Regional Inventory of 2019 Greenhouse Gas Emissions

December 2022

PENOBSCOT
CLIMATE ACTION

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Introduction

As part of the scope for developing Penobscot Climate Action, Integral Group was tasked with developing a baseline regional greenhouse gas (GHG) inventory for the Bangor Area Comprehensive Transportation System (BACTS) metropolitan planning area. This region includes eleven communities: Bangor, Bradley, Brewer, Hampden, Hermon, Milford, Old Town, Orono (including the University of Maine campus), Orrington, Penobscot Indian Island, and Veazie.

Individual communities and City Operations Inventories were not within the scope of the project, so individual communities and municipal operational emissions are not broken out in this memo. 2019 was chosen as the baseline inventory year and represents the first baseline for GHG emissions for the Penobscot Climate Action region. Due to the impacts of the global Covid-19 pandemic, both 2020 and 2021 usage are generally not representative of future emissions trends, especially from transportation; 2019 provides a more realistic and comparable baseline for future planning.

The regional inventory follows the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC).[1] The inventory was compiled and submitted using the City Inventory Reporting and Information System (CIRIS) tool from C40 Cities.[2] GHG inventories are generally divided into "scopes" 1, 2, and 3, as shown in

Figure 1.

- Scope 1: All emissions within the City
- Scope 2: Emissions occurring as a result of grid-supplied electricity consumed within City.
- Scope 3: Other emissions occurring outside the boundaries of the city as a result of activities taking place within the City.

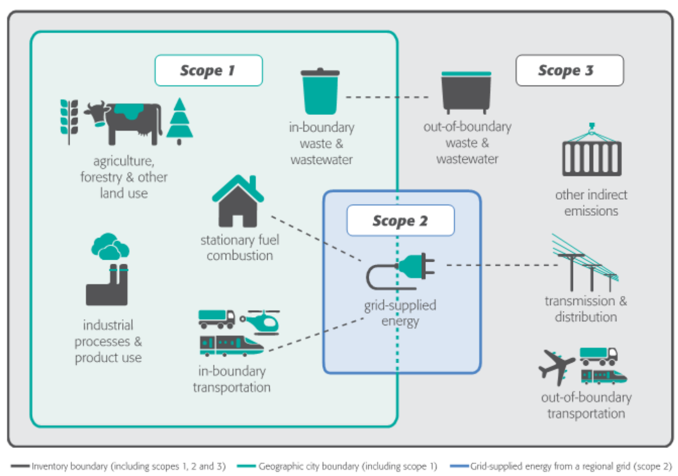

Figure 1: Inventory Scopes (graphic courtesy of World Resources Institute)

GPC-compliant inventories generally follow the "BASIC" or "BASIC+" approach; this inventory

1 GHG Protocol, Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) Washington, DC: World Resources Institute. https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities
2 C40 Cities. Reporting GHG emissions inventories https://resourcecentre.c40.org/resources/reporting-ghg-emissions-inventories

uses a hybrid approach. The inventory includes all Scope 1 and 2 emissions sources, including all the BASIC sources, but also Scope 1 emissions from Agriculture, Forestry and Other Land Use (AFOLU) in order to provide a stronger foundation for future sequestration action planning. In addition, Scope 3 emissions from electricity transmission and distribution are included. All waste was processed in within the region in 2019, so waste emissions were a Scope 1 source in 2019. Other Scope 3 emissions, including out-of-boundary transportation and indirect supply chain emissions, are excluded. Further details on the approach are found in the Citywide Protocol section of the methodology, which follows the regional inventory results.

Regional Inventory Results

Summary

The overall output of data from the CIRIS tool for the Penobscot Climate Action region for 2019 is shown in Table 1 and in Figure 2. Note that totals shown in these, and future tables, may differ from the sum of the rows due to rounding. Overall, the region was responsible for 1,036,402 tons of greenhouse gas emissions, measured in metric tons Carbon Dioxide Equivalents (MTCO2e).

tCO2e	BASIC+	Scope 1	Scope 2	Scope 3
	Stationary	470,633	149,448	7,622
	Transportation	345,700		
	Waste	16,164		
	IPPU			
	AFOLU	46,835		
	Other Scope 3			
	TOTAL	1,036,402		

Intensity indicators	Per capita	Per unit land area (km2)
Emissions	13.5	1,185

Figure 2: Penobscot Climate Action Region GHG Inventory Summary

Table 1. Regional GHG Emissions by Sector and Scope

Sector	Scope 1 Emissions ($MTCO_2e$)	Scope 2 Emissions ($MTCO_2e$)	Scope 3 Emissions ($MTCO_2e$)	Total GHG Emissions ($MTCO_2e$)
Buildings	470,633	149,448	7,622	627,703
Transportation	345,700			345,700
Waste	16,164			16,164
AFOLU	46,835	-	-	46,835
BACTS Region	879,332	149,448	7,622	1,036,402

On a per capita basis, this is 13.5 tons per resident. This compares favorably to the US National average of 20.7 tons per resident, due in large part to the low emissions intensity of the regional electricity grid (ISO-NE). However, it is more emissions intensive than other larger Northeast cities, such as Portland and Boston. In general, this difference reflects the greater demand for heating fuels, particularly fuel oil, and a greater reliance on personal cars rather than public transit. Figure 3 shows a comparison of the per capita GHG emissions in the Penobscot Climate Action region among peers and within the national and global context.

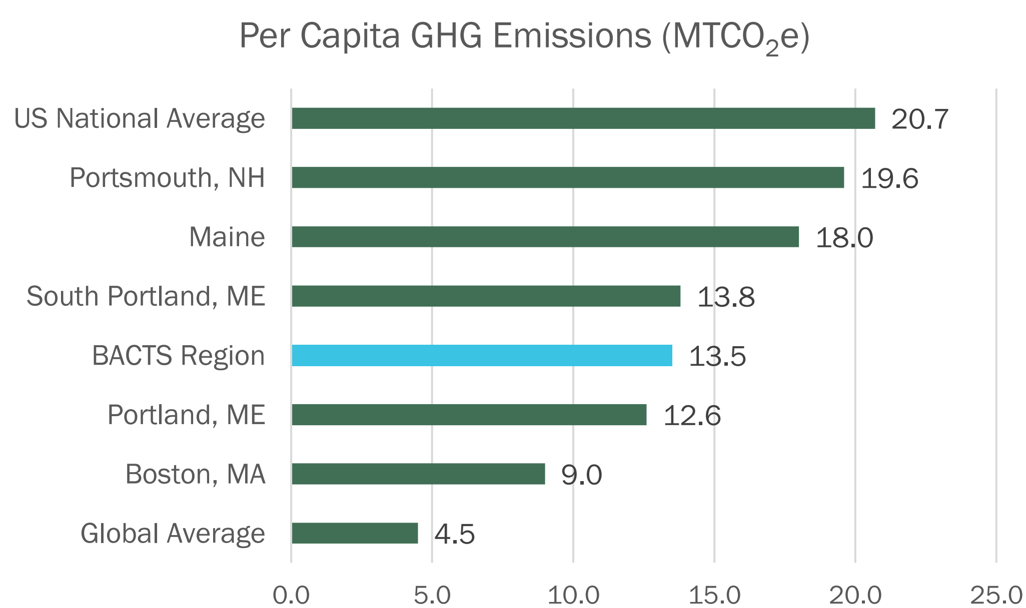

Figure 3: Comparison of GHG Emissions Intensity Among Peers

Greenhouse gas emissions can be looked at by source or by sector; sources are the fuels and waste decomposition that produces greenhouse gas emissions, while sectors are different portions of the economy.

Overall, the use of electricity, natural gas, and fuel oil in buildings is the main driver of the region's GHG footprint, with buildings being responsible for 60.6% of regional GHG emissions. Mobile sources within regional boundaries, such as cars and trucks, are responsible for 33.4%. Agriculture, Forestry and other Land Use (AFOLU) sources, such as livestock and land use changes, are responsible for 4.5%. Lastly, the disposal of solid waste and processing of wastewater is responsible for the remaining 1.6%.

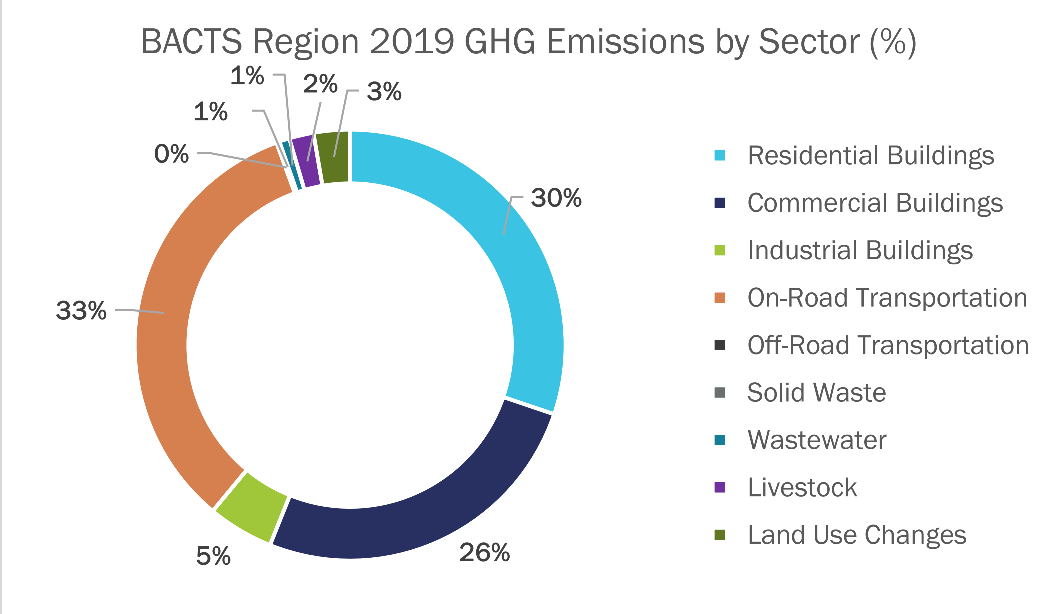

Figure 4: 2019 Regional GHG Emissions by Sector

Table 2. Regional Energy Use and GHG Emissions by Sector

Sector	Energy Use (MMBTU)	% of Energy Use	GHG Emissions ($MTCO_2e$)	% of GHG Emissions
Buildings	9,916,185	67.2%	627,703	60.6%
Residential Buildings	4,494,876	30.5%	310,736	30.0%
Commercial Buildings	4,464,504	30.3%	266,146	25.7%
Industrial Buildings	956,806	6.5%	50,820	4.9%
Transportation	4,833,477	32.8%	345,700	33.4%
On-Road Transportation	4,811,322	32.6%	344,100	33.2%
Off-Road Transportation	22,155	0.2%	1,600	0.2%
Waste	-	0%	16,164	1.6%
Solid Waste	-	0%	8,301	0.8%
Wastewater	-	0%	7,864	0.8%
AFOLU	-	0%	46,836	4.5%

Table 2. Regional Energy Use and GHG Emissions by Sector				
Sector	Energy Use (MMBTU)	% of Energy Use	GHG Emissions ($MTCO_2e$)	% of GHG Emissions
Livestock	-	0%	18,782	1.8%
Land Use Changes	-	0%	28,054	2.7%
BACTS Region Total	14,749,662	100%	1,036,403	100.0%

Table 3. 2019 Regional CO_2, CH_4, and N20 Emissions by Sector				
Sector	CO_2 emissions ($MTCO_2e$)	CH_4 Emissions ($MTCO_2e$)	N_2O Emissions ($MTCO_2e$)	Total GHG Emissions ($MTCO_2e$)
Buildings	625,128	1,085	1,489	627,703
Transportation	343,112	634	1,954	345,700
Waste	791	6,071	1,794	16,164
AFOLU	-	-	-	46,835
BACTS Region	969,031	7,790	5,237	1,036,402

Note that in Table 3, the total GHG emissions are larger than the sum of the gas-specific emissions, due to some emissions being reported only as total carbon dioxide equivalent ($MTCO_2e$).

Within buildings, most residential emissions come from fuel oil, while most commercial emissions come from natural gas; both sources outweigh the emissions from electricity.

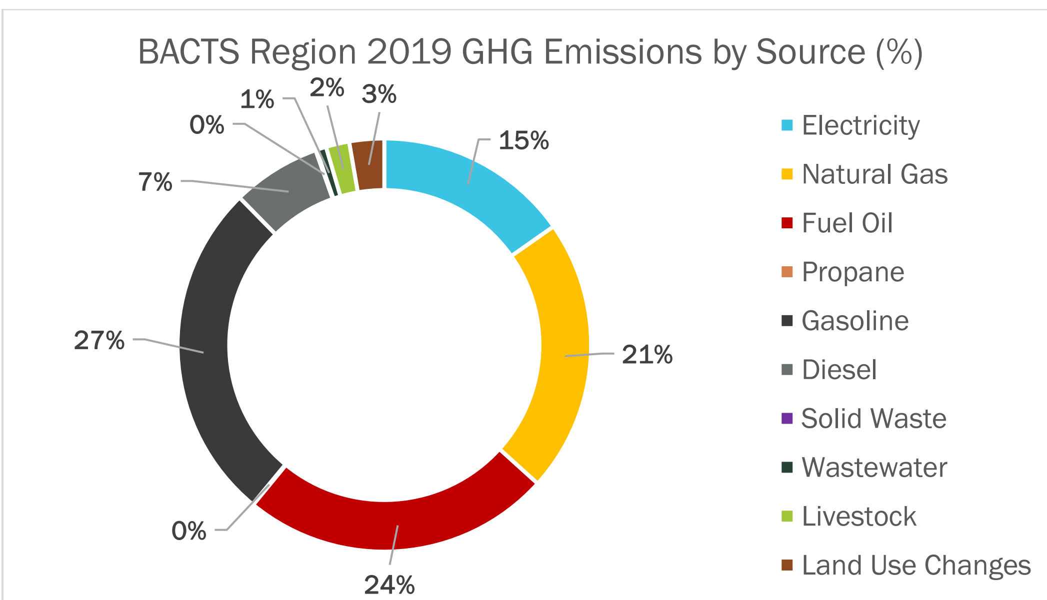

Figure 5: 2019 Regional GHG Emissions by Source

Table 4. 2019 Regional Energy Use and GHG Emissions by Source					
Fuel	Activity Data (Variable Units)	Site Energy Consumption (MMBTU)	% Energy	GHG Emissions ($MTCO_2e$)	% Emissions
Electricity	667,347,965 kWh	2,276,991	16%	157,070	15%
Natural Gas	41,511,470 Therms	4,151,147	28%	220,486	21%
Fuel Oil	24,183,209 Gal	3,361,466	23%	246,129	24%
Propane/Kerosene	113,641 Gal	10,455	0.1%	665	0%
Gasoline	32,250,267 Gal	3,870,032	26%	274,191	26%
Diesel	6,931,259 Gal	963,445	7%	71,509	7%
Solid Waste	26,183 Tonnes	-		8,301	1%
Wastewater	-	-		7,864	1%
Livestock	10,002 Head	-		18,782	2%
Land Use Changes	10.457 ha	-		28,054	3%
Total		14,633,536	100%	1,033,050	100%

Note that total emissions reported in these tables may be slightly different than those reported for the regional inventory due to differences in how some of the data is reported by fuel source and emissions category.

Table 5. 2019 Regional CO_2, CH_4, and N20 Emissions by Fuel Type				
Fuel	CO_2 emissions ($MTCO_2e$)	CH_4 Emissions ($MTCO_2e$)	N_2O Emissions ($MTCO_2e$)	Total GHG Emissions ($MTCO_2e$)
Diesel	71,282	79	149	71,509
Electricity	155,541	686	843	157,070
Fuel Oil	245,323	278	527	246,129
Gasoline	271,830	555	1,805	274,191
Natural Gas	220,260	117	110	220,486
Solid Waste	791	1	3	8,301
Wastewater	-	6,070	1,794	7,864
Livestock	-	-	-	18,782
Land Use Changes	-	-	-	28,054
Total	965,027	7,786	5,231	1,032,386

Buildings

60.6% of the region's GHG emissions footprint is attributable to energy use in buildings, with a total of 627,703 metric tons CO_2e. Building GHG data was computed from a combination of regional electricity and natural gas consumption information, and estimated use of other fuels. Fuel oil use was modeled using the methodology described in the Stationary Sources section of the Methodology. Some direct No. 6 fuel oil, propane, and kerosene use data was provided by the University of Maine; all other fuel oil use was estimated and was assumed to be No. 2 fuel oil. In practice, other grades of fuel oil may also be in use in commercial or industrial buildings, and some residential or small commercial buildings may use propane or kerosene in place of fuel oil; these fuels have sufficiently similar emissions intensities to be grouped together. Wood use for heating is excluded from the inventory as the GPC considers a "biogenic" source and treats emissions from wood combustion as carbon neutral (this is admittedly a highly contested position, but we have opted to align with global reporting protocols).

Table 6. Site and Source Energy Use by Building Sector

Energy Source	Building Sector	Site Energy (MMBTU)	GHG Emissions ($MTCO_2e$)
Electric	Single Family	552,509	38,113
	Multifamily	147,069	10,145
	Commercial		
	Industrial	1,577,413	108,812
Gas	Single Family	488,241	25,933
	Multifamily	294,020	15,617
	Commercial	2,412,080	128,116
	Industrial	956,806	50,820
Fuel Oil and Propane	Single Family	2,510,885	186,315
	Multifamily	466,473	34,614
	Commercial	394,563	29,218
All	Total	9,800,059	627,703

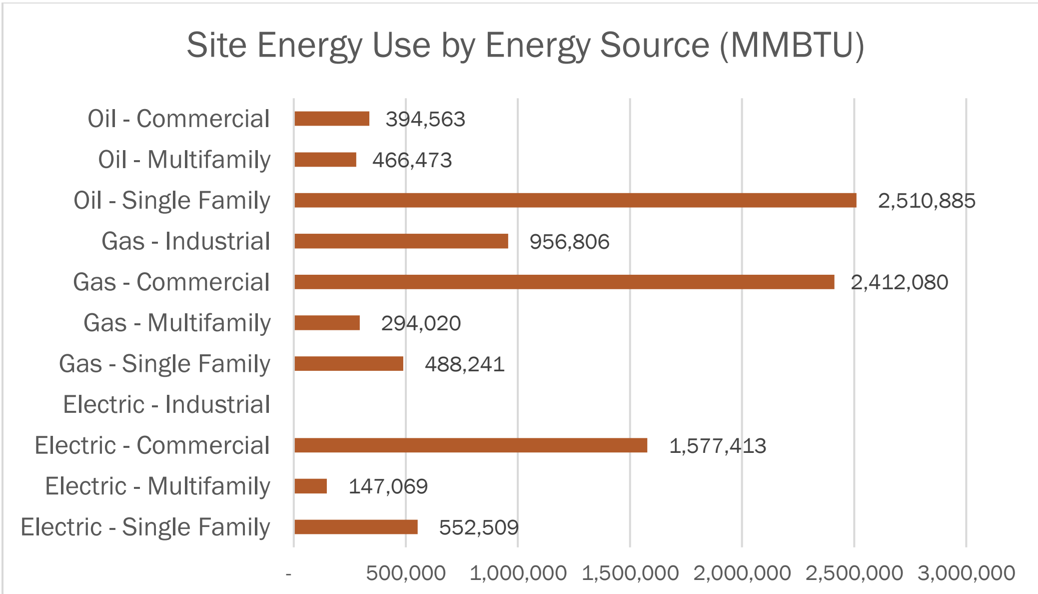

Figure 6: Regional Site Energy Use by Fuel Type

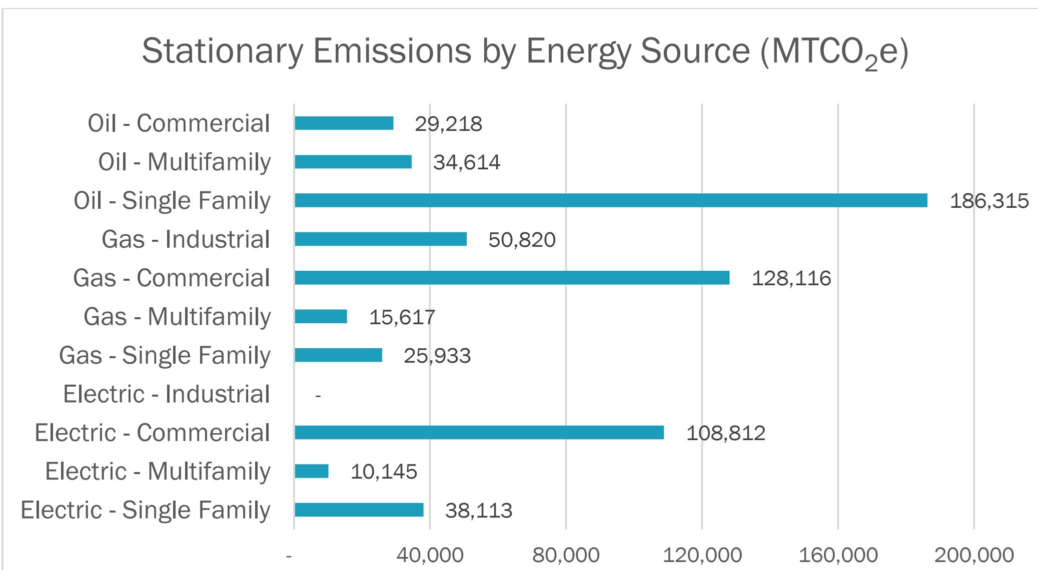

Figure 7: Regional Stationary Emissions by Fuel Type

Transportation

Transportation is responsible for 345,700 $MTCO_2e$, or about 33.4% of the region's GHG footprint. Transportation GHG emissions for the Penobscot Climate Action region were estimated for all on-road and off-road transportation occurring within regional boundaries. Data was provided by the State Department of Transportation for total Vehicle Miles Traveled within regional boundaries, and the types and model years of vehicles registered in the region; on-road GHG emissions were estimated from this data as described in the Mobile Sources section of the Methodology. Gasoline and Diesel fuel economies were weighted based on the makeup of vehicle types registered in the region, as shown in Figure 8. Off-road transportation data was provided by Bangor International Airport and the University of Maine for ground vehicles used at the airport and University of Maine campus. As discussed in the Methodology, air travel was not included in the inventory. Emissions from boats and trains was not available and was considered negligible.

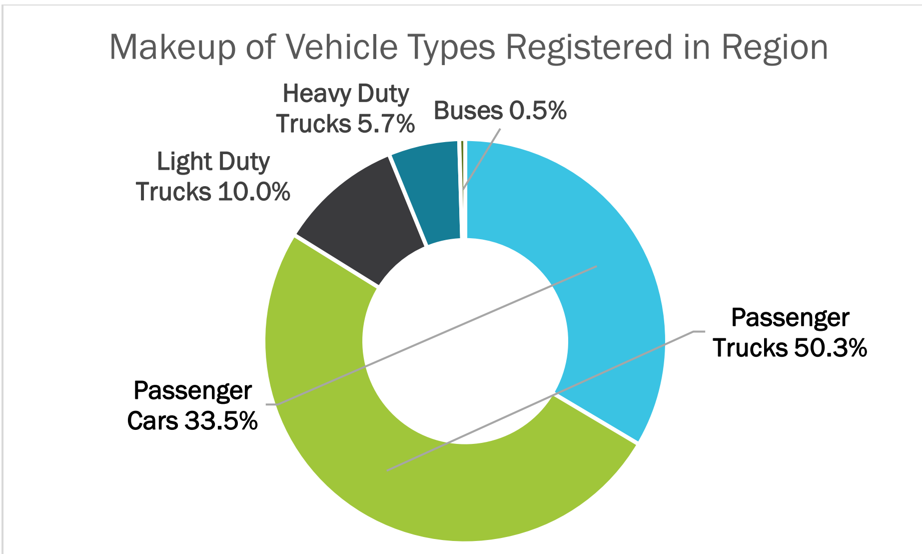

Figure 8: Registered Vehicles in the Penobscot Climate Action Region

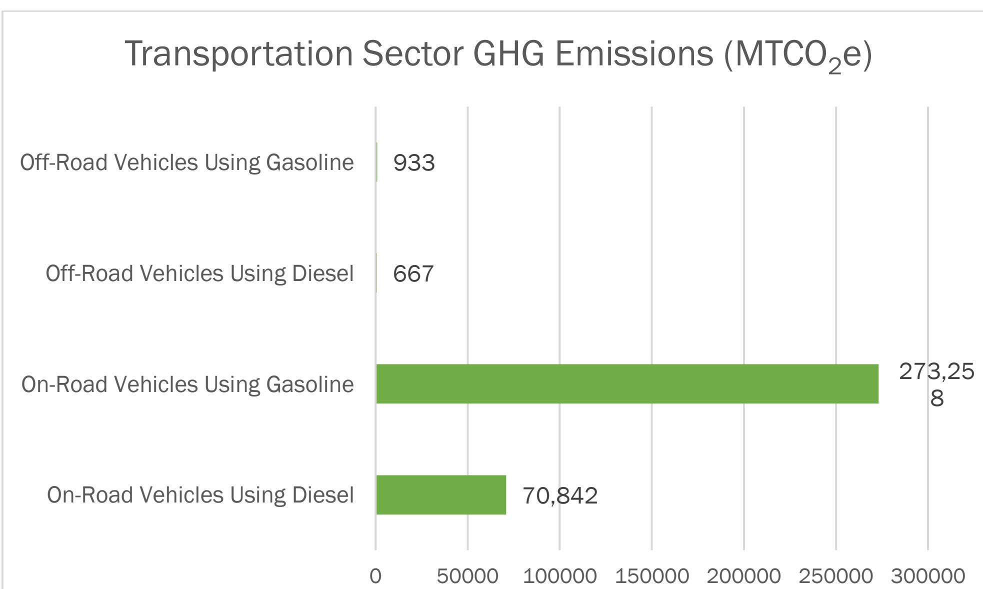

Figure 9: 2019 Regional Transportation Emissions, $MTCO_2e$

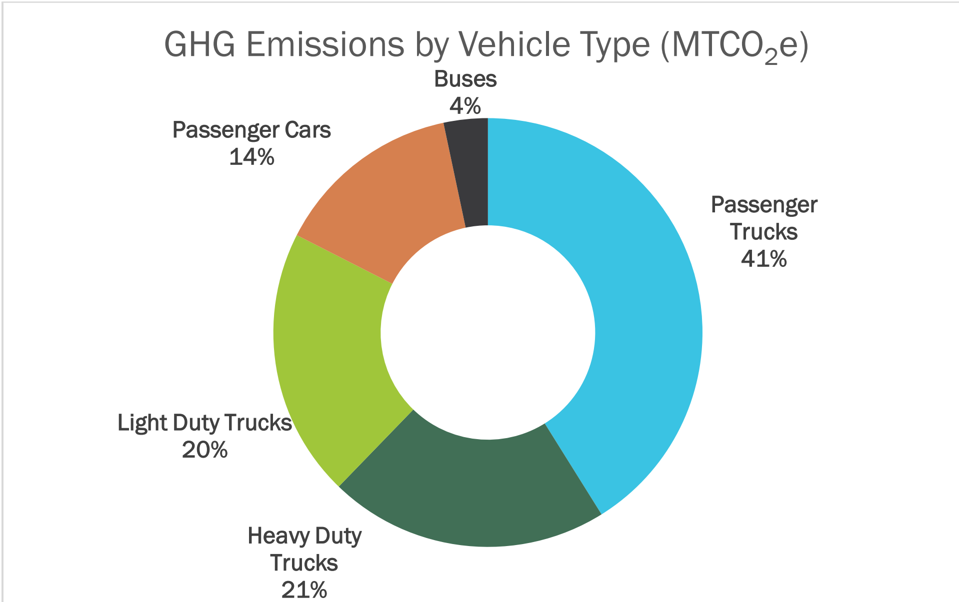

Figure 10: Regional GHG Emissions by Vehicle Type, $MTCO_2e$

Waste

The waste sector is responsible for 16,164 $MTCO_2e$ of GHG emissions, or 1.6% of the Penobscot Climate Action region's GHG footprint. For the purpose of this inventory, all solid waste was assumed to be landfilled at the Juniper Ridge Landfill due to the landscape of waste collection and disposal in the region during the inventory year of 2019. No waste characterization study was available for the region, so quantities of different categories of solid waste were estimated based on the 2011 Maine Residential Waste Characterization Study[3]. Baseline waste management emissions were then calculated using the EPA Waste Reduction Model (WARM) tool[4]. The unique waste situation of the 2019 inventory year and the methodologies for estimating solid waste and landfill gas emissions attributable to the region are described in more detail in the Waste and Wastewater section of the Methodology.

Wastewater emissions listed here are estimated process emissions from the breakdown of wastewater; the energy used for processing wastewater is captured within the buildings sector, under industrial energy use. There were no regional or city-specific organic waste programs (e.g., composting or anaerobic digestion) reported, although the UMaine campus does have a large-scale composter that handled an estimated 530 metric tons of organic cafeteria and grounds waste during the 2019 inventory year. This composted waste was

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[3] The University of Maine. 2011 Maine Residential Waste Characterization Study. https://umaine.edu/wp-content/uploads/sites/2/2017/04/2011-Maine-Residential-Waste-Characterization-Study.pdf
[4] US EPA, Waste Reduction Model. https://www.epa.gov/warm

included in the calculations of baseline waste management emissions. Tons of waste by source are included in the Methodology section.

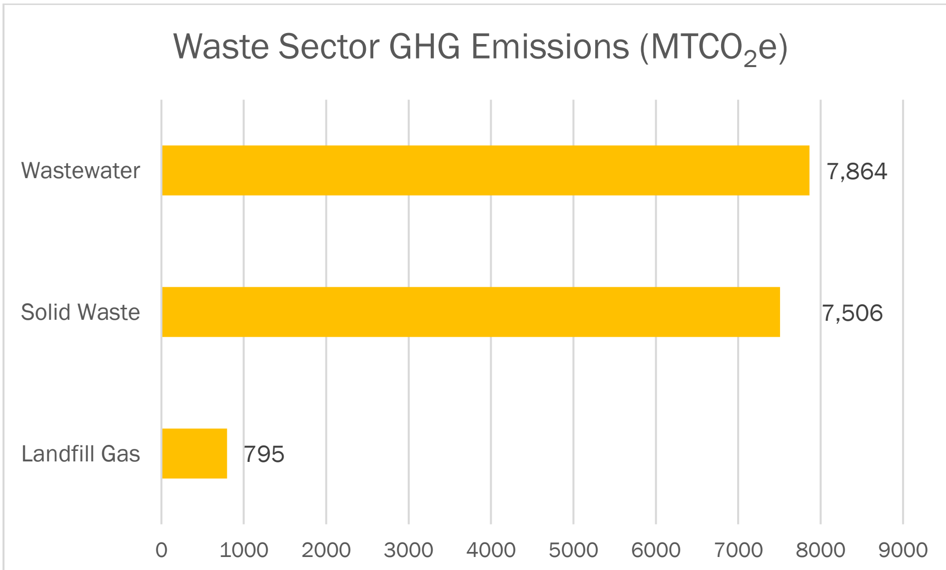

Figure 11: 2019 Regional Waste Sector Emissions

Agriculture, Forestry and Other Land Use

Agriculture, Forestry and Other Land Use (AFOLU) is not included in the GPC BASIC inventory approach but is a requirement of BASIC+ and was included in the hybrid approach of this regional inventory due to the importance of this sector to the Penobscot Climate Action region. A more detailed description of this hybrid approach is included in the Citywide Protocol section of the Methodology. Agriculture, Forestry and Other Land Use is responsible for 46,836 $MTCO_2e$ of GHG emissions, or about 4.5% of the region's GHG footprint.

About 40% of AFOLU emissions come from livestock in the region, and the vast majority of this figure is attributable to emissions from cattle. Livestock emissions were estimated based on the 2017 Census of Agriculture County Profile for Penobscot County[5]. About 60% of AFOLU emissions come from land use changes in the region. These emissions were calculated using the ICLEI US Community Protocol's Land Emissions And Removals Navigator (LEARN) tool[6]. This methodology is described in more detail in the Agriculture, Forestry and Other Land Use section of the Methodology, including total heads of livestock by type.

5 US Department of Agriculture, 2017 Census of Agriculture, County Profile, Penobscot County Maine. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Maine/cp23019.pdf
6 ICLEI, LEARN Tool. https://icleiusa.org/tools/learn/

The LEARN tool accounts for both emissions (e.g., resulting from deforestation) and removals or carbon sequestration (e.g., resulting from reforestation). The total annual carbon sequestration of undisturbed forest in the Penobscot Climate Action region is equal to 313,547 $MTCO_2e$/year, from 53,474 hectares of forest land, which vastly outweighs any emissions associated with livestock and land use changes. In comparison to some of the largest emissions sources, the sequestration effect of forest in the area balances out roughly 90% of the GHG emissions associated with the transportation sector.

While it is important to recognize the positive contribution of forest carbon sequestration (i.e., the removal of carbon from the atmosphere), the removals of carbon associated with undisturbed forest were not included in the regional inventory of GHG emissions. This decision was made in order to focus on the impact of emissions sources in the region and is consistent with the Maine State Emissions Inventory. Reporting the magnitude of carbon forest sequestration in tandem with this regional inventory, however, is valuable for informing future land use decisions, particularly around the conservation of forests.

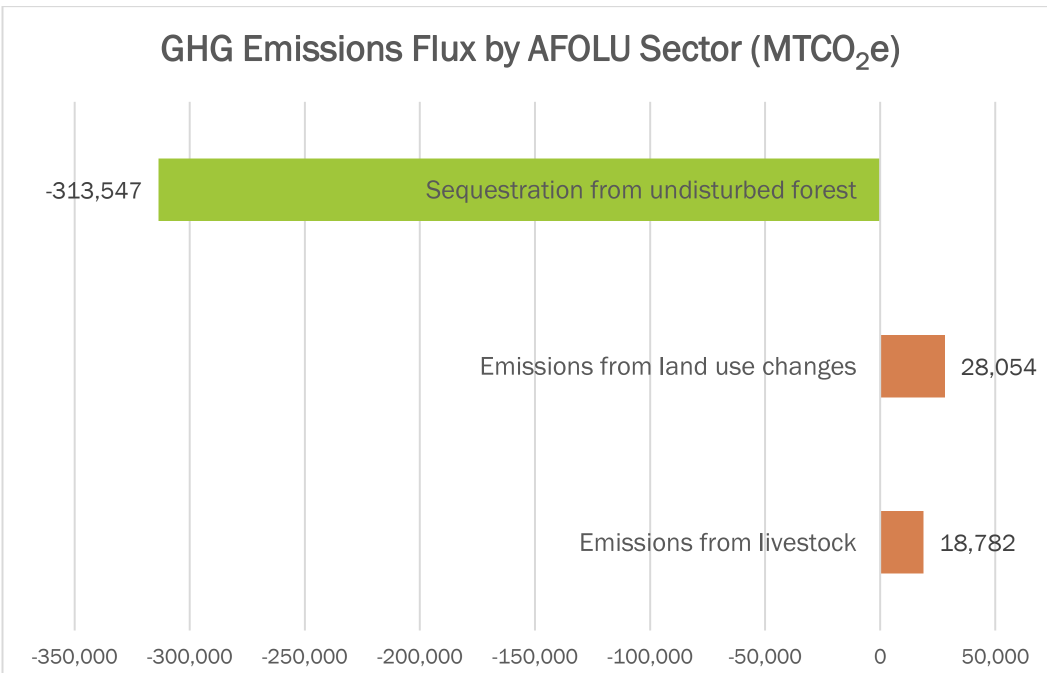

Figure 12: 2019 Regional AFOLU Sector GHG Emissions Flux

Methodology

Uncertainty

The inventory is compiled using measured data, projections, models, and, where data is unavailable, best estimates. The inventory can be regularly revised as new and better data become available, as models are improved, and as international standards and guidance evolve. For these reasons, longer-term trends are likely to prove more reliable than absolute numbers or year-to-year changes. The greatest area of uncertainty in the inventory is the estimate for fuel oil consumption.

Citywide Protocol

The regional inventory follows the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)[7] developed by the World Resources Institute. The inventory was compiled and submitted using the City Inventory Reporting and Information System (CIRIS) tool from C40 Cities[8], version 2.5, which is compliant with the Global Covenant of Mayors Common Reporting Framework (CRF)[9], a framework followed by many cities globally, including Portland, Maine.

GPC-compliant inventories usually follow the "BASIC" or "BASIC+" approach, which largely differ in the extent of Scope 3 emissions included. Table 7 shows the major sources included in the GPC—BASIC inventories include only sources with blue cells, while BASIC+ inventories include both blue and red cells.

It was decided by BACTS and the consultant team to use the BASIC approach to GPC, with some modifications that align the inventory better with elements that the participating communities can control. BASIC includes all scope 1 and 2 emissions, as well as the scope 3 out-of-boundary waste and wastewater emissions. Certain elements of the GPC BASIC+ methodology were included in the inventory based on availability of data and topics of interest to the region. These included emissions from electricity lost in transmission and emissions from livestock and land use changes. Compared to many cities using the GPC, the Penobscot Climate Action region encompasses many rural areas with farms, pasturelands, forests, and other green spaces that have seen significant changes over the past decades. It was

7 GHG Protocol, Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) Washington, DC: World Resources Institute. https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities
8 C40 Cities. Reporting GHG emissions inventories https://resourcecentre.c40.org/resources/reporting-ghg-emissions-inventories
9 Global Covenant of Mayors for Climate and Energy. Global Common Reporting Framework. https://www.globalcovenantofmayors.org/our-initiatives/data4cities/common-global-reporting-framework/

therefore valuable to the team to reflect the emissions – and carbon removals – resulting from these elements of the region.

Conversely, two major sources of emissions commonly included in BASIC+ inventories were excluded from the regional inventory: emissions from transboundary transportation, and emissions from Industrial Processes and Product Use (IPPU). Transboundary transportation is considered a Scope 3 source, and includes ground travel and air travel of residents of the region beyond regional borders. These emissions are very difficult to exert any influence on at the local government level, yet can be quite substantial in aggregate. Most communities in Maine exclude these sources, and we recommend the Penobscot Climate Action Communities continue to do so. IPPU emissions are generally estimated based on national studies, and may have little relationship with actual industrial processes occurring in the community. As little data was available on industrial activity locally, and national estimates do not provide significant value, IPPU emissions were excluded from the inventory. However, as the region collects better data on local industrial activity, including these sources may become valuable.

Table 7. GPC Emissions Sources

Sectors and sub-sectors	Scope 1	Scope 2	Scope 3
STATIONARY ENERGY			
Residential buildings	✓	✓	✓
Commercial and institutional buildings and facilities	✓	✓	✓
Manufacturing industries and construction	✓	✓	✓
Energy industries	✓	✓	✓
Agriculture, forestry, and fishing activities	✓	✓	✓
Non-specified sources	Not Available	Not Available	Not Available
TRANSPORTATION			
On-road	✓	✓	×
Railways	Not Available	Not Available	×
Waterborne navigation	N/A	N/A	×
Aviation	✓	✓	×
Off-road	✓	✓	
WASTE			
Disposal of solid waste generated in the city	✓		✓
Biological treatment of waste	✓		✓
Incineration and open burning of waste	N/A		N/A
Wastewater generated in the city	✓		✓
INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU)			
Industrial processes	×		
Product use	×		
AGRICULTURE, FORESTRY AND OTHER LAND USE (AFOLU)			
Livestock	✓		
Land	✓		
Aggregate sources and non-CO_2 emission sources on land	Not Available		

✓ = *Included in BACTS Region 2019 Inventory | BASIC = blue cells | BASIC+ = red Cells*

Greenhouse Gases Included

The inventory quantified three of the six internationally recognized GHGs, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Data for fugitive N_2O emissions from healthcare facilities were not available at the time of the inventory, so these emissions, which are assumed to be minimal, were excluded from the regional inventory. Data on emissions of the other three internationally recognized groups of GHGs—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—was not available. HFC emissions were also considered negligible under the assumption that all refrigerators, heat pumps, and air conditioners were installed and disposed of properly under State regulations. Industrial emissions of SF_6 were not researched. Emissions of the three measured GHGs were converted to Metric Tons Carbon Dioxide equivalent ($MTCO_2e$) emissions using the Global Warming Potential (GWP) coefficients of each gas developed by the Intergovernmental Panel on Climate Change (IPCC), 5th Assessment Report (AR5), as shown in Table 8. Table 9 shows the main GHG factors used for the calculations; where only CO_2e factors were used, it indicates that the tool for that item did not produce gas-specific data.

Table 8. Global Warming Potential

Gas	Chemical Formula	100-year Global Warming Potential (GWP), AR5
Carbon Dioxide	CO_2	1
Methane	CH_4	28
Nitrous Oxide	N_2O	265

Table 9. Emission Factors Used

Source	Unit	CO_2/unit (tCO_2e)	CH_4/unit (tCO_2e)	N_2O/unit (tCO_2e)	CO_2e/unit (tCO_2e)
Electricity	kWh	2.22E-04	9.78E-07	1.20E-06	
Natural gas	MMBtu	5.31E-02	2.80E-05	2.65E-05	
Fuel Oil No. 2	MMBtu	7.40E-02	8.40E-05	1.59E-04	
Fuel Oil No 6	MMBtu	7.51E-02	8.40E-05	1.59E-04	
Kerosene	MMBtu	7.52E-02	8.40E-05	1.59E-04	
Diesel oil	gal (US)	1.02E-02	1.15E-05	2.12E-05	
Propane	MMBtu	6.29E-02	8.40E-05	1.59E-04	
Cattle	Head				2.83E+00
Pigs	Head				1.37E-01
Sheep & Goats	Head				2.05E-01
Poultry	Head				5.52E-07
Horses	Head				1.13E+00
Fuel Oil No 6	MMBtu	7.51E-02	8.40E-05	1.59E-04	
Landfill gas	ft^3	2.53E-05	4.35E-08	8.11E-08	

Stationary Sources

Data Sources

Electricity consumption data for the Penobscot Climate Action region for 2019 was provided directly to BACTS via email by Versant Power, broken out between residential, commercial, and industrial sectors, including total consumption and number of accounts. Natural gas consumption data for 2019 was provided directly to BACTS via email by Bangor Natural Gas for their entire service area, broken out between residential and combined commercial and industrial customers. Natural gas consumption for the Penobscot Climate Action region was estimated based on customer meter counts provided by Bangor Natural Gas for 2018. Fuel oil and propane use was estimated via the methodology outlined below. Wood heat is excluded from the inventory due to a lack of available data, and the fact that under the GPC, wood is considered a "biogenic" source and is treated as carbon neutral.

Other than for the Bangor International Airport and the University of Maine, no direct fuel oil data was available. Fuel oil is delivered by many companies; these companies were unwilling to share data on their sales. This situation is very common across the country. In rural parts of the state, statewide fuel oil sales data can be used to estimate local fuel oil use, but because of the significant amount of natural gas infrastructure in the region, this was not feasible. To estimate fuel oil consumption for Penobscot Climate Action, the consultant team had to develop Energy Use Intensity (EUI), measured in $kBtu/ft^2$, for various building types within and outside Bangor Natural Gas service area, as well as estimating floor areas by building type and likely heating fuel.

Energy Use Estimation and Assumptions for Fuel Oil

To allocate a specific energy consumption to various building categories that were not located in the Bangor Natural Gas service area, the consultant team first compiled building floor areas from municipal parcel data. The team then developed a set of preliminary energy use intensities based on EIA's nationwide building energy surveys—the Commercial Building Energy Consumption Survey (CBECS) for 2018 and the Residential Energy Consumption Survey (RECS) from 2015. [10,11] Fuel oil use in residential buildings was estimated using Residential Prototype Building Models from the U.S. Department of Energy and Pacific Northwest National Laboratory (PNNL) for the state of Maine.[12] Fuel oil consumption in commercial buildings used the 2018 CBECS for New England. These models were used to develop EUI estimates for heating loads by fuel type.

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10 https://www.eia.gov/consumption/commercial/data/2012/index.php?view=consumption
11 https://www.eia.gov/consumption/residential/data/2015/
12 https://www.energycodes.gov/development/residential/iecc_models

Table 10. Energy Use Intensity (EUI) by Building and Fuel Type			
Building Type	Electricity EUI ($kBtu/ft^2$)	Natural Gas EUI ($kBtu/ft^2$)	Fuel Oil EUI ($kBtu/ft^2$)
Single Family	18.26	137.16	93.72
Multifamily	18.26	137.16	37.35
Commercial	43.50	90.52	90.52

Not all towns in the region have natural gas service, and even in towns with natural gas service, access is not universal. BNG provided meter counts from 2018 for each town; these were used to assign buildings to either natural gas or fuel oil based on the following assumptions:

- We assume no buildings heat with electricity, including heat pumps. This is very likely to be overly conservative, especially given recent heat pump uptake in Maine (though recent growth in heat pump use would not show up in 2019 data), but is the best we are able to make with the available data. Any heat pump energy usage that does exist is captured in the electricity totals from Versant.
- We assume either 0 or 1 gas meter per home, apartment unit, or commercial. While large multifamily buildings do often have single gas meters, most of the multifamily stock in the region is 2-to-4-unit buildings, and these smaller buildings are more likely to have separate gas meters for each unit.
- We assume that all commercial customers that can get natural gas service will opt to do so, as natural gas provides significant cost savings over fuel oil, and commercial customers are generally more sensitive to these price signals and have greater access to the capital needed for building upgrades. The number of gas meters exceeds the number of commercial/industrial buildings in Bangor, Brewer, Old Town, Orono, and Veazie. In these communities, we assume there is no commercial fuel oil use (other than the amount recorded by the University of Maine). In Hampden and Hermon, there are fewer gas meters than there are commercial buildings; in these communities we assume that the remainder of commercial buildings use fuel oil.
- For the towns where there are more gas meters than commercial/industrial buildings, the remaining meters are assigned to the residential units, in equal proportion to the breakdown of single-family vs. multifamily housing in the town. For towns with fewer gas meters than commercial buildings, we assume all residential buildings use fuel oil heating.
- All fuel oil use is assumed to be No. 2 fuel oil. In practice, some of these buildings may use differ grades of fuel oil, diesel, or propane; while the emissions intensity of these fuels does differ, the difference is less than the uncertainty on the total consumption.
- Wood use is excluded from the inventory as a biogenic source with limited available data.
- This results in total estimates for the number of homes, and the resulting floor area, for each fuel in each town.

Table 11. Regional Floor Area Estimation by Building and Fuel Type									
City or Town	Gas Heat			Oil Heat			Total		
	Single Family	Multi-family	Comm.	Single Family	Multi-family	Comm.	Single Family	Multi-family	Comm.
Bangor	1,434	749	1,636	5,171	2,703	0	6,605	3,452	1,636
Brewer	462	366	321	1,817	1,436	0	2,279	1,802	321
Hampden	0	442	2	2,572	0	205	2,572	442	207
Hermon	0	415	54	1,808	0	139	1,808	415	193
Old Town	345	172	140	2,062	1,026	0	2,407	1,198	140
Orono	54	90	786	1,053	1,732	0	1,107	1,822	786
Veazie	36	12	5	470	153	0	506	165	5
Bradley	N/A	N/A	N/A	534	91	13	534	91	13
Indian Island	N/A	N/A	N/A	92	293	0	92	293	0
Milford	N/A	N/A	N/A	716	140	26	716	140	26
Orrington	N/A	N/A	N/A	1,249	232	29	1,249	232	29
Total	**2,331**	**2,247**	**2,944**	**17,544**	**7,806**	**412**	**19,875**	**10,052**	**3,356**

These building counts were then converted into total building area based on the relative proportion of each fuel, and the average building size by type. EUIs for fuel oil were applied to the total floor areas, resulting in estimates for total energy use by building type and fuel.

Table 12. Regional Energy Use by Building Type and Fuel			
	Units	Floor Area (ft^2)	Energy Use (MMBTU)
Electric - Single Family	19,875	30,351,006	552,509
Electric - Multifamily	10,052	8,078,950	147,069
Electric - Commercial	3,356	30,376,204	1,577,413 (includes commercial and industrial)
Electric - Industrial	87	1,724,295	
Gas - Single Family	2331	3,559,658	488,241
Gas - Multifamily	2247	2,143,638	294,020
Gas - Commercial	2944	26,647,063	2,412,080
Gas - Industrial	87	1,724,295	956,806
Oil - Single Family	17544	26,791,348	2,510,885
Oil - Multifamily	7,806	5,935,312	278,129
Oil - Commercial	412	3,729,141	337,560
Oil - Industrial	0	0	0

Mobile Sources

Road Traffic

The GHG emissions for vehicles were based on the Vehicle Miles Traveled (VMT) and the GHG intensities of fuel sources. As is standard for calculating VMT and tracking transportation sector emissions, VMT numbers were based on the miles traveled within the boundaries of the Penobscot Climate Action region, regardless of whether the vehicle owners reside in the region or not, or the vehicles are purchased at dealers within the region or not. Because pickup trucks are a common mode of transit in Maine, passenger vehicle VMT was broken out between passenger vehicles and passenger trucks. SUVs are considered to be passenger vehicles.

Maine Department of Transportation Data was used to estimate the total VMT on roads within the Penobscot Climate Action region, and from this, we can assume that the total vehicle miles traveled in the region during the baseline year of 2019 was 634,322,244 miles.

This extremely granular data does not tell us what vehicles traveled on which roads, however. To estimate energy use and emissions, vehicle registration data was used to look at the registered vehicle stock within every town of the Penobscot Climate Action region. U.S. Department of Transportation and U.S. Energy Information Administration data for the fuel economy of vehicles sold in each class and model year was matched to the registered vehicle stock, and from this, weighted average fuel economy calculations were created for each vehicle class in the region. Any emissions resulting from the charging of electric vehicles is included under stationary sources and accounted for within regional electricity data, so no electric Scope 2 emissions are included. The resulting table is shown below.

Table 13. 2019 Regional On-Road VMT and Fuels

Vehicle Type	Fuel Type	Vehicles	VMT	Mpg (weighted)	Fuel Use (gallons)	Fuel Use (MMBTU)	GHG ($MTCO_2e$)
Passenger Cars	Diesel	257	2,233,511	33.3	67,072	9,256	687
	Electric	194	1,685,997	N/A	N/A	N/A	N/A
	Gasoline	19,740	171,554,535	32.9	5,214,424	651,803	46,200
	Hybrid Electric	840	7,300,193	34.1	214,082	26,760	1,897
Passenger Trucks	Diesel	350	3,041,747	17.2	176,846	24,405	1,811
	Electric	11	95,598	N/A	N/A	N/A	N/A
	Gasoline	30,997	269,385,812	17.2	15,661,966	1,957,746	138,765
	Hybrid Electric	210	1,825,048	17.2	106,107	13,263	940
Light Duty Truck	Diesel	352	7,541,942	17.3	435,950	60,161	4,464
	Gasoline	5,901	126,434,662	17.2	7,350,852	918,857	65,129
	Hybrid Electric	15	321,390	17.2	18,685	2,336	166

Table 13. 2019 Regional On-Road VMT and Fuels							
Vehicle Type	Fuel Type	Vehicles	VMT	Mpg (weighted)	Fuel Use (gallons)	Fuel Use (MMBTU)	GHG ($MTCO_2e$)
Buses	Diesel	255	3,179,676	3.3	963,538	132,968	9,867
	Gasoline	47	586,058	3.3	177,593	22,199	1,573
Heavy Duty Truck	Diesel	2,550	27,946,511	5.3	5,272,927	727,664	53,995
	Gasoline	1021	11,189,564	5.3	2,111,238	263,905	18,706
Total	Diesel	3,764	43,943,388	6.4	6,916,333	954,454	70,823
	Gasoline	5,7706	579,150,631	19.0	30,516,074	3,814,509	270,372
	Hybrid Electric	1,065	9,446,631	27.9	338,875	42,359	3,002
	Electric	205	1,781,595	N/A	N/A	N/A	N/A

Off-Road Transportation

Off-road transportation emissions were considered for the Bangor International Airport and the University of Maine's Orono campus. Both have vehicle fleets that either operate primarily or entirely on their respective grounds rather than on and through local and regional roadways. For this reason, these vehicles were considered off-road. Total diesel and gasoline consumption data were provided by the airport and UMaine, as shown in the table below.

This is certainly not a complete capture of all off-road emissions in the region. Additional off-road gasoline and diesel use that is not included in the inventory due to a lack of available data include vehicles used in agriculture. As well as public lands and parks maintenance vehicles operated by the state or a municipality. Emissions from idling vehicles, either on or off road, also could not be estimated.

Table 14. 2019 Regional Off-Road Vehicles			
Vehicle Location & Fuel Type	Fuel Use (gallons)	Fuel Use (MMBTU)	GHG ($MTCO_2e$)
Airport Vehicles Using Diesel	35,818	4,943	367
Airport Vehicles Using Gasoline	31,598	3,950	280
UMaine Vehicles Using Diesel	29,335	4,048	300
UMaine Vehicles Using Gasoline	73,710	9,214	653
Off-Road Included Total	170,461	22,155	1,600

Air, Rail, and Waterborne Transportation

As discussed above, transboundary air travel emissions were excluded from the inventory; while air travel that took off and landed from within the region would be included, no data on such flights was available. No data was available on waterborne transportation emissions or train emissions. All these sources are negligible.

Waste and Wastewater

Solid Waste

During the 2019 inventory year, all municipal solid waste (MSW) collected in the Penobscot Climate Action region was assumed to be landfilled at the Juniper Ridge Landfill, which is physically located within the region in Old Town, ME. Under normal circumstances, the vast majority of MSW in the region is sent to Penobscot Energy Recover Company (PERC), a waste-to-energy incineration facility located in Orrington, ME. However, this facility was under construction and slowly starting to accept a portion of MSW from the region during the latter half of 2019. Since the vast majority of MSW from the region bypassed this facility and went to Juniper Ridge in 2019, and due to the difficulty in accurately estimating the small percentage that may have been incinerated at PERC, the entire 2019 inventory year is considered a landfill-only year.

MSW collection for most towns in the region is tracked by the Municipal Review Committee (MRC), which provided BACTS with collection data for the 2019 year. Waste from other private haulers was not included in the data received from MRC and Juniper Ridge Landfill. For towns that were not MRC members, MSW weights were estimated based on population size compared to other MRC member towns. Since no waste characterization study was provided for the region, including any for Juniper Ridge Landfill, quantities of various categories of solid waste were estimated based on the 2011 Maine Residential Waste Characterization Study,[13] shown in Table 13 below.

Table 15. 2019 Landfill Quantities by Waste Category

Major Category	Subcategory	% Of Landfilled Waste (2011 waste characterization study)	2019 Landfill Quantity (tons)
Organics		43.28%	11,332
	Food	27.86%	7,295
	Remainder/Composite Organic	10.97%	2,872
	Diapers	2.97%	778
	Yard Waste	1.48%	388
Paper		25.57%	6,695
	Compostable Paper	7.93%	2,076
	Other Recyclable Paper	4.90%	1,283
	R/C Paper	4.08%	1,068
	Magazine/Catalogs	2.88%	754

[13] The University of Maine. 2011 Maine Residential Waste Characterization Study. https://umaine.edu/wp-content/uploads/sites/2/2017/04/2011-Maine-Residential-Waste-Characterization-Study.pdf

Table 15. 2019 Landfill Quantities by Waste Category			
Major Category	**Subcategory**	**% Of Landfilled Waste** (2011 waste characterization study)	**2019 Landfill Quantity (tons)**
Paper	Newsprint	2.43%	636
	High Grade Office Paper	1.64%	429
	Occ/Kraft	1.61%	422
	Phone Books	0.11%	29
Plastics		13.44%	3,519
	All Film	4.78%	1,252
	All Other Plastic	3.76%	984
	#3 - #7	1.38%	361
	PETE (#1)	1.18%	309
	HDPE (#2)	1.15%	301
	Grocery/Merch Bags	0.82%	215
	Plastic ME Dep. Bev Cont.	0.36%	94
Other Waste		5.77%	1511
	Textiles (non-carpet)	4.26%	1115
	Other Waste	1.51%	395
Construction and Demolition Waste		3.35%	877
Metals		3.26%	854
	Other Metal	1.71%	448
	Tin/Steel Cont.	1.45%	380
	Al. ME Dep. Bev Cont.	0.10%	26
Glass		2.71%	710
	Clear Glass Cont.	1.96%	513
	Glass ME Dep. Bev. Cont.	0.41%	107
	Amber & Green Glass	0.15%	39
	All Other Glass	0.18%	47
Household Hazardous Waste		1.72%	450
Electronics		0.92%	241
Total		**100.00%**	**26,183**

These above quantities were then inputted into the EPA Waste Reduction Model (WARM) tool[14], with minor adjustments to fit the same categories used in the tool, along with quantities of composted waste streams reported by UMaine. Recycling data from UMaine was excluded from the WARM tool calculations in order to focus on emissions within the boundary of the regional inventory. Furthermore, emissions from any materials that were potentially

[14] US EPA, Waste Reduction Model. https://www.epa.gov/warm

recycled within the region would be captured in the industrial energy use. The resulting baseline solid waste management emissions for the region are 7,506 MTC02e, as shown in Table 14 below. Note that totals may differ from the sum of the rows due to rounding.

Table 16. Regional GHG Emissions from Baseline Waste Management

Material	Tons Landfilled	Tons Composted	Emissions ($MTCO_2e$)
Corrugated Containers	422	N/A	188
Magazines/third-class mail	754	N/A	-279
Newspaper	636	N/A	-475
Office Paper	429	N/A	650
Phonebooks	29	N/A	-21
Mixed Paper (general)	2,351	N/A	707
Food Waste	7,295	160	4,091
Yard Trimmings	388	425	-87
HDPE	301	N/A	6
PET	309	N/A	6
Mixed Plastics	2,909	N/A	59
Mixed Electronics	241	N/A	5
Aluminum Cans	26	N/A	1
Steel Cans	380	N/A	8
Mixed Metals	448	N/A	9
Glass	710	N/A	14
Mixed Organics	5,726	0	1,325
Mixed MSW	2,830	N/A	1,298
Total	**26,183**	**585**	**7,506**

Juniper Ridge Landfill also operates a landfill gas recovery program, which is important for significantly reducing the amount of methane leakage that can result from the decay of organic materials in the landfill. The proportion of MSW attributable to the Penobscot Climate Action region was applied to the total amount of landfill gas reported to be extracted and flared at Juniper Ridge Landfill over the course of the inventory year. The total landfill gas emissions attributable to the region were calculated to be 795 $MTCO_2e$, as shown in Table 15 below.

Table 17. 2019 Landfill Emissions Attributable to Region

Juniper Ridge Landfill	Municipal Solid Waste (tons)	Landfill Gas (cubic feet)	Emissions ($MTCO_2e$)
Attributable to BACTS Region	26,183	31,306,193	795
Not Attributable to BACTS Region	53,727	64,239,471	1,630
Total	79,910	95,545,664	2,425

Adding the baseline solid waste management emissions and landfill gas emissions results in total emissions of 8,301 MTC02e attributable to solid waste disposal. Despite the fact that Juniper Ridge Landfill is located within the Penobscot Climate Action region, the emissions resulting from waste generated outside of the region are not included in the GPC inventory for BASIC or BASIC+. After 2019, the majority of MSW in the region started going to the Penobscot Energy Recovery Center (PERC), which uses brand new technology that results in about 80% diversion (waste converted directly to energy) and 20% residual waste which is inert, landfilled, and considered carbon neutral. This means emissions from solid waste are likely to decrease for the region in future inventory years.

Wastewater

Wastewater energy use is included in the industrial energy use sector for the inventory. Wastewater process emissions were modeled using the "CIRIS Wastewater Emissions Calculator." Wastewater process emissions were estimated at 7,864 MTCO2e annually.

Agriculture, Forestry and Other Land Use

Livestock

Livestock emissions were estimated based on the 2017 Census of Agriculture County Profile for Penobscot County[15], shown in Table 16 below. The total number of head for each livestock category was estimated for the region based on a ratio of the area of pastureland located in the Penobscot Climate Action region (10,173 ha) to the total area of pastureland in Penobscot County (21,999 ha). About 46% of the pastureland in the county is located in the Penobscot Climate Action region. The land use data for the region was provided by the consulting team based on GIS work completed for the climate vulnerability assessment, while the area of pastureland county-wide was given in the 2017 Census of Agriculture. The emissions factors associated with various types of livestock were obtained from a previous study completed by the consultant team for another North American regional GHG inventory. These emissions do not include the life cycle emissions from the growing of feed, processing, or transportation of animals, and are therefore likely to be an underestimate of the actual emissions attributable to livestock in the region. Emissions from poultry are non-zero but round down to zero.

15 US Department of Agriculture, 2017 Census of Agriculture, County Profile, Penobscot County Maine. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Maine/cp23019.pdf

Table 18. 2017 Livestock Emissions Attributable to Region				
Livestock Inventory (2017)	# Head, Penobscot County	# Head, BACTS Region	Emissions, Penobscot County ($MTCO_2e$)	Emissions, BACTS Region ($MTCO_2e$)
Cattle	13,883	6,420	39,225	18,139
Pigs	675	312	93	43
Sheep & Goats	798	369	164	76
Poultry	5,273	2,438	0	0
Horses	1,002	463	1,133	524
Total	21,631	10,002	40,616	18,782

Land Use Changes

The emissions associated with land use changes were calculated using the ICLEI US Community Protocol's Land Emissions And Removals Navigator (LEARN) tool[16]. The LEARN tool accounts for land use changes that have occurred over the past two decades (2000-2019) to calculate the average annual GHG flux – emissions or removals – associated with each land use change category. The tool required the selection of a reference city that was proximate to the region and as similar as possible. The two closest available options were Boston, MA and Syracuse, NY. The latter was chosen for having a more similar climate to the Bangor region. As with the livestock calculations, the land use data used as inputs in this tool were based on GIS work completed by the consulting team for the climate vulnerability assessment. Land use changes that involve wetlands are included, but any carbon removals associated with undisturbed wetlands are not included in the LEARN tool calculations. Results of the LEARN tool output are summarized in Table 17 below.

Table 19. Average Annual GHG Emissions Flux from Land Use Change (2000-2019)				
Land Use Change (2000-2019)		GHG Emissions / Removals	Area (ha, total)	GHG Flux ($MTCO_2e$/year)
Category	Change Type			
Forest Change	To Cropland	Emissions	0	0
Forest Change	To Grassland	Emissions	1,122	10,468
Forest Change	To Settlement	Emissions	431	6,643
Forest Change	To Wetland	Emissions	219	2,317
Forest Change	To Other	Emissions	91	2,305
Forest Change	Reforestation (Non-Forest to Forest)	Removals	1,312	-9,137
Forest Remaining Forest	Undisturbed	Removals	53,474	-313,547
Forest Remaining Forest	Fire	Emissions	0	0
Forest Remaining Forest	Insect/Disease	Emissions	0	0
Forest Remaining Forest	Forest Harvested	Emissions	3,828	44,617
Trees Outside	Tree canopy loss	Emissions	54	1,036

16 ICLEI, LEARN Tool. https://icleiusa.org/tools/learn/

Table 19. Average Annual GHG Emissions Flux from Land Use Change (2000-2019)				
Land Use Change (2000-2019)		GHG Emissions / Removals	Area (ha, total)	GHG Flux ($MTCO_2e$/year)
Category	Change Type			
Forest				
Trees Outside Forest	Tree canopy maintained/gained	Removals	3,400	-30,194
Harvested Wood Products	N/A	Removals	N/A	0
Total Emissions				67,385
Total Removals				-352,879
Net GHG Flux				-285,494
Net GHG Flux without Undisturbed Forest				**28,054**

As discussed earlier, the carbon removals associated with undisturbed forest were excluded from the regional inventory in order to keep the focus on changes in emissions sources in the region. This is consistent with the Maine State Emissions Inventory approach, which reports the impact of forest carbon sequestration in the state but does not reflect the net GHG removal of forests in its inventory of GHG emissions. The GHG removals associated with reforestation (-9,137 $MTCO_2e$) and urban forest canopy maintained/gained (-30,194 $MTCO_2e$) were included in the calculation of net GHG emissions for the region because these categories reflect recent, active land use changes that have been made in the region.