CAPE COD
COMMISSION

Cape Cod Regional Greenhouse Gas Inventory

2017 BASELINE

FEBRUARY 2021

Prepared by Cape Cod Commission Staff.

Cape Cod Regional Greenhouse Gas Emissions Inventory

2017 BASELINE

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- Mass Coastal Railroad
- MassWildlife
- National Oceanographic and Atmospheric Administration
- Peter Pan Bus Line
- Provincetown Airport
- Woods Hole, Martha's Vineyard and Nantucket Steamship Authority

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Abbreviations

ACS - American Community Survey
BMP - Best management practice
C-CAP - Coastal Change Analysis Program
CCRTA - Cape Cod Regional Transit Authority
CH_4 - Methane
CO_2 - Carbon dioxide
Commission - Cape Cod Commission
CTPS - Central Transportation Planning Staff
EF - Emissions factor
EIA - Energy Information Administration
EPA - Environmental Protection Agency
FHWA - Federal Highway Administration
FOD - First order decay
GHG - Greenhouse gas
GWP - Global Warming Potential
HFCs - Hydrofluorocarbons
HWG - Horsley Witten Group
IPCC - Intergovernmental Panel on Climate Change
ISWMF - Integrated Solid Waste Management Facility (Bourne)
JBCC - Joint Base Cape Cod
MAPC - Metropolitan Area Planning Council
MassDEP - Massachusetts Department of Environmental Protection
MBTA - Massachusetts Bay Transit Authority
MPG - Miles per gallon
MPO - Metropolitan Planning Organization
$MTCO_2E$ - Metric ton carbon dioxide equivalent
MWh - Megawatt hour
N - Nitrogen
N_2O - Nitrous oxide
NOAA - National Oceanic and Atmospheric Administration
NTD - National Transit Database

P&B - Plymouth and Brockton Street Railway Company
PFCs - Perfluorocarbons
RMV - Registry of Motor Vehicles
SF_6 - Sulfur hexafluoride
SIT - State Inventory Tool
SSA - Steamship Authority
U.S. - United States
USDA - United States Department of Agriculture
VMT - Vehicle miles traveled
WBNERR - Waquoit Bay National Estuarine Research Reserve
WHOI - Woods Hole Oceanographic Institution

Executive Summary

Certain gases that trap heat in the Earth's atmosphere such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are known as greenhouse gases (GHGs) and are widely acknowledged to contribute to climate change. GHGs occur naturally, and they are also emitted from human activities like using fossil fuels, through certain land management practices, or from manufacturing of the products we use. To prevent climate change from worsening, it is critical to understand GHG contributions at various scales.

The 2018 Cape Cod Regional Policy Plan includes a recommended Cape Cod Commission (Commission) planning action to encourage and engage communities to better understand regional GHG emissions, and specifically to develop an estimated baseline of GHG emissions for the region (Barnstable County, also known as Cape Cod) using available models and data. This baseline can provide communities with the information to understand the contributing factors to Cape Cod's GHG emissions.

This inventory uses methods described in the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories, and includes calculation of emissions from five sectors – transportation, stationary energy, waste, industrial processes and product use, and agriculture and soil management – and sequestration from land use and forestry. Data were collected to calculate emissions for the following gases: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulfur hexafluoride (SF_6).

A baseline year of 2017 was chosen as this aligned with the most recently published Massachusetts state inventory at the time, and when the most recent data was available for certain sectors. For a baseline year of 2017, the inventory shows that emissions from Cape Cod are greater than 3.5 million metric tons of CO_2, and that the Cape has the potential to sequester in excess of 340,000 metric tons of CO_2. The transportation sector accounts for the largest amount of emissions (approximately 55% of the total inventory), followed by stationary energy (39%), waste (3%), industrial processes and product use (2%), and agriculture and soil management (0.4%). Land Use and forestry have the potential to sequester approximately 9% of total emissions. The largest overall contributors to GHG emissions are from fossil fuel use for operating personal vehicles and residential energy use.

Introduction

The 2018 Cape Cod Regional Policy Plan identified key regional challenges facing the natural, built, and community systems of Cape Cod. Among them, climate change was recognized to pose many threats to the region.

Sea level rise poses a major and particular threat to Cape Cod, which has 586 miles of vulnerable, tidal shoreline. Projected sea level rise will increase flooding, elevating the height of storm and non-storm surges and flood levels, and exacerbate inundation and storm surge by sending floodwaters further inland, resulting in potential inoperable first response facilities and substantial loss to property, economic prosperity, and habitat. In addition to structural and economic losses, sea level rise also threatens Cape Cod's groundwater with potential higher groundwater levels and, to a lesser effect, saltwater intrusion.

Flooding and erosion will be exacerbated by sea level rise and changing storm frequency and intensity. Scientists anticipate that climate change will bring stronger storms with more precipitation and the threat of more frequent and extensive flooding to the region. Storms have resulted in power outages, which limits access to necessary services, and increased storm activity is likely to further impact the region's power resources. In addition, temperatures are anticipated to rise, with related degradation of air quality, strain on local indigenous flora and fauna, increases in foreign pest migration, and more health-related problems, and significantly for Cape Cod, changes in sea surface temperature and the viability of the coastal environments for the region's native wildlife.

It is likely that the region's vulnerability will increase in the future as sea levels continue to rise, climate change intensifies, and the region experiences an increase in storm activity and severity, all of which can cause loss of life, damage buildings and infrastructure, impair coastal environments, and otherwise impact a community's economic, social, and environmental well-being.

Certain gases that trap heat in the Earth's atmosphere such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are known as greenhouse gases (GHGs) and are widely acknowledged to contribute to climate change. GHGs occur naturally, and they are also emitted from human activities like using fossil fuels, through certain land management practices, or from manufacturing of the products we use. Reducing the emissions of greenhouse gases will help to mitigate climate change. However, in order to take action to reduce the greenhouse gases of a defined area (town, region, state, or even nation), it is first necessary to understand an area's current or baseline greenhouse gas emissions. This data can also be used to track progress toward supporting state GHG reduction goals.

About the Inventory

Prior to determining the GHG accounting method that best fits the land uses and development patterns of Cape Cod, Commission staff reviewed GHG inventories from eight (8) cities and towns, seven (7) regions, two (2) states, and the United States national inventory to better understand the considerations, challenges, and accounting methods used in calculating GHG emissions. Commission staff reviewed these inventories to understand the accounting framework, accounting tools or resources, what data sets were used, what sectors emissions were calculated for, and what gases were evaluated related to GHG emissions.

FRAMEWORK

To understand our regional GHG emissions by sector and contribution to global climate change, the Commission developed a framework[1] to guide calculation of a comprehensive greenhouse gas emissions inventory for the region.

The inventory includes the following sectors:

- Stationary Energy
- Transportation
- Industrial Processes and Product Use
- Agriculture
- Waste
- Land Use and Forestry

The following greenhouse gases are included, which are also included in the Massachusetts 2017 state inventory:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)

[1] https://www.capecodcommission.org/resource-library/file?url=%2Fdept%2Fcommission%2Fteam%2FWebsite_Resources%2Fghg%2F2019-12-CC-GHG-Emissions-Inventory-Framework.pdf

Emissions were calculated for activities occurring inside Barnstable County and from certain activities outside of Barnstable County, namely electricity generation, transportation, and waste. Greenhouse gas removals (sequestration) were calculated in the Land Use and Forestry sector.

GENERAL METHODOLOGY

Greenhouse gas emissions for a baseline year of 2017 were calculated using the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, unless otherwise documented in the Methodology section. The IPCC Guidelines focus on calculating GHG emissions and removals from anthropogenic (man-made) sources and activities.

Emissions factors used in these calculations are from the IPCC Guidelines, except for the annual average system-wide electricity emissions factor for 2017 obtained from ISO-New England, and emissions factors used by the Massachusetts Department of Environmental Protection (MassDEP) in the calculation of the Massachusetts state 2017 inventory.

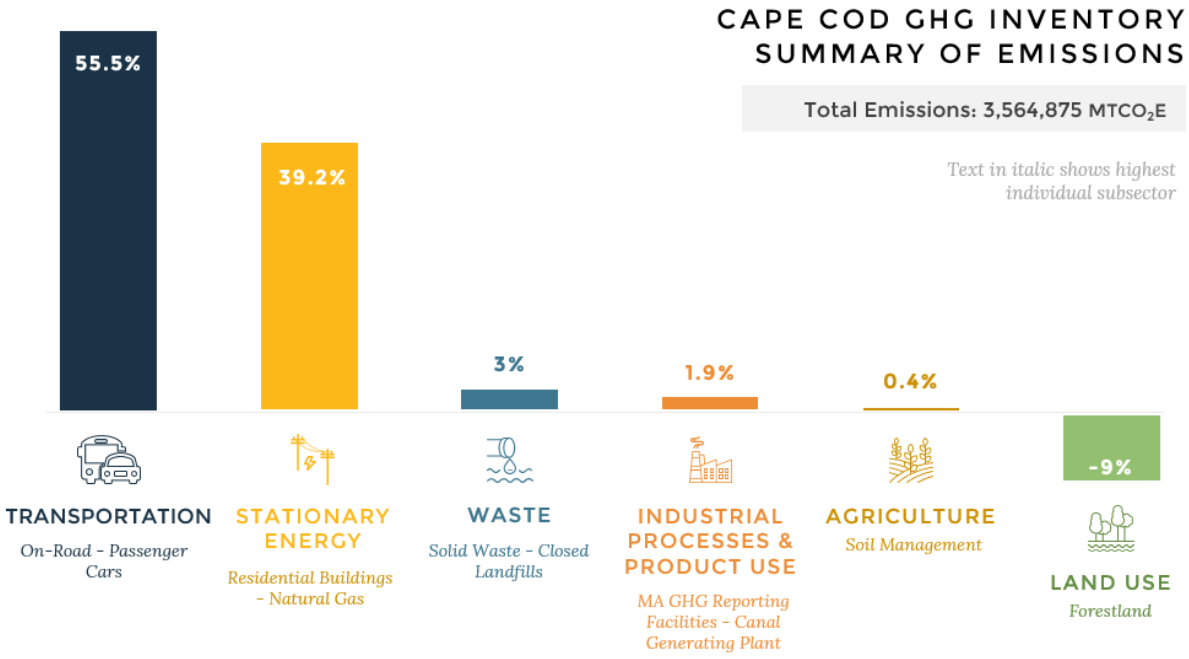
Global warming potentials (GWP) used are from IPCC's Fourth Assessment Report, consistent with those GWPs used in the Massachusetts state 2017 inventory.

All emissions and removals in the inventory are reported in metric tons and expressed by CO_2 equivalents ($MTCO_2E$) of activity emissions.

Summary of Findings

GHG emissions for Cape Cod in 2017 equal 3,564,875 $MTCO_2E$, approximately 4-5% of Massachusetts state emissions. The highest amount of emissions is associated with transportation, equaling 55.5% of total Cape inventory emissions. The second highest amount of emissions are from stationary energy use at 39% of total inventory emissions. The remaining 5% of emissions are attributed to the waste (3%), industrial processes (2%), and agriculture (0.4%) sectors.

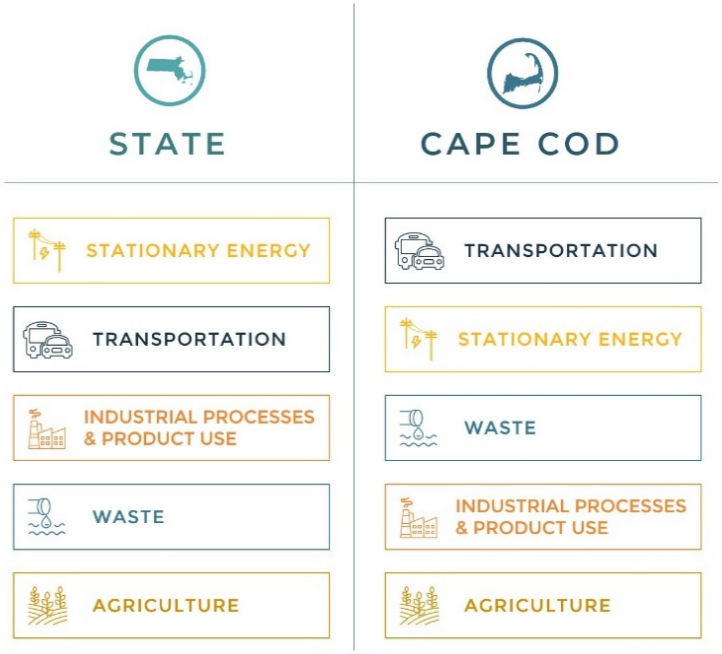
SECTOR	EMISSIONS ($MTCO_2E$)
Stationary Energy	1,398,549
Transportation	1,979,525
Industrial Processes and Product Use	66,093
Agriculture	15,152
Waste	105,556
Total Emissions	**3,564,875**



Emissions on Cape Cod differ from the state in that where transportation is the largest emissions sector for the Cape, transportation is the second highest emissions sector for the state, behind stationary energy use. Similarly, where the Cape has higher emissions from waste as a percentage of

this inventory, the state has higher emissions from industrial processes followed by waste. Agriculture in both inventories represent the lowest amount of total inventory emissions.

Where comparable emissions data are available, the Cape is proportionally comparable to the state level emissions from electricity use and residential fuel use (natural gas, fuel oil, propane, and wood). The Cape has higher emissions relative to the state from on-road transportation use, and slightly higher emissions from solid waste and agriculture. The Cape has lower emissions than the state in commercial fuel use (natural gas, fuel oil, propane), aviation, industrial processes, and wastewater treatment and disposal.



Also calculated are the effects of land use and forestry on the region (represented by forestland, grassland, and cropland), which has the potential to sequester 340,582 $MTCO_2E$ per year, equal to 9% of total inventory emissions. The largest potential for sequestration comes from forestland. This percentage of sequestration is consistent with the sequestration from forestland calculated for the state. Wetlands also contribute significantly to the carbon sequestration potential of the region. However, with the lack of a consistent methodology at this time to estimate such potential, that analysis should be considered for future inventories.

Methodology

STATIONARY ENERGY

Introduction

The stationary energy sector includes emissions from residential, commercial, and industrial uses of electricity, natural gas, fuel oil, propane, and wood (residential only). Combined, natural gas, fuel oil, electricity, propane, and wood account for 99% of home heating on Cape Cod.

Electricity emissions represent indirect emissions from electricity generation, which uses a variety of sources, including fossil fuels. According to ISO-New England "2017 ISO New England Electric Generator Air Emissions Report", 48% of the electricity produced by generators in New England that year came from natural gas, while 31% came from nuclear power, and 8% came from hydropower, totaling 87% of the electricity generated. The remaining electricity generation was from refuse, wind, and wood (each approximately 3%), coal (2%), and solar, oil and landfill gas (each ≤1%).

In 2017, Barnstable County used 4% of the total electricity use of the state, making it the ninth ranked county for electricity use (out of 14), above Berkshire, Hampshire, Franklin, Dukes, and Nantucket counties. In Massachusetts, commercial/industrial uses account for 64% of electricity usage, whereas in Barnstable County, residential electricity use is higher than commercial/industrial use (56% and 44%, respectively). This makes Barnstable County one of four counties (Barnstable, Dukes, Nantucket, and Plymouth) whose residential electricity use is higher than its commercial/industrial electricity use.

Similarly, for natural gas use, Barnstable County used 4% of the total natural gas use of the state. Of the 12 Massachusetts counties with available natural gas, Barnstable County also ranked ninth in usage, followed by Berkshire, Hampshire, and Franklin counties. In Massachusetts, most natural gas usage is also from the commercial/industrial sector (55%). Again, in Barnstable County, residential natural gas usage is higher than commercial/industrial usage (69% and 31%, respectively). Barnstable County is one of three counties (Barnstable, Essex, and Plymouth) whose residential natural gas use is higher than its commercial/industrial natural gas use. Two counties have natural gas usage split evenly between residential and commercial/industrial users.

According to the U.S. Census Bureau's annual American Community Survey's (ACS) 2017 5-year estimate, there were 162,629 housing units in Barnstable County. Of those, 95,011 units (58%) were identified as year-round, 61,563 units (38%) as seasonally vacant (seasonal, recreational, or occasional use), and 6,055 units (4%) under one of several other categories of vacant. To more properly account for greenhouse gas emissions from seasonal units, the Commission developed a method to estimate consumption of non-metered fuels (home heating oil, propane) for these units.

Data from the Commission's 2017 Cape Cod Second Homeowners Survey was used to estimate days of annual occupancy during the heating season. This methodology is described in the Fuel Oil methods section.

In total, stationary energy equals approximately 39% of total County emissions (1,398,549 $MTCO_2E$), with the highest emissions coming from the Residential subsector (947,077 $MTCO_2E$), followed by the Commercial/Industrial subsector (452,400 $MTCO_2E$). Natural gas use is the largest source of residential energy emissions (393,463 $MTCO_2E$), while commercial/industrial uses produce the most emissions from electricity use (237,185 $MTCO_2E$).

Residential

ELECTRICITY

Residential electricity usage data were obtained from MassSave[2] and are directly reported by the utility provider. Emissions were calculated by multiplying the total residential usage for Barnstable County in megawatt hours (MWh) by an annual average emissions factor calculated by ISO-New England as reported in "2017 ISO New England Electric Generator Air Emissions Report" based on that year's mix of energy sources powering the electric grid.

NATURAL GAS

Residential natural gas usage data were obtained from MassSave[3] and are directly reported by the utility provider. Emissions were calculated by multiplying the total reported residential usage for Barnstable County by MassDEP's emissions factor for natural gas. Emissions from natural gas distribution system losses are included and were calculated based on the amount of natural gas used multiplied by an IPCC emissions factor for distribution system losses.

FUEL OIL

Residential fuel oil use emissions were calculated based on the number of year-round occupied homes using fuel oil as a household heating source reported in the ACS. Five-year average fuel use for 2014-2018 was calculated using information from the Massachusetts Department of Energy Resources[4] data on household heating costs. A 5-year average was used due to the variability in year-specific data, which reflect yearly variations in winter temperatures. MassDEP emissions factors for fuel oil were used for these calculations.

[2] https://www.masssavedata.com/Public/GeographicSavings?view=C
[3] Ibid.
[4] https://www.mass.gov/info-details/household-heating-costs

A separate methodology was used to calculate fuel oil and propane use for home heating in seasonal and vacant homes, as detailed below. Electricity and natural gas use are reported directly by the service providers and as such reflect actual usage data.

SEASONAL AND VACANT HOME FUEL USE

Cape Cod has a high percentage of seasonal homes (38%), which are not in use for most of the winter months, when the greatest portion of home heating occurs; therefore, a method to more accurately estimate the fuel oil and propane use contribution of seasonally-used homes is appropriate. This method considers when during the year the seasonal homes are being used, for how long, and what level of heating effort is needed during that time. This method was also applied to homes categorized as vacant.

The 2017 ACS was used to determine the number of housing units in Barnstable County and their vacancy status. Total units, occupied (year-round), vacant (all) and seasonally vacant (subset of all vacant) are as follows:

TOTAL UNITS	YEAR-ROUND	VACANT-ALL	VACANT-SEASONAL
162,629	95,011	67,618	61,563

The ACS was also used to estimate the type of heating fuel for seasonal units, which is only reported for year-round units. This model assumes heating methods in seasonal units are at the same percentages as fuels in year-round units.

HOUSE HEATING FUEL AS A PERCENT OF OCCUPIED HOMES	
Utility Gas	58.85%
Fuel Oil	25.20%
Electricity	10.59%
Liquid Propane	3.02%
Wood	1.57%
Other	0.35%
Coal	0.17%
No Fuel	0.15%
Solar	0.10%

Timeframes

The U.S. Energy Information Administration (EIA) recognizes Winter as October 1 through March 31. This model adds April to better align with local practices in the use of second homes. May 1 through September 30 include the busiest of the Cape's "shoulder season" months, as indicated in the 2017 Cape Cod Second Homeowners Survey.

The 2017 Cape Cod Second Homeowners Survey[5] respondents indicated the following average occupancy:

- **May-September (In-Season)**: 73 days (out of 153 total days, 48.2% occupancy)
- **October-April (Off-Season)**: 29 Days (out of 212 total days, 13.5% occupancy)
- **Total**: 102 Days

Monthly Fuel Consumption

Unlike natural gas and electricity, home heating oil and propane usage lacks standardized monthly reporting mechanisms at the local level. Three-year averages (2016-2018) of monthly natural gas use in Barnstable County from MassSave were used to develop monthly percentages of fuel use. These percentages were used as a proxy for level of heating effort for a given month and applied to annualized home heating fuel oil and propane usage estimates.

PERCENT OF FUEL USE FOR THE YEAR:

- **October-April**: 84%
- **May-September**: 16%

MONTHLY FUEL CONSUMPTION AS A PERCENT OF TOTAL YEARLY USAGE	
January	17%
February	14%
March	14%
April	9%
May	5%
June	3%
July	3%
August	3%
September	3%
October	5%
November	10%
December	17%

Numbers presented are rounded to the nearest whole number.

[5] https://www.capecodcommission.org/resource-library/file/?url=/dept/commission/team/Website_Resources/economicdevelopment/Report_Cape_Cod_Second_Homeowners_2017_FINAL.pdf

Calculating In-Season and Off-Season Average Daily Fuel Use

HEATING FUEL OIL

The 5-year average household heating fuel oil use for 2014-2018 from the Commonwealth of Massachusetts[6] is **707 gallons.**

This results in the following estimated fuel oil use for the specified periods:

- **October-April (Off-Season)**: 594 gallons (84% of yearly fuel oil use)
- **May-September (In-Season)**: 113 gallons (16% of yearly fuel oil use)

Based on the 5-year average estimate of 707 gallons of fuel oil use per year, the average daily usage for each time period would be:

PERIOD	GALLONS	AVE/DAY
October-April (84%)	594	2.80 gal
May-September (16%)	113	0.74 gal

PROPANE

The 5-year average household heating propane use for 2014-2018 from the Commonwealth of Massachusetts[3] is **582 gallons.**

This results in the following estimated propane use for the specified periods:

- **October-April (Off-Season)**: 489 gallons (84% of yearly propane use)
- **May-September (In-Season)**: 93 gallons (16% of yearly propane use)

Based on the 5-year average estimate of 582 gallons of propane use per year, the average daily usage for each time period would be:

PERIOD	GALLONS	AVE/DAY
October-April (84%)	489	2.31 gal
May-September (16%)	93	0.61 gal

[6] https://www.mass.gov/info-details/household-heating-costs

OFF-SEASON LEVEL OF HEATING EFFORT

Average temperatures were calculated using monthly data for Barnstable County from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information[7] for 2010-2019.

- **May-September (In-Season)**: 66.3 degrees
- **October-April (Off-Season)**: 41.3 degrees

Assuming a target heating temperature of 68 degrees when a home is occupied [based on Environmental Protection Agency (EPA) recommended settings] and a target heating temperature of 50 degrees when a home is not occupied, in the off-season the temperature inside a home when it's being occupied would need to be raised 26.7 degrees above the average off-season temperature of 41.3 degrees to reach 68 degrees. Similarly, in the off-season the temperature inside of a home when it is unoccupied would need to be raised 8.7 degrees to reach 50 degrees. Raising the temperature 8.7 degrees when unoccupied represents 33% of the heating effort needed to raise the temperature 26.7 degrees when occupied.

CALCULATION BASED ON OCCUPIED AND UNOCCUPIED DAYS

To calculate the seasonal fuel usages, the number of occupied days during in-season and off-season were multiplied by their corresponding average daily use amounts for fuel oil usage. Unoccupied daily usage was used at a rate of 33% of the occupied usage, based on the reduced level of heating effort[8].

In-Season daily usage was calculated based on days used and the average daily usage for the May-September period without any factors applied.

	AVE GALLONS/DAY	DAYS IN USE	GALLONS USED
Daily Use In-Season (May-September)	0.74	74	54.47
Off-Season Occupied Consumption at 68 Degrees	2.80	29	80.28
Off-Season Unoccupied Consumption at 50 Degrees	0.91	183	167.35
Annual			**302.11**

302.11/707 gallons = 0.43 (seasonal homes use 43% of the fuel of a year-round home, on average)

[7] NOAA National Centers for Environmental Information, Climate at a Glance: County Time Series, published June 2020. https://www.ncdc.noaa.gov/cag/county/time-series/MA-001/tavg/all/10/2010-2020

[8] The effects of heat transfer differences for higher or lower degree days, unit size or other unit characteristics were not calculated.

Using this method, 43% of the average year-round use of fuel oil and propane was used to calculate emissions from seasonal and vacant homes, equal to 302.11 gallons for fuel oil and 250.26 gallons for propane.

PROPANE

Emissions from propane use were calculated based on the number of occupied homes using propane as a household heating source as reported in the ACS. Five-year average propane use for 2014-2018 was calculated using information from the Massachusetts Department of Energy Resources data on household heating costs. A 5-year average was used due to the variability in year-specific data, which reflect yearly variations in winter temperatures. MassDEP emissions factors for propane were used for these calculations.

To calculate propane use in seasonal and vacant homes the same methodology was used as in calculating seasonal/vacant fuel oil use.

WOOD

Emissions from the use of wood were apportioned from the state reported emissions from wood use for 2017 (0.8 $MMTCO_2E$, or 800,000 $MTCO_2E$) based on the number of Cape Cod homes using wood as a household heating source compared to the state, as identified in the ACS.

RESULTS

The largest amount of residential stationary energy emissions is from natural gas use, followed by electricity use. These energy sources can be used to power multiple components of residential buildings (heating sources and appliances), while emissions calculated for fuel oil, propane and wood are only associated with home heating.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Electricity	297,280
Natural Gas	393,464
Fuel Oil Total Emissions	222,809
Residential (Occupied)	*170,844*
Residential (Seasonal/Vacant)	*51,966*
Propane Total Emissions	12,596
Residential (Occupied)	*9,642*
Residential (Seasonal/Vacant)	*2,954*
Wood	20,000
Total	**946,149**

Commercial/Industrial

ELECTRICITY

Commercial/industrial electricity usage data were obtained from MassSave and are directly reported by the utility provider. Electricity emissions were calculated by multiplying commercial/industrial reported usage in megawatt hours (MWh) by an annual emissions factor calculated by ISO-New England based on that year's mix of energy sources powering the electric grid.

NATURAL GAS

Natural gas usage data for commercial/industrial uses were obtained from MassSave and are directly reported by the utility provider. Emissions were calculated by multiplying commercial/industrial reported usage in therms[9] by the state's emissions factor for natural gas. Emissions from natural gas distribution system losses are included and were calculated based on the amount of natural gas used multiplied by an IPCC emissions factor for distribution system losses.

FUEL OIL

Commercial/industrial fuel oil use was estimated using data on the sectors' statewide use and the relative statewide portion of commercial/industrial buildings square footage on Cape Cod. Total state commercial/industrial fuel oil use was averaged over a 5-year period (2014-2018) using data from the U.S. Energy Information Administration[10]. The relative statewide portion of Cape Cod commercial/industrial building square footage was calculated using the Metropolitan Area Planning Council's Land Parcel Database[11]. This number was used to estimate the amount of fuel oil use as a portion of the state-reported total. MassDEP emissions factors were used to calculate emissions on the Cape's estimated portion of fuel oil use.

PROPANE

Commercial/industrial propane use was estimated using data on the sectors' statewide use and the relative statewide portion of commercial/industrial buildings square footage on Cape Cod. Total state commercial/industrial propane use was averaged over a 5-year period (2014-2018) using data from the U.S. Energy Information Administration. The relative statewide portion of Cape Cod commercial/industrial building square footage was calculated using the Metropolitan Area Planning Council's Land Parcel Database. This number was used to estimate the amount of propane use as a

[9] A therm is a unit of heat equal to 100,000 British thermal units (Btus).
[10] https://www.eia.gov/state/seds/seds-data-complete.php?sid=MA
[11] https://datacommon.mapc.org/

portion of the state-reported total. MassDEP emissions factors were used to calculate emissions on the Cape's estimated portion of propane use.

The Commission also collected data on propane and diesel fuel use from certain commands at Joint Base Cape Cod. Emissions were calculated for CO_2, CH_4, and N_2O by multiplying the amount of fuel used by a specific emissions factor for each fuel type and gas. MassDEP emissions factors were used for each type of fuel.

RESULTS

The highest amount of emissions in the commercial/industrial subsector comes from electricity use, followed by natural gas use.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Electricity	237,185
Natural Gas	174,181
Fuel Oil	32,812
Propane	6,039
Fuel Use at JBCC	2,183
Total	**452,400**

TRANSPORTATION

Introduction

The transportation sector on Cape Cod accounts for 55.5% of the total Greenhouse Gas (GHG) emissions for the region. The GHG analysis captures mobile emissions from on-road and off-road vehicle use and various forms of transportation, including ferry, aviation, transit, and rail. The majority of transportation-related emissions (78%) are attributed to on-road vehicles, which is based on the annual vehicle miles traveled (VMT) within the region. In total, emissions from the transportation sector equate to 1.979 million $MTCO_2E$ ($MMTCO_2E$).

On-Road Vehicles

Based on 2017 Massachusetts Registry of Motor Vehicles (RMV) data, there are approximately 224,575 registered vehicles in Barnstable County, which include passenger cars, SUVs, motorcycles, buses, and light and heavy-duty trucks. Of the 224,575 registered vehicles, there are approximately 160[12] electric vehicles in Barnstable County. For the on-road vehicle emissions calculation, the Commission referenced the annual average Vehicle Miles Travelled (VMT) estimate for Barnstable County, which was obtained from the regional travel demand model prepared by the Central Transportation Planning Staff (CTPS) of the Boston Metropolitan Planning Organization (MPO). Additionally, fuel economy estimates were referenced from the U.S. Department of Energy's Alternative Fuels Data Center (March 2020) as part of the on-road vehicle fuel usage calculation. To account for the zero tailpipe emissions associated with electric vehicles within the County, the total number of passenger cars was reduced by the total number of electric vehicles prior to emission calculations. Note that emissions associated with electric vehicle charging would be captured under stationary energy use.

The following calculation was used to determine the amount of fuel use for each RMV vehicle type recorded in Barnstable County.

$$\text{Vehicle Fuel Use} = \frac{\text{VMT} * \text{RMV vehicle type \%}}{\text{Average miles per gallon}}$$

Emissions were calculated for CO_2, CH_4, and N_2O by multiplying the amount of fuel used for each vehicle type by a specific emissions factor for each fuel type and greenhouse gas. The emission

[12] Based on cumulative MOR-EV rebates (https://mor-ev.org/program-statistics) Note: In 2020, data on the number of registered EVs by county and town became available from the Massachusetts Registry of Motor Vehicle (RMV). As of May 2020, the RMV reported 1,256 EVs registered in Barnstable County. RMV data on registered EVs is anticipated to be used in future greenhouse gas analyses.

factors (EF) for the on-road vehicle emission calculations were referenced from the IPCC 2006 mobile combustion guidelines for gasoline and diesel vehicles (Volume 2, Chapter 3).

RESULTS

On-road vehicles contribute 1.55 $MMTCO_2E$, with passenger cars/SUVs as the largest contributor, accounting for 64% of on-road emissions. Light-duty trucks account for 22% of on-road emissions, heavy-duty trucks account for 12% of emissions, and motorcycles account for the remaining 1% of emissions.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Passenger Cars	991,271
Light-duty Trucks	348,199
Heavy-duty Trucks	193,095
Motorcycles	17,206
Total	**1,549,771**

Public Transportation

The public transportation subsector includes both transit and ferry service. The transit providers within the region consists of regional and local service provided by the Cape Cod Regional Transit Authority (CCRTA) and inter-city transit service to the region from Boston provided by Plymouth & Brockton Street Railway Co. (P&B) and Peter Pan Bus Lines. Additionally, the transit emissions analysis includes service provided by the Mashpee Wampanoag Tribe vans and the Steamship Authority buses. This analysis presents emissions from round-trip service, not just the portion of service within Barnstable County. These transit services are captured in the on-road subsector within the VMT model, and as such represents a portion of the on-road emissions. Therefore, these emissions have not been added to the overall total for transportation emissions.

Passenger ferry service within the region is provided by a range of seasonal and year-round operators and routes further discussed below. The Steamship Authority (SSA) is the only ferry operator in Barnstable County that carries both passengers and vehicles, including commercial freight, to and from Cape Cod and the islands of Nantucket and Martha's Vineyard. For purposes of this analysis, a passenger ferry generally includes ferry service to and from Cape Cod to the islands of Martha's Vineyard and Nantucket as well as the ferries to and from Boston to Provincetown. Emissions from passenger ferry service are included in the total emissions from the transportation sector.

TRANSIT

Transportation emissions associated with transit service in Barnstable County were based off 2017 fuel usage data. Fuel usage data for the CCRTA, SSA buses, and the Mashpee Wampanoag Tribe vans

were based on 2017 data provided by the National Transit database (NTD).[13] NTD fuel usage records for P&B were only available for 2015 as they stopped reporting to the NTD in 2016. Based on a comparison review of bus schedules in 2015 and 2017, it appears that there were additional service stops in 2017 for P&B that may have increased transit emissions slightly and are not included in this analysis. Fuel usage data was not available for Peter Pan Bus Lines and therefore was estimated based on a review of their 2017 bus schedule to calculate an estimate of their annual VMT. Based on a comparison review of P&B data within the NTD, an average fuel economy for a coach bus of 4 miles per gallon (mpg) was used to estimate fuel usage for Peter Pan buses.

Emissions were calculated for CO_2, CH_4, and N_2O by multiplying the amount of fuel used for each transit provider by a specific emissions factor for each fuel type and gas. The emission factors (EF) for the on-road transportation emission calculations were from the IPCC 2006 mobile combustion guidelines for gasoline and diesel vehicles (Volume 2, Chapter 3).

Transit Results

Transit service within, and to and from, Barnstable County contributes emissions of approximately 10,720 $MTCO_2E$. Transit emissions account for approximately 1% of the overall transportation sector emissions.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Transit	10,720
Total	**10,720**

FERRY

Fuel usage data was requested from the major passenger ferry service providers in Barnstable County. The SSA reports their annual fuel usage to the NTD, which was obtained for the 2017 baseline analysis. Data requests for fuel usage figures from 2017 were also provided by Hy-Line Cruises and Bay State Cruises for their ferry services out of Hyannis and Provincetown, respectively. It should be noted that the fuel usage data provided by Hy-Line Cruises may also be related to their scenic tour operations in addition to their regular passenger ferry operations.

To account for other smaller ferry operators within the region, estimates for annual VMT were calculated based on review of the route mileage and operating schedules found online. The analysis also accounts for the following smaller ferry operators: Boston Harbor Cruises, Island Queen, Pied Piper, Freedom Ferry and the Vineyard Shuttle operated by Patriot Party Boats, Inc. An estimate of average ferry boat fuel consumption was calculated based on a review of the 2017 NTD Energy and

[13] https://www.transit.dot.gov/ntd/ntd-data

Route data for all NTD reporting ferry operators. Based on our review of ferry operators in the U.S., a passenger ferry averages approximately 0.51 miles per gallon (mpg) of fuel. This fuel consumption estimate was applied to the VMT analysis for the small ferry operators where fuel use data was unavailable.

Emissions were calculated for CO_2, CH_4, and N_2O by multiplying the amount of fuel used for the ferry operators by a specific emissions factor for each fuel type and gas. The emission factors (EF) for the waterborne navigation emission calculations were from the IPCC 2006 mobile combustion guidelines for gasoline and diesel fuel (Volume 2, Chapter 3).

Ferry Results

Ferry operations within, and to and from, Barnstable County emit approximately 49,441 $MTCO_2E$. Emissions associated with ferry operations account for approximately 2% of the emissions within the overall transportation sector. Within the subsector of Public Transportation, emissions from ferry operations account for over 80% of total emissions while transit accounts for approximately 20%.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Ferry	49,441
Total	**49,441**

PUBLIC TRANSPORTATION RESULTS

Combined, public transportation (ferry and transit service) accounts for a total emission of 61,161 $MTCO_2E$ within Barnstable County and equates to 3% of the total emissions from the transportation sector and 0.7% of on-road emissions (excluding ferries).

Off-Road

The off-road subsector estimates emissions for non-highway vehicles and equipment. Categories in this subsector include:

- agricultural equipment (ex. tractors, balers, and other cultivation equipment);
- aviation ground support (ex. baggage tractors and cargo loaders);
- commercial and industrial equipment and trucks (ex. forklifts and tractors);
- construction equipment and trucks (ex. back hoes, cranes, and drill rigs);
- commercial and private lawn and garden equipment (ex. chainsaws, mowers, leaf and snow blowers);
- pleasure craft (ex. recreational boating and personal watercraft);

- off-road recreational vehicles (ex. all-terrain vehicles and golf carts); and,
- Fuel use and sales and jet fuel use on Joint Base Cape Cod.

Data for all off-road categories, except Joint Base Cape Cod, were obtained from the Metropolitan Area Planning Council's (MAPC) DataCommon. MAPC used the Environmental Protection Agency's (EPA) MOVES2014b NONROAD Model to estimate CO_2 and CH_4 emissions from those categories. This tool was developed by the EPA to assist states with air quality modeling and to predict emissions from non-road engines based on estimates of equipment populations and fuel consumption. To supplement these data, MAPC incorporated Federal Highway Administration (FHWA) data on construction, commercial, and industrial truck non-highway gasoline consumption. Together, the EPA model and FHWA data use information from a combination of state reporting programs, engine production and manufacturing sales, federal surveys, private research firms, industry organizations, and modeling.

In addition to the EPA model run by MAPC, the Commission collected data on vehicle fuel use and sales and jet fuel use from certain commands at Joint Base Cape Cod (JBCC). Emissions were calculated for CO_2, CH_4, and N_2O by multiplying the amount of fuel used by a specific emissions factor for each fuel type and gas. The emissions factors used for each type of fuel are from the IPCC 2006 mobile combustion guidelines for on-road gasoline and diesel vehicles (Volume 2, Chapter 3) and MassDEP emissions factors for jet fuel.

RESULTS

The largest amount of off-road emissions is attributed to the commercial and industrial categories, followed by pleasure craft, the construction category, and lawn and garden equipment.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Agricultural Equipment	158
Aviation Ground Support	299
Commercial/Industrial Equipment and Trucks	146,725
Construction Equipment and Trucks	64,366
Lawn and Garden Equipment	61,464
Pleasure Craft	72,846
Recreational Vehicles	6,617
Fuel Use at JBCC	7,305
Total	**359,781**

Aviation

Emissions associated with aviation activities (commercial and recreational) for the region are attributed to the three municipally owned airports: Barnstable, Chatham, and Provincetown. The analysis also includes aviation activities associated with the Coast Guard operations on Joint Base Cape Cod. There are additional recreational aviation activities that occur within the region at two local airfields; Marstons Mills and Falmouth, however, fuel usage data from these local airfields was not obtained as part of this inventory and would likely be a small contributor to the overall emissions from the aviation subsector. Fuel usage data for both jet fuel and aviation gas sales in 2017 were provided from the operators of the three commercial airports and the Coast Guard for our analysis purposes. Similar to public transportation, these emissions represent flights to and from Barnstable County.

Emissions were calculated for CO_2, CH_4, and N_2O by multiplying the amount of type of aviation fuel used by a specific emissions factor for each fuel type and greenhouse gas. The emission factors (EF) for the aviation gasoline emission calculations were referenced from the IPCC 2006 mobile combustion guidelines for aviation gasoline fuel (Volume 2, Chapter 3). The emissions factors for the jet fuel calculations were referenced from the U.S. Energy Information Administration (EIA) guides for jet fuel.

RESULTS

Aviation to and from Barnstable County attributes to an emission of approximately 19,614 $MTCO_2E$ and accounts for approximately one percent of the emissions within the overall transportation sector.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Aviation	19,614
Total	**19,614**

Rail

Within Barnstable County are two active rail lines and three rail operators. The Upper Cape rail line connects to the Upper Cape Regional Transfer Station on Joint Base Cape Cod in Falmouth. The Mid Cape rail line connects to the Yarmouth-Barnstable Regional Transfer Station with a rail spur line connecting to Hyannis. Mass Coastal provides rail service for the two truck-to-rail trash transfer facilities on Cape Cod to the Covanta SEMASS waste-to-energy plant in Wareham, Massachusetts. Cape Cod Central Railroad operates scenic rail tours out of the Hyannis Transportation Center. Additionally, the Massachusetts Bay Transit Authority (MBTA) provides seasonal passenger rail service to and from Boston and Hyannis during the summer peak period on Friday evenings, Saturdays, and Sundays from the end of June to Labor Day. Fuel usage data for all rail operations

within, and to and from, Barnstable County were provided by the rail operators to calculate the emissions associated with railroad operations. Similar to public transportation and aviation, these emissions represent service to and from Barnstable County.

Emissions were calculated for CO_2, CH_4, and N_2O by multiplying the amount of fuel used by a specific emissions factor for the fuel type and each greenhouse gas. The emission factors (EF) for the railroad emission calculations were referenced from the IPCC 2006 mobile combustion guidelines for railroad diesel fuel (Volume 2, Chapter 3).

RESULTS

Railway operations within, and to and from, Barnstable County attributes to an emission of approximately 918 $MTCO_2E$ and accounts for less than one percent of the emissions within the overall transportation sector.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Rail	918
Total	**918**

INDUSTRIAL PROCESSES AND PRODUCT USE

Introduction

The Commission defined the Industrial Processes and Product Use sector as those facilities that report GHG emissions to the state GHG Reporting Program, and emissions of sulfur hexafluoride (SF_6) associated with electricity system transmission and distribution.

The state GHG Reporting Program requirements (310 CMR 7.71) were established pursuant to the Massachusetts Global Warming Solutions Act of 2008 which required the reporting and verification of state GHG emissions from, in part, facilities emitting more than 5,000 tons of CO_2E per year. In 2015, the most recent MassDEP GHG Reporting Program Summary Report and Facility List available on the Program's website, there were 296 reporting facilities.

SF_6 is an insulator in gas-insulated switchgear equipment used in large, high-voltage electricity generation, transmission, and distribution equipment. Emissions of this gas from equipment can occur at each phase of the equipment lifecycle, such as equipment manufacturing, installation, use, servicing, and disposal.

Emissions from this sector total 66,092 $MTCO_2E$; where GHG Reporting Program facilities equal 63,668 $MTCO_2E$, and emissions of SF_6 from electricity transmission and distribution equal 2,424 $MTCO_2E$. This represents 2% of total inventory emissions.

Massachusetts GHG Reporting Program Facilities

Emissions associated with industrial processes and/or product use at facilities on Cape Cod were obtained from the Massachusetts GHG Reporting Program for 2017. Four such facilities were identified as reporting to the program that year: Cape Cod Hospital, Woods Hole Oceanographic Institution (WHOI), Canal Generating Plant, and the Bourne Integrated Solid Waste Management Facility. Emissions associated with the Bourne solid waste facility are reported in the Waste sector.

RESULTS

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Cape Cod Hospital	6,610
WHOI	3,718
Canal Generating Plant	53,341
Total	**63,668**

Electricity System Transmission and Distribution Losses

Emissions from electricity system transmission and distribution losses of SF_6 were calculated by apportioning the state reported emissions of SF_6 for 2017 (60,610 $MTCO_2E$) based on the portion of electricity consumption in Barnstable County versus the state.

RESULTS

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Electricity Losses	2,424
Total	**2,424**

AGRICULTURE

Introduction

According to the 2017 U.S. Department of Agriculture (USDA) Census of Agriculture for Massachusetts, Barnstable County has 4.4% of the total number of farms[14] in Massachusetts, and 6,564 acres of land in farms, equal to 1% of the total 491,653 acres of farmland in the state. The average estimated market value per acre of farmland and associated buildings in Barnstable County is $30,555, higher than the state average of $10,894, making Barnstable County the third highest county in the state for average estimated market value per acre behind Suffolk and Nantucket counties, respectively.

This sector includes emissions from livestock digestion (both enteric fermentation and manure management) and soil management, including synthetic and organic fertilizer, and lime use. The application of fertilizers that include nitrogen can enhance nitrification and denitrification rates, increasing the production of N_2O (direct emissions). Emissions also occur from the volatilization and deposition of nitrogen gases (indirect emissions). Chemical processes also lead to a loss of CO_2 from the application of nitrogen fertilizers, and similarly, carbonates in lime undergo a series of chemical processes which can release CO_2.

Emissions associated with the biomass (vegetative) growth of cropland are considered in the Land Use and Forestry sector.

Agriculture sector emissions equal 15,153 $MTCO_2E$, 0.4% of total inventory emissions. Livestock and soil management emissions equal 2,769 $MTCO_2E$ and 12,384 $MTCO_2E$, respectfully.

Livestock

Using data on the number of livestock from the 2017 USDA Census of Agriculture[15], methane emissions from enteric fermentation and manure management were both calculated by multiplying the number of livestock by type by an emissions factor specific to each animal for the following livestock that have an IPCC emissions factor: cows, sheep, goats, horses, mules, swine, poultry, and alpaca. Barnstable County reportedly has 3,603 of these types of livestock, with the large majority of those being birds categorized as poultry.

Direct and indirect N_2O emissions for manure management were calculated using the number of each type of livestock multiplied by standard nitrogen excretion rates and an emissions factor for each type of animal. Direct N_2O emissions occur from nitrification and denitrification of nitrogen.

[14] A farm is defined by the USDA as any place where ≥ $1,000 in agriculture product is produced and sold.
[15] https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Census_by_State/Massachusetts/index.php

Indirect N_2O emissions occur from volatilization of nitrogen in the form of ammonia and nitrogen oxides (NOx).

RESULTS

Due to the relatively small number of livestock on Cape Cod, most emissions from this subsector are attributed to manure management.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Livestock	435
Manure Management	2,333
Total	**2,769**

Soil Management

Generic IPCC methodologies are used for the inventory of nitrous oxide (N_2O) emissions from managed soils, including indirect N_2O emissions from additions of nitrogen (N) to land due to deposition and leaching, and emissions of carbon dioxide (CO_2) following additions of liming materials and urea-containing fertilizer. The IPCC methodology estimates N_2O emissions from the human-induced net N additions to soils (e.g., synthetic or organic fertilizers, deposited manure, crop residues, sewage sludge), mineralization of N in soil organic matter following drainage/management of organic soils, and cultivation/land-use change on mineral soils.

Liming is used to reduce soil acidity and improve plant growth in managed systems. Limited data on lime use on Cape Cod is available; however, given the region's sandy, acidic soils, this analysis assumed liming occurs, especially in agricultural and landscaped settings. According to Horsley Witten Group's (HWG) 2014 Cape Cod Pesticide and Fertilizer Use Inventory[16], since most soil in New England is acidic, it is common to have to raise the pH of soils in order to provide good conditions for growing lawn. Based on the 2014 HWG report and 2016 University of Massachusetts Extension Service Best Management Practices (BMP) for Lawn and Landscape Turf[17], this inventory assumes BMP lime application rates in proportion to HWG reported fertilizer application rates and 50/50 lime/dolomite use.

To estimate and report on emissions from urea fertilization, data from the 2014 HWG report was used for the estimated areas fertilized and fertilizer application rates for residential, commercial, municipal, golf course, and agricultural uses. As noted in the IPCC guidelines, urea is often applied in combination with other nitrogenous fertilizers; however, if the proportion of urea is not known, it is

[16] https://www.capecodcommission.org/resource-library/file/?url=/dept/commission/team/Website_Resources/waterresources/Cape_Cod_Pesticide_and_Fertilizer_Use_Inventory_Final_Report_April_2014.pdf

[17] https://ag.umass.edu/sites/ag.umass.edu/files/pdf-doc-ppt/lawn_bmp_establishment_2016_final.pdf

considered good practice to assume that the entire solution is urea. Therefore, this analysis assumed all fertilizer used was urea fertilizer.

Animal manure, urea fertilizer, and lime were assumed to be the only fertilizers used on Cape Cod. Although compost may be used as well, no data on compost use was identified and is assumed to be a small percentage as compared to other inputs. Sewage sludge was assumed to not be used as a fertilizer on Cape Cod. Data from the Massachusetts Agriculture Census and USDA's Vegetable and Fruit reports[18] on crops and crop yields were used to estimate crop residues. No change in soil carbon stocks from land use change or management was used in the Land Use and Forestry sector analyses; therefore, we assumed no mineralization of N or emissions of N_2O in our direct and indirect emissions from soils estimates.

RESULTS

Soil management results are based on estimates of fertilizers and crop residues used on Cape Cod and do not include estimates of mineralization of N or emissions of N_2O due to management or conversions. As noted in the Land Use and Forestry sector, there is a lack of detailed data on soil types or soil management practices associated with all land uses to calculate accurate estimates of soil carbon stock changes. Soil carbon stock changes in the Land Use and Forestry sector could inform N mineralization and N_2O emissions estimates in the soils management sector.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Synthetic and Organic Fertilization	5,806
Lime	6,578
Total	**12,384**

[18] https://www.nass.usda.gov/Statistics_by_State/Massachusetts/index.php

WASTE

Introduction

This sector includes emissions from solid waste processing and disposal and wastewater treatment and disposal, which combined account for 105,556 metric tons of GHG emission, equal to 3% of total inventory emissions.

Solid waste processing and disposal includes Cape Cod's one operational landfill, the Bourne Integrated Solid Waste Management Facility (ISWMF), processing of solid waste from Cape Cod at the Covanta SEMASS waste-to-energy facility in Wareham, and 10 identified closed municipal landfills on Cape Cod. While solid waste processing at Covanta SEMASS is geographically outside of Barnstable County, emissions with this processing are included in this inventory as emissions related to activities occurring on Cape Cod (the use of products and subsequent disposal as trash). Solid waste accounts for most waste sector emissions. Cape Cod contributed approximately 8.7% of the total material processed at Covanta SEMASS in 2017, equaling 51,116 MWh of electricity exported to the grid via Eversource. That amount of electricity is equivalent to 5% of Cape Cod residential energy use for the year.

Wastewater treatment and disposal includes analysis of influent and effluent wastewater at five municipal scale treatment facilities on Cape Cod, and Cape Cod's portion of wastewater processed at the Wareham Wastewater Treatment Plant which receives wastewater for processing from Bourne. Those facilities on Cape Cod include the Barnstable Water Pollution Control Facility, Chatham Water Pollution Control Facility, Falmouth Wastewater Treatment Facility, Joint Base Cape Cod Wastewater Treatment Facility, and the Provincetown Wastewater Treatment Facility. While wastewater treatment processing at the Wareham Wastewater Treatment Plant is geographically outside of Barnstable County, emissions from this processing are included in this inventory as emissions related to activities occurring on Cape Cod (the generation of wastewater for processing).

Solid Waste

Emissions associated with the Bourne ISWMF and Covanta SEMASS were obtained from the Massachusetts Greenhouse Gas Reporting Program. Emissions from Covanta SEMASS were apportioned to Cape Cod from the reported data using information provided by Covanta SEMASS based on the quantity of solid waste processed from Cape Cod versus the total amount of waste processed at that facility in 2017. Barnstable County contributed approximately 95,369 tons of waste processed at the facility, equal to approximately 8.7% of the total waste processed there that year.

Ten closed municipal landfills were identified from the Massachusetts Department of Environmental Protection (MassDEP) "Inactive and Closed Landfills and Dumping Grounds" list in the towns of Barnstable, Brewster, Chatham, Dennis, Eastham, Falmouth, Mashpee, Orleans, Provincetown, and

Yarmouth. According to the MassDEP list, the first of these landfills opened in 1935 and the last closed in 1998.

The EPA's State Inventory Tool (SIT) Municipal Solid Waste Module was used to estimate emissions for closed landfills. This Module employs a first order decay (FOD) statistical model to estimate emissions over time as the organic component of solid waste breaks down and estimates emissions for the inventory year accounting for waste landfilled during the previous 30-year time period. The Module was run using the assumption that the quantity of solid waste disposal at the identified closed landfills was the maximum tons per day permitted for disposal during the landfill operational period.

RESULTS

Results of the EPA SIT Municipal Solid Waste Module show estimated CH_4 emissions increasing over time until leveling off at a maximum of 0.11 $MMTCO_2E$ from 1994-1996, when emissions began to decrease by almost half to an estimated 0.051 $MMTCO_2E$ in 2017, and are projected to be 0.045 $MMTCO_2E$ in 2020.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Bourne ISWMF	10,064
Covanta SEMASS	43,847
Closed Landfills	50,988
Total	**104,899**

Wastewater Treatment and Disposal

Emissions from wastewater treatment were estimated using the methodology described in the 2019 Refinement to the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. The IPCC methodology does not consider CO_2 emissions from wastewater treatment because they generally derive from biogenic organic matter (human waste) or food waste. It does consider the CH_4 generated in the sewer collection system that reaches the treatment plant, the CH_4 produced under anaerobic conditions within the wastewater treatment processes, and N_2O generated during the nitrification and denitrification processes used for biological nitrogen removal from wastewater.

Since the IPCC guidance is designed for national scale inventories, it utilizes population-based projections for several of its calculations (total organics in wastewater, and total nitrogen in wastewater for example). For several reasons including the seasonality of population and relatively low utilization of centralized sewer systems for wastewater disposal in Barnstable County, using a population-based estimate would have been problematic. Instead, data regarding wastewater flow, influent organics, influent nitrogen, and sludge volumes were obtained directly from the

Massachusetts Department of Environmental Protection and the wastewater treatment facilities themselves and used to estimate CH_4 and N_2O emissions from each of the treatment facilities.

RESULTS

Emissions from wastewater treatment are relatively small compared to other sectors. In terms of overall wastewater treatment, municipal wastewater facilities treat on the order of 15% of the total wastewater generated in Barnstable County, while the majority of wastewater is managed via on-site septic systems. If every property on Cape was sewered the population served would only be 33% the size of Boston, or roughly 125% the size of Worcester. Also, the bulk of the aerobic treatment process degrades organic matter to CO_2, however CO_2 emissions are not considered as they are derived from human / food waste. Formation of CH_4 occurs primarily under anaerobic conditions, which the aerobic treatment processes seek to avoid; and while N_2O can be formed during biological nitrogen removal (an increasingly important aspect of wastewater treatment particularly in Barnstable County), nitrogen is a much smaller component of wastewater than the organic portion that gets oxidized to CO_2.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Wastewater	657
Total	**657**

LAND USE AND FORESTRY

Introduction

According to data from the National Oceanographic and Atmospheric Administration (NOAA), the total area of Barnstable County is 338,138.49 hectares (1,305.56 square miles). Much of this area (66.48% or 868 square miles) is open water[19], as Barnstable County extends approximately three nautical miles from the high water line and includes Cape Cod Bay, Cape Cod Canal, Buzzards Bay, Nantucket Sound, the Atlantic Ocean, or portions thereof, and includes any harbors, embayments or ponds meeting the open water definition. The remaining area of Barnstable County (approximately 436 square miles) can be classified broadly as forest, grassland, cropland, wetland, settlement, or other.

The Land Use and Forestry sector includes estimates of greenhouse gas emissions and removals (sequestration) due to changes in biomass and from dead organic matter from the following managed land use categories: forestland, cropland, and grassland. These categories are described in Volume 4, Chapter 3, Section 3.2 of the 2006 IPCC Guidelines.

Estimates include change in carbon stocks in above- and below-ground biomass, loss of carbon from disturbance, change in carbon stocks in dead organic matter due to land conversion, and biomass burning. Sequestration of organic and mineral soils and wetlands were not calculated for this inventory, as discussed below.

Soils

Soils are classified to apply reference carbon stocks and stock change factors for estimation of soil carbon stock changes. According to IPCC guidelines, although both organic and inorganic forms of carbon are found in soils, land use and management has a larger impact on organic carbon stocks and therefore methods focus on soil organic carbon. The influence of land use and management on soil organic carbon is different in mineral versus organic soils. Organic soils develop under poorly drained conditions while all other soils are classified as mineral soils, and typically have relatively low amounts of organic matter, occurring under moderate to well drained conditions, and predominate in most ecosystems except wetlands.

Mineral and organic soils are carbon pools that are influenced by land use and management activities. In principle, soil organic carbon stocks can change with management or disturbance if the net balance between carbon inputs and carbon losses from soil is altered. Management activities influence organic carbon inputs through changes in plant production (such as fertilization or

[19] Defined as areas of open water, generally with less than 25 percent of vegetation or soil.

irrigation), direct additions of carbon in organic amendments, and the amount of carbon left after biomass removal activities, such as crop harvest, timber harvest, fire, or grazing. Management activities influence organic carbon emissions through cultivation and drainage.

In general, detailed information on soil types or soil management practices associated with the NOAA land cover classes for Cape Cod are not available; therefore, soil carbon stock changes for different scenarios were estimated assuming no changes in soil carbon stocks or changes in mineral and/or organic soil stocks making assumptions regarding whether lands were managed and contained mineral and/or organic soils. For all scenarios, soil carbon stock changes for forest remaining forest were not estimated as no data on forest soil management practices (i.e. drainage) is available and because, according to IPCC guidelines, it is assumed in the Tier 1[20] method that forest soil carbon stocks do not change with management. Based on scenarios assessed, managed soils could sequester 20,000 tons of CO_2 or emit 90,000 tons of CO_2.

Most soils on Cape Cod are likely mineral soils with low soil organic carbon content; however, wetlands likely contain organic soils with high soil organic carbon content. A conservative assumption that all land uses contained organic soils and were managed (i.e. cultivated or drained) would yield high emissions from soils. These are likely overestimates of the emissions from organic soils on Cape Cod; however, these high emissions scenarios may be viewed as worst-case scenarios if all areas contained organic soils and were managed with such practices.

Due to these uncertainties and lack of specific soils data associated with these land use categories, changes were not estimated in this inventory in carbon stocks in soils because these calculations require information on soil types and changes to management practices (i.e. tillage, drainage) on areas of land over time. Lacking information on such management practices for all land uses and assuming management practices were generally consistent over time, no change to carbon stocks in mineral soils is assumed. Mineral soil stock changes may be gains (sequestration) or losses (emissions). Both likely occur on Cape Cod, due to lands remaining the same and land conversions; therefore, it is assumed that mineral soils are in a steady-state. Organic soil stocks are likely mostly found in wetlands and may not be associated with the other land use categories. Also, due to wetlands protections, wetland organic soils are likely not cultivated or drained. Therefore, this inventory assumes mineral and organic soil carbon stocks are in steady-states.

The IPCC guidelines do not provide emissions factors or methodologies for unmanaged soils, or soils which are not undergoing any activity. However, soils in unmanaged forests, grasslands, wetlands, and other unmanaged land uses may capture and store carbon and these functions are not

[20] IPCC basic level of methodological complexity.

estimated using IPCC guidelines. These functions are described in more detail in the Carbon Stocks in Soils and Wetlands section.

Wetlands

In the 2006 IPCC guidelines, methodologies to estimate and report anthropogenic emissions and removals are provided for managed wetlands – those created through human activity or where the water level is artificially altered by human activity. According to the IPCC guidelines, managed wetlands are peatlands cleared and drained for production of peat for energy, horticultural and other uses, and reservoirs or impoundments, for energy production, irrigation, navigation, or recreation. There is a 2013 Wetlands Supplement to the 2006 IPCC guidelines; however, the supplement also provides guidance to estimate anthropogenic emissions and removals only from specific managed wetlands and management activities. The IPCC does not provide emissions factors or methodologies for unmanaged wetlands, or wetlands which are not undergoing any activity.

These human-made wetlands and anthropogenic activities as defined in the 2006 IPCC guidelines and 2013 supplement are unlikely to occur at any significant scale on Cape Cod and it is assumed most Cape Cod wetlands are unmanaged; therefore, estimates for sequestration in wetlands were not calculated. However, it is important to note that unmanaged wetlands provide important carbon capture and storage functions not estimated through the IPCC guidelines. See Considerations for Future Inventories.

Forestland, Cropland, and Grassland

Land use data from the National Oceanographic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP)[21] for 2016 was used for this analysis. The C-CAP identifies 24 land cover classes.[22] To better match the IPCC land use categories, we combined C-CAP classes into a simplified land cover scheme as follows:

IPCC Land Use Categories	NOAA C-CAP Land Cover Classes
Settlement	High Intensity, Medium Intensity, Low intensity, and Open Space Developed
Cropland	Cultivated and Pasture/Hay
Grassland	Grassland
Forest	Deciduous, Evergreen, Mixed Forest, and Palustrine Forested Wetlands
Other	Shrub/Scrub, Unconsolidated Shore, and Bare Land
Wetland	Palustrine Shrub/Scrub, Emergent, and Aquatic Bed Estuarine Forested, Shrub, Emergent, and Aquatic Bed Open Water

[21] https://coast.noaa.gov/digitalcoast/data/ccapregional.html
[22] https://coast.noaa.gov/data/digitalcoast/pdf/ccap-class-scheme-regional.pdf

For croplands, perennial crop and cropland drainage data from the 2017 Massachusetts Census of Agriculture were used.

Reporting is on all emissions by sources and removals by sinks from managed lands, while emissions and removals for unmanaged lands are not reported. Land considered managed is land where direct human intervention has influenced its condition. To complete the calculations in this sector, it is assumed that most land on Cape Cod was managed.

This analysis used a Tier 1 approach, where according to IPCC guidelines Tier 1 methods are designed to be the simplest to use, for which equations and default parameter values are provided in the guidelines. This required the selection of default emissions and reference carbon stocks from the 2006 IPCC guidelines. For our region, we selected defaults for Cape Cod's cold, temperate, and moist climate region, continental mixed forest, and sandy soils.

BIOMASS

Carbon gains from biomass growth were calculated, primarily from forestland, along with carbon losses from biomass removals for land use conversions and burning of forest and grassland using data for conversions and prescribed fires on Cape Cod. Data for other types of wood removals were not available (i.e., merchantable stock or fuelwood removal) and assume these are not common woody tree and plant management activities on Cape Cod. According to the IPCC guidelines, biomass associated with annual and perennial herbaceous (i.e., non-woody) plants is relatively ephemeral, i.e., it decays and regenerates annually or every few years so emissions from decay are balanced by removals due to re-growth making overall net carbon stocks in biomass rather stable in the long term. Thus, the methods focus on stock changes in biomass associated with woody plants and trees, which can accumulate large amounts of carbon over their lifespan. Land use conversions from forest to other land uses often result in substantial loss of carbon from the biomass pool. Trees and woody plants can occur in any of the six land-use categories although biomass stocks are generally largest on forest land.

Given the above, it is important to note that change in biomass was not estimated for all land uses. For example, a Tier 1 approach assumes no change in biomass in grassland remaining grassland. In grassland where there is no change in either type or intensity of management (which was assumed to be the case on Cape Cod), biomass will be in an approximate steady-state (i.e., carbon accumulation through plant growth is roughly balanced by losses through disturbances such as grazing, decomposition, and fire). A Tier 1 approach also assumes no change in biomass and an approximate steady-state in settlements remaining settlements. This method assumes, probably conservatively, that changes in biomass carbon stocks due to growth in biomass are fully offset by decreases in carbon stocks due to removals (i.e., by harvest, pruning, clipping) from both living and from dead biomass (e.g., fuelwood, broken branches, etc.). Considering common Cape Cod

landscaping activities of mowing, tree cutting, trimming, brushing, and other landscape maintenance, it is assumed biomass losses offset any biomass growth in settlements.

DEAD ORGANIC MATTER

Dead organic matter comprises dead wood and litter. The Tier 1 assumption for dead organic matter for all land uses is that their stocks are not changing over time if the land remains within the same land use. Inventories using a Tier 1 method assume that all carbon contained in biomass killed during a land-use conversion event is emitted directly to the atmosphere and none is added to the dead organic matter pool. Tier 1 methodology only requires dead organic matter estimates for lands converted from forest to any other land-use category (carbon losses) and for lands converted to forest (carbon gains).

RESULTS

The total area of Barnstable County is 338,138.49 hectares (1,305.56 square miles). Much of this area (66.48%) is open water. Forestland and cropland are shown to sequester carbon (resulting in negative emissions values), while grassland is shown to emit carbon due to land management practices like burning. Sequestered carbon can be attributed to biomass growth, mostly in forests remaining forests.

SUBSECTOR	EMISSIONS ($MTCO_2E$)
Forestland	-337,657
Cropland	-3,004
Grassland	79
Total	**-340,582**

Considerations for Future Inventories

STATIONARY ENERGY

Due to a lack of fuel oil and propane sales reporting at the local level, state data were used to estimate emissions from the use of those fuels. Should local reporting data on their use or sales become available, future inventories should use local data to calculate emissions from the use of these fuels.

TRANSPORTATION

Available data on the number of types of hybrid and electric vehicles registered in Barnstable County continues to evolve. Future inventories should use the best available data on hybrid and electric vehicles.

The transportation emissions analysis excludes waterborne activities including recreational boating and commercial fishing operations as there was limited data available to understand the magnitude of emissions from this subsector. Fuel usage associated with recreational boats and fishing vessels can occur at various private marinas or at many of the commercial gasoline stations within the region. The recreational waterborne activity sub-sector requires more data collection and collaboration efforts with applicable agencies/partners for future inventories.

For future inventories, additional fuel usage data could be collected from the two local airfields, however, the fuel usage at these facilities would likely attribute a small amount in the overall inventory of aviation emissions within the region.

AGRICULTURE

Future inventories should include additional livestock as appropriate where emissions factors are available.

Application rates of fertilizer and lime should be based on soil test results; therefore, application rates likely vary throughout the region. Future inventories should consider gathering updated and more detailed information on fertilizer and lime use, including compost.

Future inventories should gather more information on soil types and management activities on lands, particularly activities such as tillage and drainage.

WASTE

Wastewater treatment residuals (sludge) are generally transported off-Cape for disposal, and related greenhouse gas emissions were not included in this inventory. Future inventories may investigate further the method of sludge disposal (land application, landfilling, or incineration) and how those associated emissions may be incorporated into other sectors (likely waste and/or soil management). IPCC methodology does not provide a way to explicitly deal with wastewater discharges to groundwater. Emissions from this discharge method may be negligible or may be similar to soil application of effluent which can be estimated in the agriculture/soil management sectors.

LAND USE AND FORESTRY

Future inventories should consider collecting more detailed soils and land management data for all land uses. For example, several estimates required data on land areas drained and/or cultivated and, except for cropland, no data on these practices for other land uses was identified and were assumed to not occur.

For cropland, this inventory used data from the Massachusetts Agriculture Census which included data on cranberries; however, there may be more specific information about Cape Cod croplands, in particular cranberry bogs, and how they are managed that may inform future inventories.

Future inventories should consider other potential losses of biomass. For example, trees blown down in windstorms and biomass is burned in brush piles. No estimates for these losses were identified and currently is assumed that any resulting greenhouse gas emissions would be relatively low and may be offset by biomass growth; however, as information is available, these losses may be factored into future inventories.

The IPCC guidelines for the Land Use and Forestry sector focus on managed lands and management activities on those managed lands to estimate and report anthropogenic emissions and removals. According to IPCC, managed land is land where human interventions and practices have been applied to perform production, ecological, or social functions. Per IPCC guidelines, reporting is on all emissions by sources and removals by sinks from managed lands, considered to be anthropogenic, while emissions and removals for unmanaged lands are not reported. The rationale for this approach is that the preponderance of anthropogenic effects occurs on managed lands.

However, much of the land on Cape Cod could be considered unmanaged. While biomass growth in forest remaining forest is accounted for in the IPCC estimates, the soil carbon stocks in land uses, especially wetlands, remaining the same and unmanaged over time are not accounted for. Recognizing the Cape's numerous freshwater and saltwater wetland resources and that approximately 40% of Cape Cod is protected open space, it is important to investigate the potential carbon sequestration services of these relatively unmanaged lands.

Multiple tools and sources of wetland and soil data are available, through the Massachusetts Healthy Soils Action Plan, Massachusetts Audubon, Waquoit Bay National Estuarine Research Reserve, and the Massachusetts Department of Ecological Restoration, to name a few. As more wetlands are studied on Cape Cod, especially restored wetlands, more information may become available on their estimated carbon sequestration potential and those data should be factored into future inventories. Given the acreage and diversity of wetlands on Cape Cod, estimates should be developed for the different wetland types.

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