/12, dimensionless

Data Sources

Fertilizer sales data were obtained from the annual publication of Association of American Plant Food Control Officials (AAPFCO 1995-2013, TVA 1991-1994). AAPFCO reports fertilizer sales data for each fertilizer year (July through June).[18] Historical usage patterns were used to apportion these sales to the inventory calendar years (January through December).

[18] Fertilizer sales are reported by fertilizer year, corresponding to the growing season. The 2007 fertilizer year, for example, runs from July 2006 to June 2007.

The *2006 IPCC Guidelines* default emission factor of 0.2 tonnes C/ton of urea was used to estimate the carbon emissions, in the form of CO_2, that result from urea application.

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from urea application have not changed as no changes were made to the methodology, GWP values, emission factors, or activity data.

4.6. Agricultural Soil Carbon (IPCC Source Categories 3B2, 3B3)

Agricultural soil carbon refers to the change in carbon stock in agricultural soils—either in cropland or grasslands—that have been converted from other land uses. Agricultural soils can be categorized into organic soils, which contain more than 12 to 20 percent organic carbon by weight, and mineral soils, which typically contain 1 to 6 percent organic carbon by weight (U.S. EPA 2017a). Organic soils that are actively farmed tend to be sources of carbon emissions as soil carbon is lost to the atmosphere due to drainage and management activities. Mineral soils can be sources of carbon emissions after conversion, but fertilization, flooding, and management practices can result in the soil being either a net source or net sink of carbon. Nationwide, sequestration of carbon by agricultural soils is largely due to enrollment in the Conservation Reserve Program, conservation tillage practices, increased hay production, and intensified crop production. Table 22 summarizes emissions from agricultural soils in Hawaii for 1990 and 2007.

Table 22: CO_2 Emissions from Agricultural Soils (MMT CO_2 Eq.)

Source	1990	2007
Agricultural Soil Carbon	0.22	0.24

Methodology

Emission estimates for this source were taken directly from the U.S. Agriculture and Forestry Greenhouse Gas Inventory (USDA 2008) and the U.S. Inventory (U.S. EPA 2009).[19] These estimates were developed by Dr. Stephen Ogle of Colorado State University using the Century biogeochemical model, which simulates changes in soil carbon nationwide based on weather patterns, land use, management activities, and water dynamics.

[19] 2007 state-level emissions from the most recent version of the U.S. Inventory (U.S. EPA 2017a) were not available for incorporation into this report.

Data Sources

Estimates of emissions from Hawaii's agricultural soils were available for the year 1997 in the U.S. Agriculture and Forestry Greenhouse Gas Inventory (USDA 2008). 1997 values were used as a proxy for 1990. Values for 2007 were available from the 1990-2007 U.S. Inventory (U.S. EPA 2009).[20]

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 emission estimates from agricultural soil carbon have not changed, while 2007 emission estimates have decreased by 2 percent. For the 2008 inventory report, 2006 estimates from the 1990-2006 U.S. Inventory were used as a proxy for 2007 estimates. For this inventory report, the estimate was updated to reflect the 2007 estimate (U.S. EPA 2009).

4.7. Forest Fires (IPCC Source Category 3C1a)

Forest fires emit CO_2, CH_4, and N_2O as biomass is combusted. This source includes emissions from forest fires caused by lightning, campfire, smoking, debris burning, arson, equipment, railroads, children, and other miscellaneous activities reported by the Hawaii Department of Land and Natural Resources (DLNR). Table 23 summarizes emissions from forest fires in Hawaii for 1990 and 2007.

Table 23: Forest Fire Emissions by Gas (MMT CO_2 Eq.)

Source	1990				2007			
	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total
Forest Fires	0.34	0.03	0.02	**0.38**	0.55	0.04	0.03	**0.62**

Note: Totals may not sum due to independent rounding.

Methodology

The IPCC (2006) Tier 1 methodology was used to calculate GHG emissions from forest fires according to the following equation:

$$\text{Emissions} = A \times M_B \times C_f \times G_{ef} \times 10^{-3}$$

where,

A = area burnt, hectares (ha)
M_B = mass of fuel available for combustion, tonnes/ha
C_f = combustion factor, dimensionless
G_{ef} = emission factor, g/kg dry matter burnt
10^{-3} = conversion of kg to tonnes

[20] 2007 state-level emissions from the most recent version of the U.S. Inventory (U.S. EPA 2017a) were not available for incorporation into this report.

Data Sources

Data for years 1994 and 2007 on acres burned by wildfire were obtained from the DLNR *Annual Wildfire Summary Report*, published by the Fire Management Program of the DLNR (and also found in DBEDT's Hawaii Warehouse) (DLNR 1994-2008). Due to limited data availability, 1994 data were used as proxy data for 1990.

Because acres burned data is related to wildland, it was necessary to develop a forestland to wildland ratio to estimate area of forestland burned. "Wildland under Protection" data, in million acres, were obtained for years 1998 and 2002 from the National Association of State Foresters (1998, 2002). 1998 data were used for 1990 and 2002 data were used for 2007.

Managed forestland acreage time series data were obtained from the Hawaii Warehouse (DBEDT 2017b). Area estimates of private forestland in the conservation district were summed with reserve forestland in the conservation district, forested natural areas and wooded farmland in order to generate total managed forested land area in Hawaii for 1990 and 2007. The annual carbon density for the lower 48 states (i.e., the fuel available for combustion) was provided by the U.S. Forest Service (USFS 2014).[21]

IPCC (2006) default combustion factors for tropical forest and shrubland were weighted using the ratio of Hawaii forest to shrubland area provided in the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (NOAA-CCAP) Descriptive Summary of the Changes in the Main Eight Hawaiian Islands (2000). According to NOAA-CCAP, roughly half of Hawaii's forestland is shrub/scrubland, defined as land with vegetation less than 20 feet tall. Emission factors for CH_4 and N_2O emissions were obtained from IPCC (2006).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from forest fires have increased by 140 percent and 408 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). The methodology for estimating emissions from forest fires was revised to be consistent with IPCC (2006) guidelines, as opposed to IPCC (2003) guidelines. Combustion and emissions factors were also updated using the *2006 IPCC Guidelines* (IPCC 2006).

The amount of wildland under protection in 2002 was revised to the correct units for this calculation (hectares), resulting in a higher ratio of forest to wildland and thus higher emissions relative to the 2008 inventory report. The amount of fuel available for combustion was updated to the annual carbon density for the lower 48 states as provided by the USFS (2014). Previously, an average carbon density for all years was assumed in the 2008 inventory report.

In addition, for the 2008 inventory report, forest acres burned data were not available for the year 2007 and were proxied using 2006 data. The estimates presented in this inventory report were updated using

[21] Extensive research was conducted to find a Hawaii-specific factor for carbon density. Due to a lack of such a factor, annual carbon density for the lower 48 states was used, as provided by the USFS (2014).

forest acres burned data for year 2007, as reported by the DLNR. Actual forest acres burned data for year 2007 were more than twice the amount assumed for the 2008 inventory report.

4.8. Landfilled Yard Trimmings and Food Scraps (IPCC Source Category 3B5a)

Yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps continue to store carbon for long periods of time after they have been discarded in landfills. Table 24 summarizes changes in carbon stocks in landfilled yard trimmings and food scraps in Hawaii for 1990 and 2007.

Table 24: CO_2 Flux from Landfilled Yard Trimmings and Food Scraps (MMT CO_2 Eq.)

Sink	1990	2007
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.04)

Note: Parentheses indicate negative values or sequestration.

Methodology

Estimates of the carbon sequestration in landfilled yard trimmings and food scraps for Hawaii were generated by the EPA's State Inventory Tool (U.S. EPA 2017d). The State Inventory Tool calculates carbon stock change from landfilled yard trimmings and food scraps based on IPCC (2003) and IPCC (2006) Tier 2 methodologies using the following equation:

$$LFC_{i,t} = \Sigma\ W_{i,n} \times (1 - MC_i) \times ICC_i \times \{[CS_i \times ICC_i] + [(1 - (CS_i \times ICC_i)) \times e^{-k \times (t - n)}]\}$$

where:

t	= the year for which carbon stocks are being estimated
$LFC_{i,t}$	= the stock of carbon in landfills in year t, for waste i (grass, leaves, branches, and food scraps)
$W_{i,n}$	= the mass of waste i disposed in landfills in year n, in units of wet weight
n	= the year in which the waste was disposed, where 1960 < n < t
MC_i	= moisture content of waste i
CS_i	= the proportion of initial carbon that is stored for waste i
ICC_i	= the initial carbon content of waste i
e	= the natural logarithm
k	= the first order rate constant for waste i, and is equal to 0.693 divided by the half-life for decomposition

The State Inventory Tool uses data on the generation of food scraps and yard trimmings for the entire United States. Additionally, it uses data on the amounts of organic waste composted, incinerated, and landfilled each year to develop an estimate of the yard trimmings and food scraps added to landfills each year nationwide. State and national population data is then used to scale landfilled yard trimmings and food scraps down to the state level. These annual additions of carbon to landfills and an estimated

decomposition rate for each year are then used, along with carbon conversion factors, to calculate the carbon pool in landfills for each year.

Data Sources

Default values from the State Inventory Tool (U.S. EPA 2017d) for the composition of yard trimmings (i.e., amount of grass, leaves, and branches that are landfilled), food scraps, and their carbon content were used to calculate carbon inputs into landfills. Waste generation data for each year, also obtained from the State Inventory Tool (U.S. EPA 2017d), were used to calculate the national-level estimates in 1990 and 2007. Hawaii population data were obtained from the State of Hawaii Data Warehouse (DBEDT 2017b).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 carbon stock change estimates from landfilled yard trimmings and food scraps have increased by 12 percent and 21 percent, respectively. The current version of the State Inventory Tool contains updated factors for the proportion of carbon stored in grass, leaves, branches, and food scraps, and the decay rate of these materials. In addition, the ratio of Hawaii population to national population for 1990 and 2007 increased, leading to greater amounts of landfilled yard trimmings and food scraps scaled down to Hawaii from the national level, and therefore, increased carbon stock estimates.

4.9. Urban Trees (IPCC Source Category 3B5a)

Trees in urban areas (i.e., urban forests) sequester carbon from the atmosphere. Urban areas in Hawaii represented approximately 5 percent of Hawaii's total area in 1990 and 6 percent of Hawaii's total area in 2010 (U.S. Census Bureau 1990 and 2012; DBEDT 2017b). Table 25 summarizes carbon flux from urban trees in Hawaii for 1990 and 2007.

Table 25: CO_2 Flux from Urban Trees (MMT CO_2 Eq.)

Sink	1990	2007
Urban Trees	(0.28)	(0.37)

Note: Parentheses indicate negative values or sequestration.

Methodology

Carbon flux from urban trees was calculated using a methodology consistent with the U.S. Inventory (U.S. EPA 2017a) and the IPCC (2006) default Gain-Loss methodology. Carbon flux estimates from urban trees were calculated using the following equation.

$$CO_2 \text{ Flux} = A \times T_{percent} \times S_c \times CO_2\text{-C}$$

where:

A	= total urban area (including clusters), km^2
$T_{percent}$	= percent of urban area covered by trees, dimensionless
S_c	= C sequestration rates of urban trees, tonnes C/km^2
CO_2-C	= conversion of carbon to CO_2, 44/12, dimensionless

Data Sources

The City and County of Honolulu's *Municipal Forest Resource Analysis* (Vargas et al. 2007) provided data on Honolulu's carbon sequestration rates for urban trees. Using this Honolulu-specific data, a rate of annual carbon sequestration per square meter of tree canopy (kg C/m^2 tree cover) was calculated for Hawaii.

Census-defined urbanized area and cluster values were used to calculate urbanized area in Hawaii.[22] State-level urban area estimates were adapted from the U.S. Census (1990) to be consistent with the definition of urban area and clusters provided in the 2000 U.S. Census (Nowak et al. 2005). Urban area and cluster data for 2000 and 2010 were provided directly from the U.S. Census (2002, 2012). A linear trend was fitted to the 2000 and 2010 data to establish a time series from 2000 to 2007.

Nowak and Greenfield (2012) developed a study to determine percent tree cover by state. According to Nowak (2012), 39.9 percent of urban areas in Hawaii are covered by trees. With an estimate of total urban tree cover for Hawaii, the Hawaii-specific sequestration factor (kg C/m^2 tree cover) was applied to this area to calculate total C sequestration by urban trees (MT C/year).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 carbon sequestration from urban trees has increased (i.e., resulted in more sinks) by 148 percent and 185 percent, respectively. The significant increases in estimates of urban area and tree cover resulted in increased sequestration from urban trees in Hawaii for 1990 and 2007 relative to the 2008 inventory report.

For the 2008 inventory report, a state-specific estimate of Hawaii's urban tree cover was not available. The national average urban tree cover (27.1 percent) was previously used to estimate how much of Hawaii's urbanized area is covered by tree canopy. Since the 2008 inventory report, Nowak and Greenfield (2012) published *Tree and impervious cover in the United States*, which determined that 39.9

[22] Definitions for urbanized area changed between 1990, 2000, and 2010. According to the U.S. Inventory, "the 1990 U.S. Census defined urban land as 'urbanized areas,' which included land with a population density greater than 1,000 people per square mile, and adjacent 'urban places,' which had predefined political boundaries and a population total greater than 2,500. In 2000, the U.S. Census replaced the 'urban places' category with a new category of urban land called an 'urban cluster,' which included areas with more than 500 people per square mile. In 2010, the Census updated its definitions to have 'urban areas' encompassing Census tract delineated cities with 50,000 or more people, and 'urban clusters' containing Census tract delineated locations with between 2,500 and 50,000 people" (U.S. EPA 2017a).

percent of urban area in Hawaii is covered by trees. The current methodology applies this Hawaii-specific percentage to Hawaii's urban area.

To ensure time-series consistency between urban area estimates from U.S. Census reports, urban clusters were incorporated into the 1990 and 2000 urban area activity data, increasing the urban area estimates used in the previous inventory report. Urban clusters are defined in the 2000 U.S. Census as "surrounding census blocks that have an overall density of at least 500 people per square mile." The 1990 U.S. Census did not include urban clusters as a classification but instead defined "urban places" as an additional category for urban area based on population and political boundaries (U.S. EPA 2009). Urban area estimates for 1990 in Nowak et al. (2005) were used in this report because they are consistent with the definition of urban area and clusters provided in the 2000 U.S. Census. 2010 U.S. Census data were also incorporated to develop estimates of urban area for 2007.

4.10. Forest Carbon (IPCC Source Category 3B1a)

Hawaii forests and shrubland contain carbon stored in various carbon pools, which are defined as reservoirs with the capacity to accumulate or release carbon (IPCC 2006). This category includes estimates of carbon sequestered in forests and shrubland aboveground biomass, which is defined as living vegetation above the soil, and belowground biomass, which is defined as all biomass below the roots (IPCC 2006). Table 26 summarizes carbon flux from forests and shrubland in Hawaii for 1990 and 2007.

Table 26: C Flux from Forests (MMT CO_2 Eq.)

Sink	1990	2007
Forest Carbon	(2.45)	(2.59)

Note: Parentheses indicate negative values or sequestration.

Methodology

The Tier 1 Gain Loss Method as outlined by the *2006 IPCC Guidelines* (IPCC 2006) was used to calculate carbon flux in managed Hawaii forests.[23] This method requires forestland acreage time series data as well as aboveground biomass growth rate, the ratio of below ground biomass to aboveground biomass, and the carbon fraction. The Gain Loss method calculates annual increase in biomass carbon stocks using the following equation:

$$\text{Forest } CO_2 \text{ Flux} = (\Sigma_i(A_i \times G_{TOTAL\_i} \times CF_i)) \times CO_2\text{-C}$$

[23] Managed forests, under IPCC (2006) guidelines, are deemed to be a human-influenced GHG sink and, accordingly, are included here. This encompasses any forest that is under any sort of human intervention, alteration, maintenance, or legal protection. Unmanaged forests are not under human influence and thus out of the purview of this inventory.

where,

A	= forest land area, hectares
$G_{TOTAL\_i,j}$	= mean annual biomass growth, tonnes of dry matter/hectare
$CF_{i,j}$	= carbon fraction of dry matter, tonnes C/tonne of dry matter
CO_2-C	= conversion of carbon to CO_2, 44/12, dimensionless
i	= forest type (forest or shrubland in Hawaii)

Data Sources

Managed forestland acreage time series data were obtained from the Hawaii Data Warehouse (DBEDT 2017b). Area estimates of private forestland in the conservation district were summed with reserve forestland in the conservation district, forested natural areas and wooded farmland in order to generate total managed forested land area in Hawaii for 1990 and 2007.

Roughly half of Hawaii's forestland is shrub/scrubland, defined as land with vegetation less than 20 feet tall (NOAA-CCAP 2000). Forestland was divided into two sub-categories: forest and shrub/scrubland using the island-specific forestland:shrubland ratios derived from the NOAA-CCAP study.

Mean biomass growth is derived by multiplying the average annual above-ground biomass growth by the sum of one and the ratio of below ground biomass to above ground biomass. This biomass growth was then multiplied by a carbon factor to determine the net addition of carbon. In obtaining the mean annual biomass growth and carbon fraction factors, the tropical Asia Insular IPCC (2006) default values were used as default factors for forest and shrubland.[24]

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from forest carbon have not changed as no changes were made to the methodology, GWP values, emission factors, or activity data.

[24] Extensive research was conducted to find Hawaii-specific carbon factors, during the course of which many Hawaii forest experts were contacted (Cole, Giardina, Litton, Bennet, Friday, and Ostertag 2008). However, the results of this research indicated that the IPCC defaults for tropical Asia insular land would be best suited for the revised estimates.

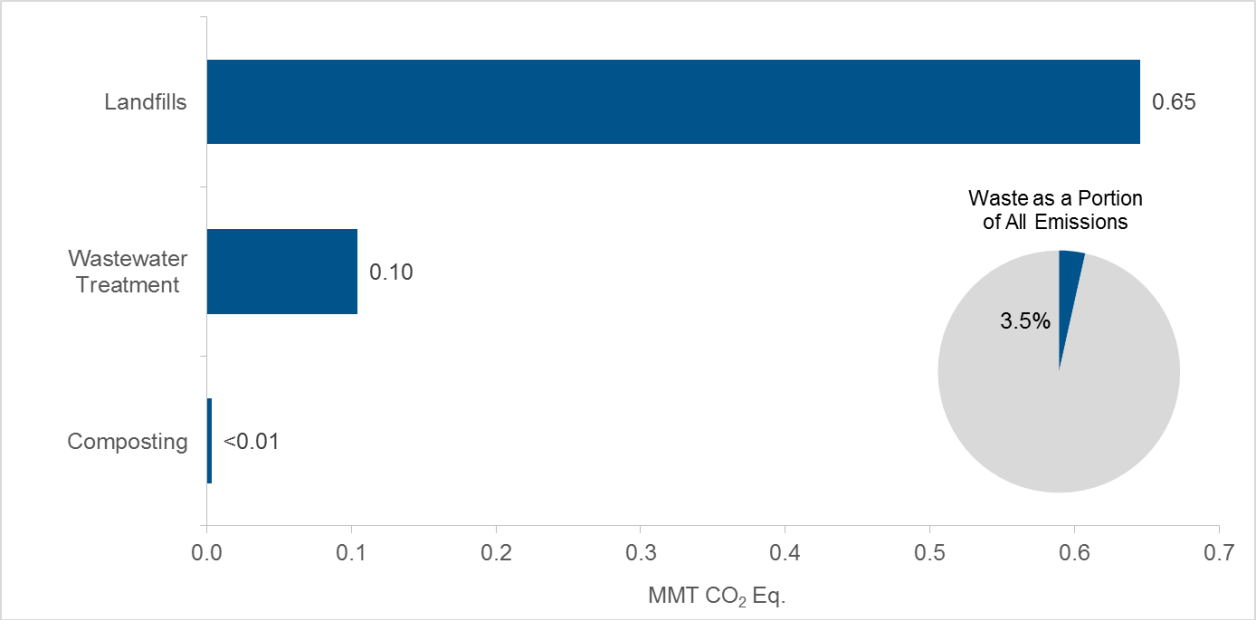
5. Waste

This chapter presents GHG emissions from waste management and treatment activities. For the state of the Hawaii, waste sector emissions are estimated from the following sources[25] and gases:

- Landfills (IPCC Source Category 5A1): CH_4
- Composting (IPCC Source Category 5B1): CH_4, N_2O
- Wastewater Treatment (IPCC Source Category 5D): CH_4, N_2O

Emissions from the waste sector were 0.75 MMT CO_2 Eq. in 1990 and 1.05 MMT CO_2 Eq. in 2007, accounting for roughly 4 percent of total Hawaii emissions for both inventory years. Figure 18 and Figure 19 graphically present waste emissions by source for 1990 and 2007. Emissions by source and year are summarized in Table 27.

Figure 18: 1990 Waste Emissions by Source (MMT CO_2 Eq.)



[25] In Hawaii, most incineration of MSW occurs at waste-to-energy facilities and thus emissions from incineration of waste are accounted for in the Energy chapter in Section 2.3.

Figure 19: 2007 Waste Emissions by Source (MMT CO_2 Eq.)

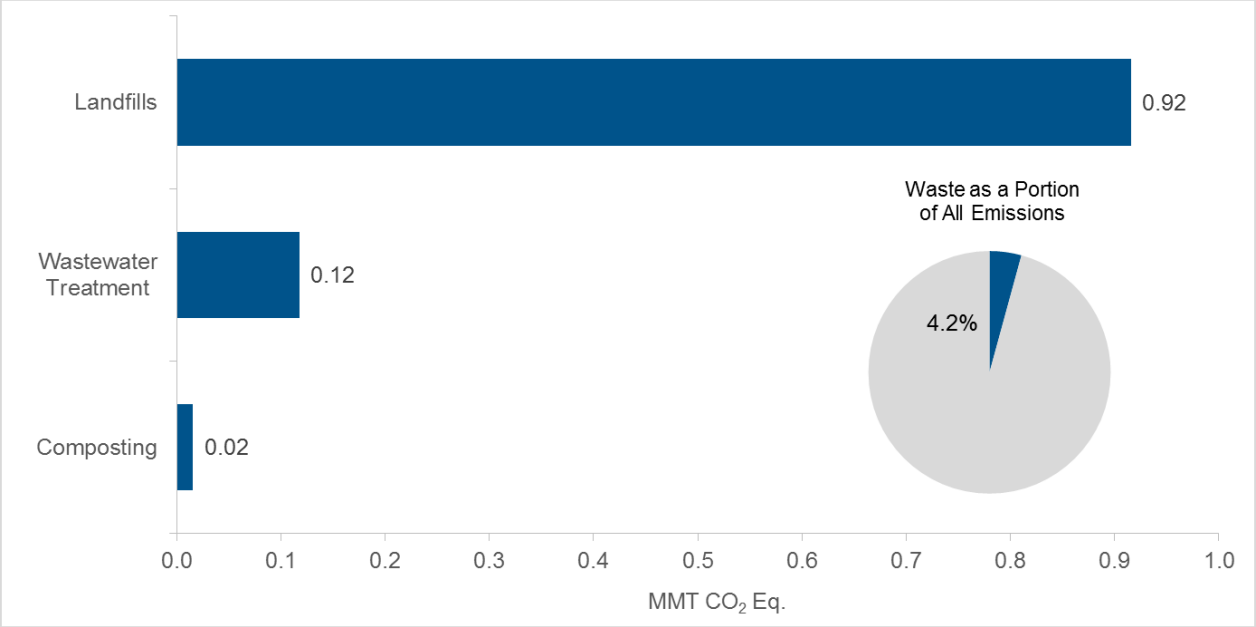


Table 27: GHG Emissions from the Waste Sector by Source (MMT CO_2 Eq.)

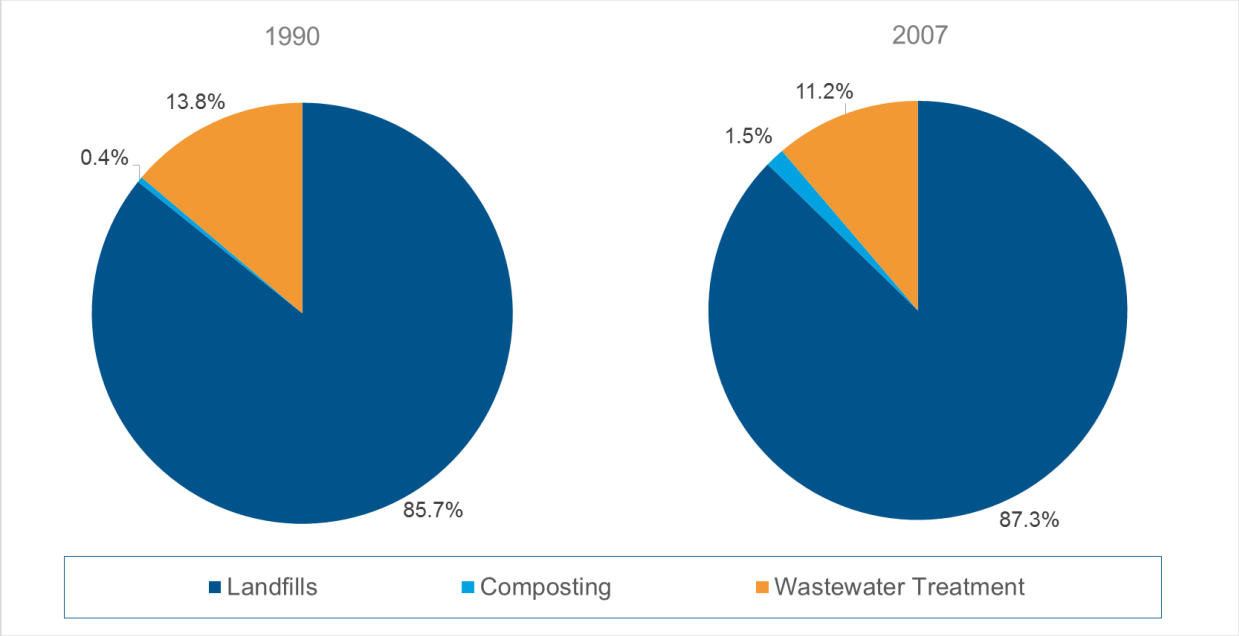
Source	1990	2007
Landfills	0.65	0.92
Composting	+	0.02
Wastewater Treatment	0.10	0.12
Total	**0.75**	**1.05**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Landfills account for the largest portion of emissions from the Waste sector, followed by wastewater treatment and composting. Figure 20 presents the breakout of GHG emissions by source within the waste sector for both 1990 and 2007.

Figure 20: Waste Emissions by Source, 1990 and 2007 (MMT CO_2 Eq.)



5.1. Landfills (IPCC Source Category 5A1)

When placed in landfills, organic material in municipal solid waste (MSW) (e.g., paper, food scraps, wood products) is decomposed by both aerobic and anaerobic bacteria. As a result of these processes, landfills generate biogas consisting of approximately 50 percent biogenic CO_2 and 50 percent CH_4, by volume (U.S. EPA 2017a). Consistent with IPCC (2006), biogenic CO_2 from landfills is not reported under the waste sector. Table 28 summarizes emissions from landfills in Hawaii for 1990 and 2007.

Table 28: CH_4 Emissions from Landfills (MMT CO_2 Eq.)

Source	1990	2007
Landfills	0.65	0.92

Methodology

Consistent with the methodology used for the U.S. Inventory (U.S. EPA 2017a), potential MSW landfill emissions are calculated using a Tier 1 first order decay (FOD) model, which looks at the waste landfilled over the past thirty years. The FOD model is based on the equation below:

$$Q_{T,x} = A \; x \; k \; x \; R_x \; x \; L_o \; x \; e^{-k(T-x)}$$

where,

$Q_{T,x}$ = amount of CH_4 generated in year T by the waste R_x
T = current year
x = year of waste input

A = normalization factor, $(1-e^{-k})/k$

k = CH_4 generation rate (yr^{-1})

R_x = amount of waste landfilled in year x

L_o = CH_4 generation potential

Using the FOD model, the emissions vary not only by the amount of waste present in the landfill, but also by the CH_4 generation rate (k). Other factors included in the FOD model are the current year (T), the year of waste input (x), and the CH_4 generation potential (L_o).

After calculating the potential CH_4 emissions for each inventory year, the calculations account for the oxidation rate at landfills and subtract any methane recovered for energy or flaring that year, yielding the net CH_4 emissions from landfills, as shown by the equation below:

$$Landfill\ methane\ emissions = Q_{CH4}\ x\ (1 - OR) - Flared - Recovered$$

where,

Q_{CH4} = potential CH_4 emissions for a given inventory year

OR = methane oxidation rate

Flared = amount of methane flared in the inventory year

Recovered = amount of methane recovered for energy in the inventory year

Data Sources

Landfill emissions were calculated using the following factors from the U.S. EPA's State Inventory Tools – Municipal Solid Waste Module (U.S. EPA 2017e):

- CH_4 generation rate – this value varies according to several factors pertaining to the climate in which the landfill is located. In the 1990 and 2007 inventories, a simplified value for non-arid states of 0.02 is used (i.e., states for which the average annual rainfall is greater than 25 inches).
- Methane generation potential – 100 m^3/metric ton
- Normalization factor – 0.98026
- Oxidation rate – 10%

Tons of waste landfilled per year was provided by the Hawaii Department of Health (DOH), Solid Waste Branch (Hawaii DOH 2008a). Landfill records, including new and historical landfills, landfill operation and gas collection system status, landfill gas flow rates, and landfill design capacity were provided by Lane Otsu of the Hawaii DOH, Clean Air Branch (Otsu 2008), Hawaii Data Warehouse (DBEDT 2017b), and Steve Serikaku of the Honolulu County Refuse Division (Serikaku 2008). Historical MSW generation and disposal volumes were calculated using population data from the Hawaii Data Warehouse (DBEDT 2017b).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from landfilling have increased by 19 percent for both inventory years. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007).

5.2. Composting (IPCC Source Category 5B1)

Composting involves the aerobic decomposition of organic waste materials, wherein large portions of the degradable organic carbon in the waste materials is converted into CO_2. The remaining solid portion is often recycled as a fertilizer and soil amendment or disposed in a landfill. During the composting process, trace amounts of CH_4 and N_2O can form, depending on how well the compost pile is managed (U.S. EPA 2017a). Data on the types of volumes of waste composted in Hawaii in 1990 and 2007 are not currently available and it is not expected that large-scale composting operations were in place in Hawaii during these years. Composting in Hawaii was assumed to be performed primarily in backyards for household yard trimmings and food scraps and in agricultural operations. Table 29 summarizes emissions from composting in Hawaii for 1990 and 2007.

Table 29: Composting Emissions by Gas (MMT CO_2 Eq.)

Source	1990			2007		
	CH_4	N_2O	Total	CH_4	N_2O	Total
Composting	+	+	**+**	0.01	0.01	**0.02**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

Methane and N_2O emissions from composting are calculated using the IPCC default (Tier 1) methodology, summarized in the equations below (IPCC 2006):

$$CH_4\ Emissions = (M\ x\ EF) - R$$

where,

M = mass of organic waste composted in inventory year
EF = emission factor for composting
R = total amount of CH_4 recovered in inventory year

No CH_4 recovery is expected to occur at composting operations in Hawaii.

$$N_2O\ Emissions = M\ x\ EF$$

where,

M = mass of organic waste composted in inventory year
EF = emission factor for composting

Data Sources

Tons of waste composted per year were calculated based on the U.S. national average per capita composting rate in the U.S. Inventory (U.S. EPA 2017a). Historical MSW composting volumes were calculated using population data from the Hawaii Data Warehouse (DBEDT 2017b). Emissions were calculated using IPCC Tier 1 composting emission factors (IPCC 2006).

Changes in Estimates since the 2008 Inventory Report

This category is newly quantified for this inventory report.

5.3. Wastewater Treatment (IPCC Source Category 5D)

Wastewater produced from domestic, commercial, and industrial sources is treated either on-site (e.g., in septic systems) or in central treatment systems to remove solids, pathogenic organisms, and chemical contaminants (U.S. EPA 2017a). During the wastewater treatment process, CH_4 is generated when microorganisms biodegrade soluble organic material in wastewater under anaerobic conditions. The generation of N_2O during both the nitrification and denitrification of the nitrogen present in wastewater. Over 20 centralized wastewater treatment plants were in operation in Hawaii in 1990 and 2007, serving most of the state's population. The remaining wastewater was treated at on-site wastewater systems. Table 30 summarizes emissions from wastewater treatment in Hawaii for 1990 and 2007.

Table 30: Wastewater Emissions by Gas (MMT CO_2 Eq.)

Source	1990			2007		
	CH_4	N_2O	Total	CH_4	N_2O	Total
Wastewater	0.07	0.04	**0.10**	0.08	0.04	**0.12**

Note: Totals may not sum due to independent rounding.

Methodology

Consistent with the methodology used for the U.S. Inventory (U.S. EPA 2017a) and the U.S. EPA's State Inventory Tools – Wastewater Module (U.S. EPA 2017f), wastewater treatment emissions were calculated using the equations described below.

To calculate CH_4 emissions from municipal wastewater treatment, the total annual 5-day biochemical oxygen demand (BOD_5) production in metric tons was multiplied by the fraction that is treated anaerobically and by the CH_4 produced per metric ton of BOD_5:

$$CH_4\ Emissions = BOD_5\ x\ EF\ x\ AD$$

where,

BOD_5 = total annual 5-day biochemical oxygen demand production
EF = emission factor for municipal wastewater treatment
AD = Percentage of wastewater BOD_5 treated through anaerobic digestion

Municipal wastewater treatment direct N_2O emissions were calculated by determining total population served by wastewater treatment plants (adjusted for the share of the population on septic) and multiplying by an N_2O emission factor per person per year:

$$Direct\ N_2O\ Emissions = Septic\ x\ EF$$

where,

Septic	= percentage of the population by region not using septic wastewater treatment
EF	= emission factor for municipal wastewater treatment

Municipal wastewater N_2O emissions from biosolids were calculated using the equation below:

$$Biosolids\ N_2O\ Emissions = \left((P\ x\ N_P\ x\ F_N) - N_{Direct}\right)\ x\ (1 - Biosolids)\ x\ EF$$

where,

P	= total annual protein consumption
N_P	= nitrogen content of protein
F_N	= fraction of nitrogen not consumed
N_{Direct}	= direct N_2O emissions
Biosolids	= percentage of biosolids used as fertilizer
EF	= emission factor for municipal waste treatment

Sewage sludge is often applied to agricultural fields as fertilizer; emissions from this use are accounted for under the AFOLU sector. Therefore, the wastewater calculations exclude the share of sewage sludge applied to agricultural soils so that emissions are not double-counted. For the 1990 and 2007 inventories, it was assumed that no biosolids were used as fertilizer.

Data Sources

Data on non-National Pollutant Discharge Elimination System (NPDES) wastewater treatment plants, including flow rate and BOD_5 were provided by Sina Pruder of the Hawaii DOH, Wastewater Branch (Pruder 2008). Population data from the Hawaii Data Warehouse (DBEDT 2017b) and U.S. Census Bureau data (1990, 2007) were used to calculate wastewater treatment volumes and the share of households on septic systems. Emissions were calculated using factors from the U.S. EPA's State Inventory Tools – Wastewater Module (U.S. EPA 2017f).

Changes in Estimates since the 2008 Inventory Report

Relative to the 2008 inventory report, 1990 and 2007 emission estimates from wastewater treatment have decreased by 20 percent for both inventory years. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007).

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Appendix A: Detailed Comparison to Previous Report

Table 31: Change in Emissions Relative to the 2008 Inventory Report ($MMTCO_2$ Eq.)

Sector/Source	1990			2007		
	2008 Report	2017 Report	Percent Change	2008 Report	2017 Report	Percent Change
Energy	**21.12**	**19.35**	**-9.1%**	**21.83**	**21.67**	**-0.7%**
Fossil Fuel Stationary Combustion	7.90	7.91	0.0%	9.25	9.28	0.3%
Electric Power	*6.79*	*6.80*	*0.1%*	*8.76*	*8.78*	*0.3%*
Residential	*0.03*	*0.03*	*-0.7%*	*0.05*	*0.05*	*0.1%*
Commercial	*0.38*	*0.38*	*-0.6%*	*0.26*	*0.26*	*0.0%*
Industrial	*0.70*	*0.70*	*-0.1%*	*0.18*	*0.19*	*2.0%*
Transportation	13.21	11.27	-14.7%	12.58	12.23	-2.8%
Ground	*3.23*	*3.41*	*5.4%*	*4.47*	*5.01*	*12.1%*
Domestic Marine	*1.65*	*1.82*	*10.6%*	*2.16*	*1.79*	*-17.3%*
Domestic Aviation	*6.80*	*4.66*	*-31.5%*	*4.83*	*4.42*	*-8.4%*
Military	*1.53*	*1.38*	*-9.9%*	*1.13*	*1.02*	*-9.9%*
Incineration of Waste[a]	NA	0.18	NA	NA	0.15	NA
Oil and Gas Operations	+	+	10,652%	+	0.01	5,328%
International Bunker Fuels[b]	*1.01*	*2.95*	*192.5%*	*1.32*	*1.54*	*16.8%*
CO_2 from Wood Biomass and Biofuel Consumption[b]	*NA*	*NE*	*NA*	*NA*	*0.16*	*NA*
Industrial Processes	**0.18**	**0.17**	**-3.5%**	**0.54**	**0.54**	**1.4%**
Cement Production	0.10	0.10	0.0%	NO	NO	0.0%
Electrical Transmission and Distribution	0.08	0.07	-9.8%	0.04	0.02	-54.0%
Substitutes of Ozone Depleting Substances	NO	+	100.0%	0.50	0.53	5.6%
AFOLU (Sources)	**0.98**	**1.34**	**35.7%**	**0.83**	**1.45**	**74.6%**
Enteric Fermentation	0.27	0.38	44.0%	0.25	0.36	46.0%
Manure Management	0.12	0.13	9.1%	0.05	0.05	9.7%
Agricultural Soil Management	0.19	0.18	-2.9%	0.17	0.16	-2.1%
Field Burning of Agricultural Residues	0.03	0.03	14.8%	0.01	0.01	14.8%
Urea Application	+	+	0.0%	+	+	0.0%
Agricultural Soil Carbon	0.22	0.22	0.0%	0.24	0.24	1.9%
Forest Fires	0.16	0.38	140.3%	0.12	0.62	408.2%
AFOLU (Sinks)	**(2.67)**	**(2.85)**	**6.8%**	**(2.75)**	**(3.00)**	**8.9%**
Landfilled Yard Trimmings & Food Scraps	(0.11)	(0.12)	12.5%	(0.03)	(0.04)	21.3%

Urban Trees	(0.11)	(0.28)	147.7%	(0.13)	(0.37)	185.5%
Forest Carbon	(2.45)	(2.45)	0.0%	(2.59)	(2.59)	0.0%
Waste	**0.85**	**0.75**	**-11.2%**	**1.07**	**1.05**	**-1.8%**
Landfills	0.54	0.65	19.0%	0.77	0.92	19.0%
Incineration of Waste[a]	0.18	NA	NA	0.15	NA	NA
Composting	NA	+	NA	NA	0.02	NA
Wastewater Treatment	0.13	0.10	-20.1%	0.15	0.12	-20.0%
Total Emissions (Excluding Sinks)	**23.13**	**21.61**	**-6.6%**	**24.27**	**24.71**	**1.8%**
Net Emissions (Including Sinks)	**20.46**	**18.76**	**-8.3%**	**21.52**	**21.72**	**0.9%**
Net Emissions (Including Sinks, Excluding Aviation)[c]	**13.66**	**14.11**	**3.3%**	**16.69**	**17.30**	**3.6%**

+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring); NE (emissions are Not Estimated).

[a] In the 2008 inventory report, emissions from incineration of waste were categorized under the Waste sector. In this inventory report, the emissions are categorized under the Energy sector.

[b] Emissions from International Bunker Fuels and CO_2 from Wood Biomass and Biofuel Consumption are not included in totals.

[c] Aviation emissions are excluded from Hawaii's GHG emissions reduction goal established in Act 234.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Appendix B: Sources Excluded from the Analysis

Table 32: Source Categories Excluded from the Analysis

Source Name	IPCC Source Category	Reason for Exclusion
Energy		
Fugitive Emissions from Solid Fuels	1B1	NO: Solid fuels (coal) are not produced or processed in Hawaii.
CO_2 Transport and storage	1C	NO: CO_2 is not transported or stored in Hawaii.
IPPU		
Lime Production	2A2	NO: Activity is not applicable to Hawaii.
Glass Production	2A3	NO: Activity is not applicable to Hawaii.
Other Process Uses of Carbonates	2A4	NO: Activity is not applicable to Hawaii.
Chemical Industry	2B	NO: Activity is not applicable to Hawaii.
Metal Industry	2C	NO: Activity is not applicable to Hawaii.
Non-Energy Products from Fuels and Solvent Use	2D	NO: Activity is not applicable to Hawaii.
Electronics Industry	2E	NO: Activity is not applicable to Hawaii.
SF_6 and PFCs from Other Product Uses	2G2	NO: Activity is not applicable to Hawaii.
N_2O from Product Uses	2G3	NO: Activity is not applicable to Hawaii.
AFOLU		
Land Converted to Forest Land	3B1b	NE: Data on land conversion and the period involved are not readily available.
Biomass Burning in Grassland	3C1c	NE: Data is not readily available and emissions from this source are likely very small.
Biomass Burning in All Other Land	3C1d	NO: Activity is not applicable to Hawaii.
Wetlands	3B4	NE: Data is not readily available and emissions from this source are likely very small.
Other Land	3B6	NE: Other Land is assumed to be unmanaged in Hawaii, so activity data are not readily available.
Liming	3C2	NE: Activity data are either withheld or zero.
Harvested Wood Products	3D1	NE: Data is not readily available and sinks from this source are likely very small.
Waste		
Incineration of Waste	5C1	In Hawaii, incineration of MSW occurs at waste-to-energy facilities and thus emissions are accounted for under the Energy sector.

NO (emissions are Not Occurring); NE (emissions are Not Estimated).

Appendix C: Energy Sector Fuel Consumption

Table 33: 1990 and 2007 Energy Sector Fuel Consumption by Source and Fuel Type (Billion Btu)

Source	Aviation Gasoline	Coal	Diesel Fuel	Fuel Gas	Jet Fuel Kerosene	Motor Gasoline	Naphtha	Propane	Residual Fuel	Total
1990										
Residential							490			**490**
Commercial			274			412		5,159	73	**5,918**
Industrial		701	3,759			404			4,130	**8,993**
Transportation - Air	226				103,969					**104,196**
Transportation - Ground			3,464			41,549		329	4	**45,346**
Transportation - Water			11,985			19			13,335	**25,339**
Electric Power			9,712						77,019	**86,731**
Military			4,860		1,449	4,785	7,122		762	**18,978**
Total	**226**	**701**	**34,054**	**0**	**105,419**	**47,169**	**7,122**	**5,978**	**95,322**	**295,991**
2007										
Residential								749		**749**
Commercial			60					4,042		**4,102**
Industrial		1,814	106			111		26		**2,057**
Transportation - Air	102				82,518					**82,620**
Transportation - Ground			11,552			58,613	8			**70,172**
Transportation - Water			6,891			36			16,715	**23,682**
Electric Power		14,780	15,682	1,763	1,224		4,065		72,860	**110,374**
Military			5,350		8,659			100		**14,108**
Total	**102**	**16,593**	**39,641**	**1,763**	**92,401**	**58,759**	**4,065**	**4,924**	**89,575**	**307,823**