2018 Greenhouse Gas Inventory
Town of Harvard, Massachusetts

Prepared by Kim Lundgren Associates
August 2020

This report was funded by an Action Grant provided to the Town of Harvard through the Massachusetts Executive Office of Energy and Environmental Affairs Municipal Vulnerability Preparedness (MVP) program.

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Introduction

This GHG inventory report provides a summary of community wide and government operations-level emissions in 2018 and a discussion of target areas and strategies to reduce emissions from key sectors. This report lists GHG emissions (GHGs) outputs in metric tons carbon dioxide equivalent ($MTCO_2e$). This report covers GHGs from municipal operations as well as those resulting from activities of residents and business at the community scale. This inventory also highlights GHGs from agricultural activities in the town as well as an estimate of the carbon sequestration benefit provided by forests and other tree cover in the community. The GHG inventory report was prepared by Kim Lundgren Associates, Inc. (KLA), from May 2020 through July 2020.

This GHG inventory report was created to follow reporting guidance outlined in the *ICLEI, US Community Protocol (ICLEI, 2019)* and *The Local Government Operation Protocol (LGOP) (California Air Resources Board [CARB], 2010)*. Calculations for GHGs at the community and government operations scales are performed independently. The data used in the community inventory is generally drawn from sources that capture all activity, such as building energy use from across the community, whereas government operations data was provided by the Town of Harvard for sources and activities the Town manages directly. This inventory also includes sources from the agricultural sector as well as estimates of carbon sequestration from forested land in the community using largely top-down approaches relying on state and federal sources for land use and land cover within the community.

This inventory covers calendar year 2018, primarily due to it being the most recent year of energy utility data currently available. The inventory includes the three primary GHGs; carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) and are presented in terms of CO_2e or CO_2 equivalent throughout this document, calculated using the IPCC 4th Assessment Global Warming Potential values for CH_4 and N_2O[1].

This assessment provides a summary of Harvard's GHGs and serves as a guide for identifying areas where additional actions may have the greatest potential for reducing GHGs and as a benchmark for evaluating progress towards any emissions reduction targets set by the Town. It also provides recommendations for further refinement of sources and methods.

Summary

Total greenhouse gas emissions for the Harvard community total 57,453 $MTCO_2e$ in 2018, primarily from on-road transportation and building energy use. Approximately 3% of those emissions are attributable to Municipal Operations. Agricultural activities are relatively small (< 1%) contributors to the GHG footprint of the community and come from unique sources related to fertilizer use, animal husbandry, and farm machinery use. However, it should be noted that building energy, solid waste, and transportation emissions specifically from farms were not able to be separated from total community emissions in those respective sectors, and thus emissions associated with agricultural operations should be assumed to be much higher than 1%.

Harvard's extensive forested areas and other tree cover create a substantial sink that may be roughly the equivalent of 80% of the Town's annual emissions. This significant service provided by trees and

[1] https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

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undeveloped land also represents significant potential for release of carbon should that land be developed. At 4.3 million metric tons of CO_2e stored in standing trees and soils, there is the potential to drastically increase Harvard's emissions and reduce ongoing sequestration capacity should there be future development of such land areas.

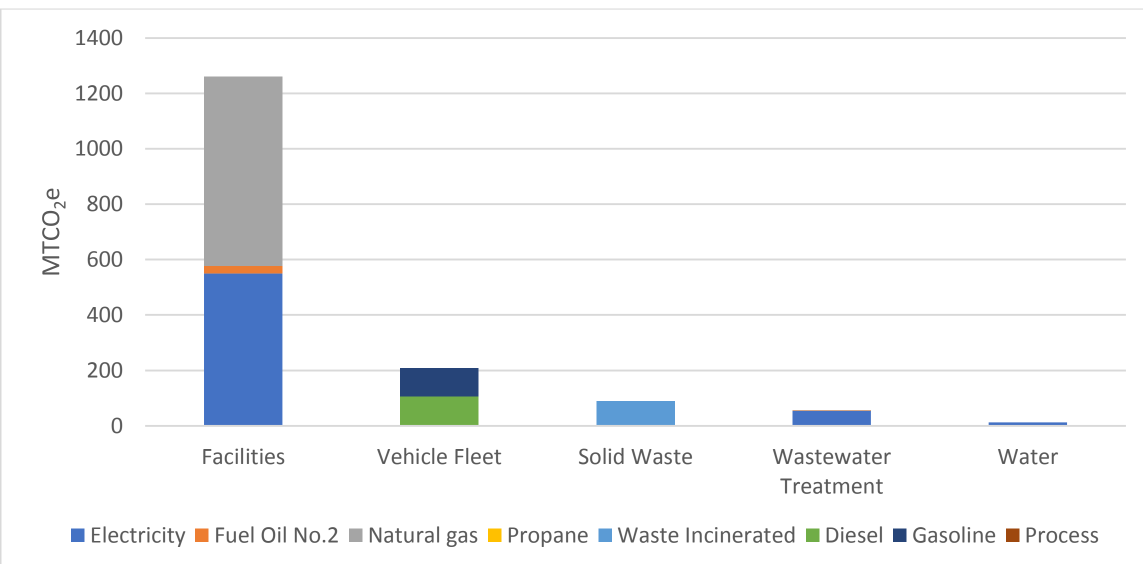
There are many options for the Harvard community to reduce GHGs from its buildings and transportation footprints. If sequestration is going to play a part in how the community assesses its contributions to climate change in the future, close tracking of changes to tree cover as a result of development or other disturbance should be included in future assessments of GHGs from the community.

Municipal Operations

The inventory of GHGs from Harvard's municipal operations covers sources including energy use within town buildings and other infrastructure, fuel consumption in fleet vehicles, waste generated in municipal facilities, and process emissions from wastewater treatment. In total, Harvard's municipal operations were responsible for the emission of 2,184 $MTCO_2$e in 2018.

Building energy use in the facilities sector is the largest contributor across municipal operations, primarily from the energy used to heat buildings and water.

Figure 1 Municipal Operations GHGs by Sector and Source



The Facilities sector was the highest emitter with 77.5% of total emissions. Natural gas was the largest source within the Facilities and Infrastructure sector, almost twice the emissions as electricity. Schools accounted for most of emissions from the Facilities sector – 62%. This pattern is not surprising given that The Hildreth and Bromfield schools are the largest buildings in the Town's portfolio. The schools have been the subject of a series of retrofit and retrocommissioning projects in the last several years to improve their performance. Benchmark studies completed in 2016 evaluated the energy use intensity (EUI) of these facilities at 68.1 (Hildreth) and 49.2 (Bromfield) kbtu/square foot (Peregrine, 2016). For

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comparison, The Department of Energy Buildings Performance Database (DOE, 2020) allows for queries of energy performance among similar buildings. Looking specifically at K-12 buildings in Massachusetts, Rhode Island, and Connecticut returned a sample of 105 buildings with an average EUI of 55 kbtu/square foot. Comparatively Bromfield has performed slightly better and Hildreth slightly worse than the average returned by the Buildings Performance Database and investments have been made to reduce energy use further over the past few years. As the Hildreth School is to be replaced in 2021 with a new facility, operations should be more efficient though different usage patterns within a new building may not lead to overall reductions in energy use.

Figure 2 Facilities GHGs by Energy Source

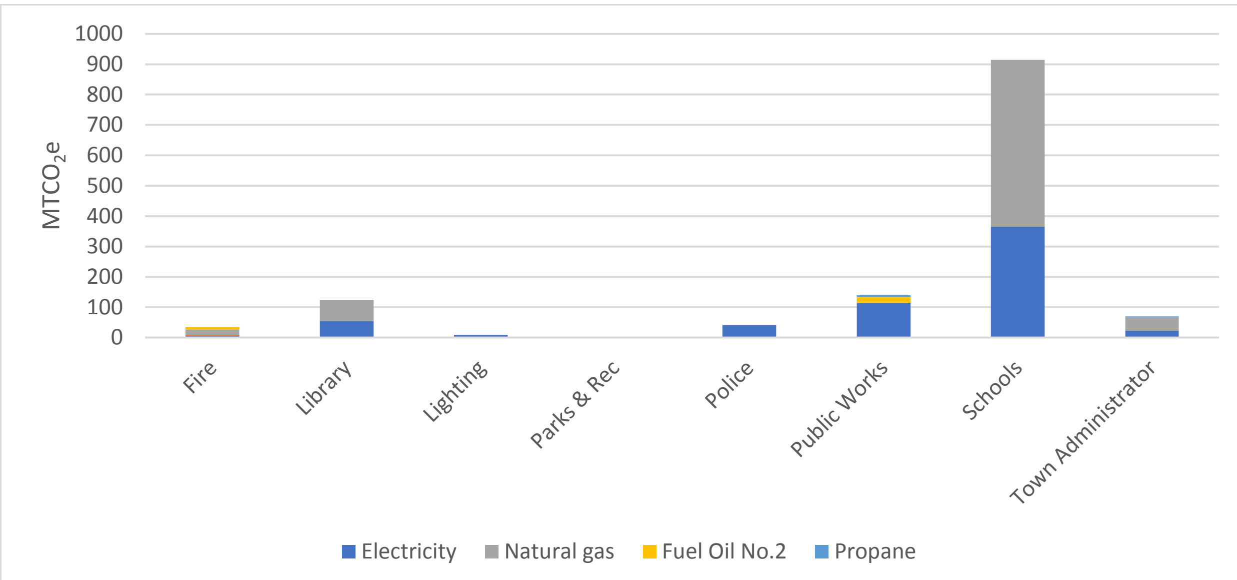

Table 1 Facilities GHGs by Energy Source

Department	**Electricity**	**Natural gas**	**Fuel Oil No.2**	**Propane**
Fire	6.2	19.1	8.9	0.0
Library	55.5	69.6	0.0	0.0
Lighting	8.2	0.0	0.0	0.0
Parks & Rec	1.2	0.0	0.0	0.0
Police	41.0	0.2	0.0	0.0
Public Works	115.6	0.0	18.6	4.9
Schools	364.8	549.6	0.0	0.0
Town Administrator	22.2	45.8	0.0	1.5

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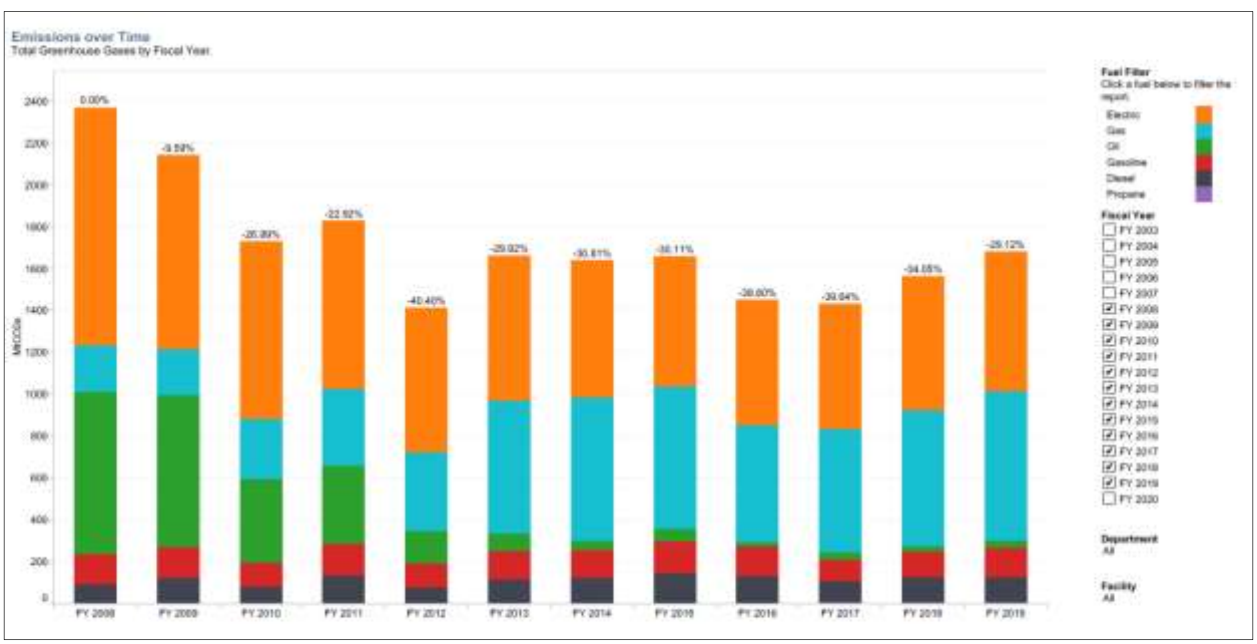
Emissions from Town vehicles represent the second highest contributing sector within municipal operations where town vehicles consumed 10,502 gallons of diesel and 11,498 gallons of gasoline. The Town's records in Mass Energy Insight records do not itemize this fuel use with specific vehicles or other uses which likely includes small equipment used in landscape maintenance, operations at the transfer station, and across the on-road vehicles the Town owns.

Waste generation data from municipal facilities was not available at the time of the inventory and was estimated on the basis of building are and default generation rates for office space.

Emissions from water and wastewater are almost entirely from electricity. Energy used to pump potable water from wells to the limited service area public water supply resulted in 12 $MTCO_2e$ and energy to pump wastewater and operate the wastewater treatment system serving the town center sewer district resulted in 53 $MTCO_2e$. Less than 1 $MTCO_2e$ was attributed to process emissions from the wastewater system.

Overall, the largest opportunity for emissions reductions within Harvard's municipal operations is from natural gas consumption. Review of past Mass Energy Insight data in Figure 3 indicates that natural gas has been an increasing part of the energy mix for Town facilities as fuel oil has been phase out. The data has also shown a drop from 2008 building energy use that has fluctuated between 30 - 40% during the 2010's which could largely be attributable to the relative efficiency of natural gas over fuel oil. Exchanging one fossil fuel for another has limits in the overall GHG reductions that can be achieved from it. Further opportunities to improve the thermal efficiency of the school buildings or exploring ways to provide supplemental heat from other sources of energy would be the most impactful way to reduce GHGs in this sector.

Figure 3 Extract of Harvard Mass Energy Insight Trend Data for all buildings



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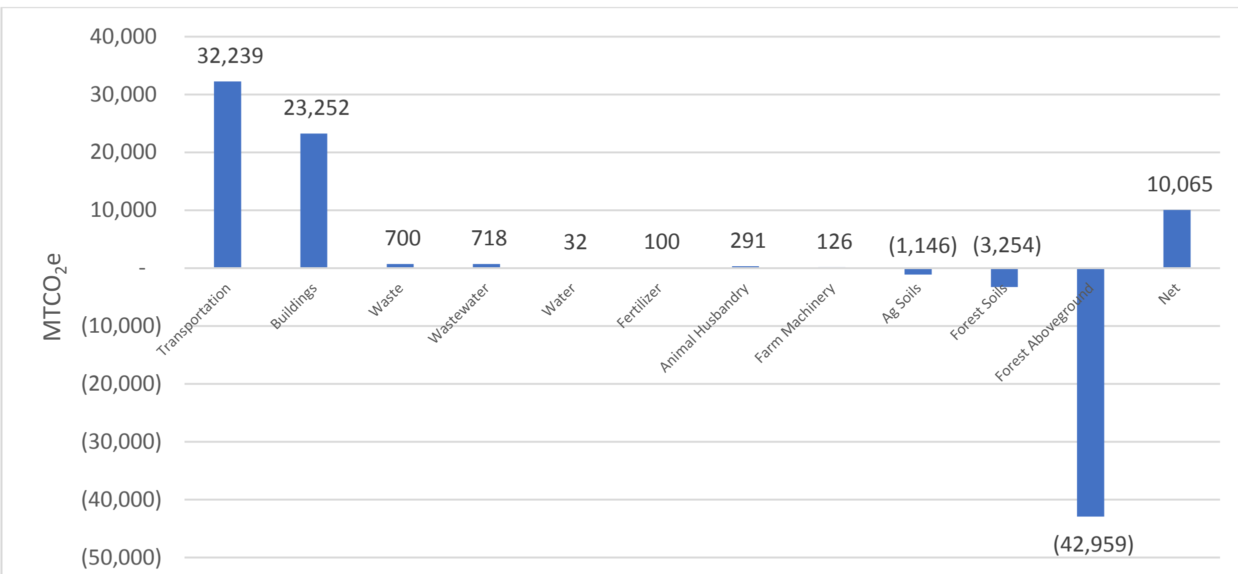
Community-Wide Emissions

Community-wide GHGs for Harvard were assessed for the basic elements of a community scale inventory, including building energy, transportation, solid waste, wastewater treatment, and the supply of potable water. As an agricultural community, the Town of Harvard also presents an opportunity to assess the contribution of agricultural activities that are rarely present in other community scale inventories. These sources include methane from enteric fermentation and manure handling from animal husbandry, energy used in farm equipment, nitrous oxide (N_2O) emissions from the addition of nitrogen fertilizer to agricultural soils. Well managed agricultural soils can also provide a climate benefit by storing carbon (also known as “sequestration”) within soil organic matter.

Harvard also contains significant areas of forest which currently hold very large quantities of carbon but also absorb significant quantities on an annual basis. Between soils and forest, Harvard’s natural and working lands provide sizeable balance to the emissions caused by other activities across the town.

Estimated community GHGs totaled 57,453 $MTCO_2e$ in 2018, with the transportation sector having the largest share followed by building energy. These two sectors combined account for nearly all of the emissions emitted across the Harvard community.

Figure 4 Harvard Community-Wide GHGs



The transportation sector includes on-road travel by vehicles registered in Harvard as well as estimated passenger miles on the MBTA Fitchburg line. Total vehicle miles traveled are 64,409,140 while an estimated 3,011,357 miles were traveled by Harvard residents on commuter rail. At 4.5% of the miles, commuter rail ridership is only responsible for 1.5% of the GHGs in the transportation sector, illustrating the significantly lower carbon footprint of utilizing mass transit for trips to Boston.

Emissions from buildings were estimated from consumption of electricity and natural gas data across all of Harvard, available through MassSave. This data was augmented by estimates of non-utility fuels such as fuel oil and propane based on the area of buildings using those fuels with average consumption of

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those fuels. A substantial portion of the GHGs from residential buildings is estimated to come from non-utility fuels like fuel oil and propane, though no mechanism exists to measure these uses directly.

Solid waste was a fairly small contributor, as were wastewater treatment and the energy to supply water, this is in part due to the relatively small size of the public utilities and the distributed nature of these activities with septic systems and private wells serving most of the community.

Within the agricultural sector, it should be noted that the building energy, on-road transportation, and waste from those activities associated with agricultural operations are included in the community wide totals for those respective sectors. Additional agricultural sources were estimated in this case at a high level due to the challenges of obtaining comprehensive farm level data from all producers in the community and there is some uncertainty associated with these figures. However, they do provide a reasonable estimate of the relative impact of these activities within the community.

For the sources associated with crop production such as fertilizer application and farm machinery, the primary driving data was the estimate of land in various types of production. Emissions from animal husbandry are more uncertain as no official count of all animals and some smaller ones like chickens can be variable year to year. While not comprehensive the Spring 2020 WPI student report (Cano et al. 2020) provides the best estimates of the number of different types of animals. The contribution of these activities is small compared to other sources and smaller than the potential of annual soil carbon sequestration within agricultural soils.

Forests and other trees cover 68% of the land in Harvard. In addition to the wealth of services these trees provide for mitigating stormwater, cleaning the air, and providing habitat; these trees and the soils beneath them absorb the equivalent of 80% of the GHGs produced by other activities in Harvard. The climate value provided by Harvard's natural resources is significant and when weighed against the GHGs of the community provide a strong basis for moving towards achieving net zero GHGs for the community. That said, due to data limitations, the sequestration analysis of this inventory only included a single year snapshot of the benefit of trees in Harvard. Proper land use accounting should incorporate emissions created from loss of tree cover over a period of multiple years. This, along with a more detailed assessment of the forest structure and health could be used to refine the values estimated in this study.

The following sections provide more detail on specific methods for estimating GHGs across the inventory and interpretation of the results.

Municipal Operations Methods and Detailed Analysis

Building Energy

Energy consumption data for Town facilities were obtained from the Town's Mass Energy Insight records. This data provided electricity, natural gas, fuel oil, and propane consumption by building. Direct fossil fuel usage for each facility was converted to $MTCO_2e$ using standard emissions factors published by US EPA. Electricity conversions were made using CO_2 emissions factor from ISO-NE in order to best capture changes to the electric grid within Massachusetts. These were supplemented by factors for CH_4

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and N_2O from EPA eGRID. The results of the analysis are summarized by department and building in the table below.

Table 2 Town of Harvard Energy by Department and Building

Department	Facility Name	Fuel Type	Units	Fuel Use	$MTCO_2e$
Fire	Center Fire Station	Electricity	(kWh)	18,640	5.6
		Natural Gas	(therms)	3,599	19.1
	Still River Fire Station	Electricity	(kWh)	2,121	0.6
		Oil	(gallons)	869	8.9
Library	New Library	Electricity	(kWh)	184,360	55.5
		Natural Gas	(therms)	13,104	69.6
Lighting	Elementary School Lighting	Electricity	(kWh)	906	0.3
	Elementary School Traffic Signal	Electricity	(kWh)	43	0.0
	Fire Station Lighting	Electricity	(kWh)	1,961	0.6
	Town Beach Lighting	Electricity	(kWh)	5,105	1.5
	Town Center Traffic Signal	Electricity	(kWh)	589	0.2
	Town Hall Lighting	Electricity	(kWh)	18,671	5.6
Parks & Rec	Beach House	Electricity	(kWh)	3,894	1.2
	Town Green	Electricity	(kWh)	59	0.0
Police	Police/Ambulance Station	Electricity	(kWh)	136,160	41.0
		Natural Gas	(therms)	29	0.2
Public Works	Highway Department	Electricity	(kWh)	32,160	9.7
		Oil	(gallons)	1,815	18.6
		Propane	(gallons)	858	4.9
	Transfer Station	Electricity	(kWh)	7,587	40.3
Schools	Bromfield House	Electricity	(kWh)	11,163	3.4
		Natural Gas	(therms)	1,926	10.2
	Bromfield School	Electricity	(kWh)	906,544	0.0
		Natural Gas	(therms)	57,262	272.8
	Hildreth School	Electricity	(kWh)	294,880	304.1
		Electricity (Solar)	(kWh)	6,129	88.7
		Natural Gas	(therms)	44,290	0.0
Town Administrator	Bellevue Cemetery	Electricity	(kWh)	651	235.2
	Hildreth House	Electricity	(kWh)	14,660	0.2
		Natural Gas	(therms)	2,106	4.4
	Old Ambulance Building	Electricity	(kWh)	13,078	11.2
		Propane	(gallons)	255	3.9
	Old Library	Electricity	(kWh)	8,456	1.5
		Natural Gas	(therms)	3,399	2.5
	Town Hall	Electricity	(kWh)	37,041	18.1

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		Natural Gas	(therms)	3,109	11.1

Fleet

Mass Energy Insight also tracks fuel use in town operations, however fuel consumption is not tracked by department or by individual vehicle. Gallons of gasoline and diesel were converted to $MTCO_2e$ with standard emissions factors published by US EPA.

Table 3 Town of Harvard Fleet Fuel Use

Fuel Type	Fuel Use (gallons)	$MTCO_2e$
Diesel	10,502	107
Gasoline	11,498	101.43

Solid Waste

Solid waste generation data is not specifically tracked by the town and was estimated using best available published generation rates of waste generation per square foot of office facilities.

Water Energy

Energy for extracting water within the central public water supply system was obtained from the Town Mass Energy Insight records, totaling 39,459 kWh. Electricity emissions calculated as described for buildings, resulting in 12 $MTCO_2e$.

Wastewater

Energy for pumping wastewater within the central sewer district and operating the wastewater treatment system was obtained from the Town Mass Energy Insight records, totaling 177,980 kWh. Electricity emissions calculated as described for buildings, resulting in 54 $MTCO_2e$.

Process emissions from the wastewater treatment system that serves the central sewer district were estimated for nitrification/denitrification. These emissions were based on the approximate population served by the facility of 260 and standard emissions factors for the process. Results were 0.54 $MTCO_2e$.

Municipal Operations Conclusion

Overall Harvard's municipal operations emissions are dominated by building energy use and the Town's use of Mass Energy Insight should continue to be used to benchmark and identify where energy performance can be improved. Future inventories would benefit from regular tracking of waste generated by municipal facilities. Due to their size, Schools are likely the largest single source of waste generation. Monitoring of waste could be an enlightening real-world service learning opportunity for students. Classification of fleet fuel consumption by the departments or activities that consume gasoline and diesel fuel is another key recommendation for advancing action. Greater transparency in how these

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fuels are used within operations is critical to understanding where there are opportunities to reduce usage and cost for the Town.

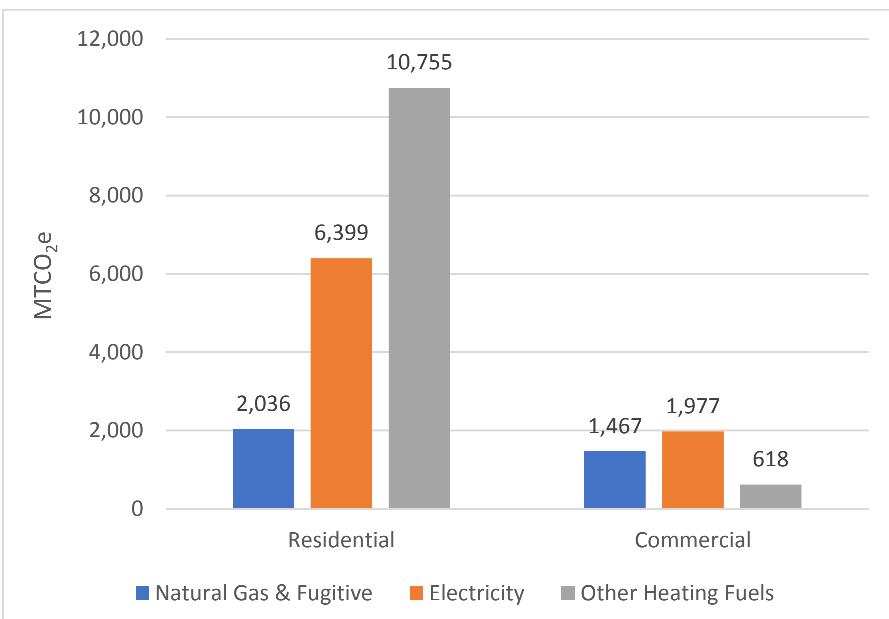
Community Scale Methods and Detailed Analysis

Building Energy

Utility energy use in Harvard was obtained from the MassSave database for electricity and natural gas usage by residents and commercial accounts for calendar year 2018. Electricity related GHGs are calculated using emissions factors published by ISO-NE, the regional electric grid operator and reflect the mix of generation sources that provided power to the region in 2018.

Due to Harvard's rural density, it is known that natural gas distribution serves a relatively small portion of the town. In order to estimate other heating fuels consumed in buildings, the number of households primarily using fuel oil and propane was estimated using Harvard's property tax assessor database. This number was then multiplied by the Massachusetts state average consumption of those fuels per household (Mass DOER 2020).[2] For commercial fuel oil consumption a similar approach was used; however in this case, average energy intensity was sourced from the US Energy Information Administration Commercial Building Energy Survey, using commercial properties in the Northeast by building size classification.[3]

Figure 5 GHGs from Building Energy



[2] https://www.mass.gov/info-details/household-heating-costs
[3] https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/c35.pdf

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The pattern in GHGs from different building energy sources is largely a reflection of the amount of building area in the community using the respective fuel. The key strategy to reducing GHGs from buildings is to replace fossil fuels with renewable sources. Much of Harvard lacks natural gas infrastructure, which can be difficult to move away from when making choices for new heating equipment. The potential for a rapid transition to all electric homes exists in Harvard as current fuel oil consumers leapfrog ahead to using heat pump technology for primary home heating.

Harvard is largely a residential community and performance comparisons can be made by benchmarking against consumption levels within the Northeast region. The Energy Information Administration Residential Energy Consumption Survey[4] provides a good point of comparison. Home size is likely to be the strongest predictor of use and Harvard's average household living area is 2,687 square feet. Compared to other households in the Northeast of similar size, Harvard uses on average 22% more electricity and 13% more natural gas per household. One component of higher electrical usage could be attributable to the fact that many homes in Harvard are on individual well water where pumping energy is aggregated with other electricity consumption.

Transportation

Harvard transportation emissions are the largest source of GHGs totaling 32,239 $MTCO_2e$, accounting for 56.6% of community-wide GHGs. The 2014 Statewide Vehicle Census[5] reports total miles and number of households for each community which was used to estimate 88.3 miles per household per day for Harvard residents. This places Harvard at 326 out of the 351 municipalities for the largest transportation footprint per capita in the Commonwealth.

Total resident miles for 2014 were scaled by 5.52% annual average statewide growth in VMT rates (MassDOT, 2019) resulting in 69,409,140 total miles for the community. Using standard fuel economies for on-road vehicles from the DOE Alternative Fuels Data Center (DOE AFDC, 2020), and emissions factors from US EPA, Harvard's VMT translates to 31,751 $MTCO_2e$.

This method of estimating VMT undercounts emissions that can be attributed to the town since it focuses only on miles travelled by vehicles registered to town residents. Given the draws of farm properties, historical sites, and scenic drives; visiting traffic to the town may be significant.

Harvard resides approximately 34 miles outside of Boston and has one main option for commuting residents, the MBTA Fitchburg line with nearby stations include Littleton and Ayer. For this inventory, boarding and alighting data from the MBTA were attributed to Harvard assuming 1/3 of the passengers came from Harvard versus other communities served by those stations. This resulted in an estimate of 240 daily riders from Harvard. Total trip distances assumed that riders were going the entire length of the line to North Station. In total 3,011,357 passenger miles on commuter rail were estimated for Harvard, resulting 488 $MTCO_2e$ attributable to the community.

[4] https://www.eia.gov/consumption/residential/data/2015/c&e/pdf/ce2.2.pdf

[5] https://www.mapc.org/learn/data/#vehiclecensus

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Maximizing the existing public transportation options may be the most direct way for Harvard to reduce its transportation-related emissions in the short/medium term. Along these lines, the Harvard Town Center Transportation Study recommends expanding bicycle and pedestrian facilities in the commercial center of town which will lower miles driven by facilitating non-car travel to the center of town (MRPC, 2016). Transit passenger miles from MBTA travel accounted for only 4.5% of total travel miles (VMT and passenger miles) attributed to Harvard residents, despite the relatively long trip length for those travelers, assumed to be to Boston North Station.

There may be significant opportunity to expand transit use with improved first/last mile connections to each station. While there are likely some small number of EVs in Harvard today, there is no data on their actual numbers. Future updates to the vehicle census will likely provide some insights, but incentives or other promotional strategies for converting to electric vehicles may also be useful for reducing transportation emissions in the long term.

Waste

Waste accounted for 1.2% of total community emissions in Harvard in 2018 at a total of 700 $MTCO_2e$. According to the Massachusetts 2018 Statewide Solid Waste and Recycling Survey, 1,180 tons of waste was collected at the transfer station. All waste is sent to the Covanta waste to energy facility and emissions were calculated based on standard emissions factors for incinerated waste from the US Community Protocol.

To estimate waste generation, data on total waste collected at the town transfer station was supplemented by scaling up from the number of households served by the transfer station (1,370) to the total number in the community (1,851), assuming per-household waste generation rates of 1,723 lbs / household from transfer station users were consistent across the two groups.

Commercial waste was estimated from reports provided to the Town from private haulers that service commercial properties and some residential properties. The residential portion was subtracted from this portion leaving an estimated 422 tons of waste generated by commercial operations in 2018.

Table 4 Harvard Community Waste Generation

Generation Source	Tons of Waste
Collected at Transfer Station	1,180
Residential Private Haul Estimate	414
Commercial Private Haul Estimate	422

Potable Water

The water-energy footprint of Harvard is only partially known. Many communities rely predominantly on a centralized supply system that uses energy to extract, treat, and distribute water to consumers.

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Harvard's water system is much smaller with only approximately 100 customers drawing from public system. From the municipal operations inventory, we know how much energy is used to extract and deliver water to those residents and businesses, 39,459 kWh. For the remainder of the town, water comes from individual wells serving individual properties. For these homes energy use was estimated using the town's population multiplied by average 53 gallons per capita per day water use rates for self-supply in Worchester County from USGS (USGS, 2018), which led to an estimated 124 million gallons per year. This value was multiplied by the low end of water extraction energy intensity from the US Community Protocol of 540 kWh / million gallons and 67,007 kWh of energy from well water. Total electricity from both sources was multiplied to result in 32.03 $MTCO_2e$ from water supply. One significant other water user not accounted for in this study is for irrigation. Similar to household wells, the electricity used is captured by community-wide values obtained through MassSave, but workable methods to estimate this specific use case were not available.

Wastewater

Most residences in Harvard use private septic systems for wastewater treatment. These systems create small amounts of methane gas in their normal operation and is estimated at 717 $MTCO_2e$ for the entire community.

There is also a central Sewer District serving approximately 260 individuals spread across, residents and businesses in the central downtown with a system that provides some additional treatment processes for managing nitrogen. The result of this calculation is 0.5 $MTCO_2e$ and this value is included in the government operations totals for the town.

Overall wastewater treatment currently accounts for 1.3% of total GHG emissions from the community and this is a relatively low contribution as compared to communities with energy intensive wastewater treatment plants that treat wastewater from the entire community. Final figures for the wastewater treatment operation do not include two sources of GHGs for which data was not readily available. One is the introduction of methanol to drive nitrification/denitrification processes as well as the incineration of residuals periodically removed from the system. Both sources are believed to be small given the overall capacity of the system as evidenced by the small value calculated for nitrification/denitrification directly. These activities are necessary to continue to protect Harvard's water resources from excessive nitrogen and other contaminants.

Agriculture and Land Use

Much of the short history of community scale GHG inventories has been in largely developed communities where the vast majority of emissions come from energy use, transportation and from the disposal and treatment of solid waste and wastewater. While Harvard contains those things is also contains substantial areas of undeveloped land as well as significant agricultural activities that create unique sources of GHGs, but also act as carbon sinks, pulling carbon from the air. In addition, there are substantial quantities of carbon stored in the land which have the potential of significant release of GHGs depending on future development decisions.

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Agriculture in Harvard occurs across a range of farm sizes, production methods and intensities, however complete information on the production practices happening in Harvard is incomplete. This inventory estimates GHGs from agriculture using a 'top-down' approach. While this method will miss a certain amount of detail, it does provide a reasonable estimate of GHGs from these activities relative to the other sources of emissions in energy use, transportation, and waste while also providing a basis for considering the potential climate benefit of improved agricultural practices.

Estimating the Scale of Harvard Agriculture

At the time of this inventory, existing activity data on agricultural activities was incomplete and a combination of factors including timing of the agricultural season beginning prevented additional new data collection specifically for this project. Past surveys had limited reach and official records of properties in Chapter 61-A classification missed many smaller producers. Thus, estimating GHGs from agriculture activities was estimated using a top-down approach that would be able to provide estimates of the relative impact of agricultural activities in the community as compared to the sources such as building energy use, transportation, and waste.

To get the most-complete estimate of the area of land in production, the USDA "Cropscape" tool was used to obtain acreage in various types of agricultural production. Cropscape allows users to query the National Cropland Data Layer (CDL) for a specific geographic area. The CDL is developed by the USDA National Agricultural Statistics Service and uses a combination of satellite imagery to classify land cover but also specific crop types in production at a 30-meter grid resolution, slightly smaller than a quarter acre. As a result, CDL data may miss small plots that may be portions of larger farms or production areas in close proximity to forests. In addition, some specific crops types identified by Cropscape may not be accurate for what is actually grown in Harvard, however for this inventory no differences in production practices were assumed between different crop types and that each received. Acres of crop types from the Cropscape tool are listed in Table 5.

Table 5 USDA Cropscape Estimate of Harvard Agricultural Areas

Category	Acreage
Corn	81.4
Tobacco	0.2
Oats	1.8
Alfalfa	1.8
Other Hay/Non Alfalfa	918.9
Potatoes	0.2
Misc. Vegs & Fruits	0.7
Herbs	0.2
Sod/Grass Seed	0.9

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Fallow/Idle Cropland	8.5
Grass/Pasture	43.1
Apples	180.1
Blueberries	2

Acres of crops were used to drive estimates of GHGs from fertilizer applications, machinery fuel use, and soil carbon sequestration. The following sections summarize the methods used to estimate the level of GHG generating activity that occurs from agricultural activities and how those activity levels translate to GHGs

Fertilizer Use

Under fertilizer use, the N_2O resulting from natural nitrification and denitrification in soils and waterways as a result of N fertilizer application was accounted for. The basis for fertilizer application rates was from Cornell Extension guidelines and it was assumed that a generic rate of 120 lbs. N / Acre for all row crops (Reiners et al. 2019). Orchards were estimated at 60 lbs. N / Acre. This led to an estimated total activity level of 139,383 lbs. N applied for all of Harvard agriculture. From the WPI study (Cano et al. 2020), it was known that manure from animal husbandry in the community was typically applied to fields locally and that there is a preference among Harvard producers for additions of organic matter as a nitrogen source as well as other benefits. However inorganic forms of nitrogen fertilizer are common across many production methods and it was assumed a 50:50 split between organic and inorganic sources. Using these values with the EPA State Inventory tool yields a result of 100 $MTCO_2e$ of N_2O from fertilizer applications.

Machinery Fuel Use

Many of Harvard's farms are small without significant mechanization. Fuel use from farm equipment was estimated using per-acre diesel consumption figures for various tractor-driven field tasks that may be in place for row crops and hay (Downs and Hansen. 1998). The exact combination of tasks used in Harvard are unknown, but a selection was made that seemed appropriate for row crops and hay production. To be conservative and recognize that multiple hay crops are possible in a year, these values were doubled.

Table 6 Estimated Fuel Use for Tractor Operations

Production Type	Operation	Gal/Acre
Cropland	Field Cultivate	0.6
	Tandem disk - chiseled	0.55

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	Planting	0.5
	Anhydrous Application	0.6
	Total	2.25
	Value Doubled	**4.5**
Hay	Mower	0.35
	Rake	0.25
	Baler	0.45
	Stack Wagon	0.5
	Total	1.55
	Value Doubled	**3.1**

In addition, one WPI study respondent, believed to represent one of the larger farms with significant mechanization reported approximately $20,000 in annual fuel use. This value was converted to gallons using the average price of diesel fuel and combined with per /acre estimates above to result in an estimated 12,191 gallons of diesel used for agricultural equipment across the community resulted in 125 $MTCO_2e$

Emissions from Livestock

Animal husbandry for food, fiber, and recreation is also common in Harvard, however a complete count of animals within the community was unavailable at the time of this inventory. While animals are an important part of Harvard's agricultural landscape there is no indication that any individual farm has the number of animals where emissions would be significant. In addition, the emissions for a single animal are generally small as compared to other sources of GHGs. Given these conditions an approach was taken to estimate the ceiling of what emissions from animals might account for in Harvard. For this portion of the inventory, animal related GHGs from enteric fermentation and manure were estimated using approximate populations from the Spring 2020 WPI study (Cano et al. 2020). While these are likely not comprehensive they do provide a reasonable estimate, especially for the number of pigs which is by far the largest potential source of GHGs on a per-animal basis. Table 7 displays estimated GHGs for each of the broad animal type that exists in Harvard. Emissions were calculated using the US EPA State Inventory Tool for enteric fermentation and emissions from manure management.

Table 7 Estimated Animal Populations and Resulting GHGs

Animal Type	**Number of Animals**	**Enteric Fermentation CH_4**	**Manure CH_4**	**Manure N_2O**	**Total $MTCO_2e$**
Chickens	100	0.00	0.00	0.43	0.43

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Goats	20	2.50	0.00	0.00	2.50
Pigs	3	0.11	51.53	0.01	51.64
Horses	30	13.50	0.00	0.00	13.50
Alpacas	20	4.33	1.07	0.68	6.08
Cows	20	32.85	173.05	10.55	216.45
Total	193	53	226	12	290.60

Most of these emissions associated with livestock are difficult to control with management techniques. A certain amount of enteric fermentation comes with each animal and this analysis assumes that manure is managed by field application, which is on the low end of potential GHG sources, the one exception is for pigs, which is believed to use a lagoon system for stabilizing manure. Lagoon treatment is a source of methane which is why this source is significantly higher than other animal types but is also most practical for the nature pig manure relative to other animal types. At larger scales, methane capture could reduce these emissions and provide a clean energy source, which may be worth considering as animal production evolves in Harvard.

Land Use and Sequestration

GHG inventories can account for both additions of GHGs to the atmosphere as well as subtractions from it, often called ‘sequestration’. Sequestration is a fairly recent addition to community scale accounting and has some unique aspects relative to the other activities included in the inventory. Unlike energy use and transportation where GHGs only go in one direction (release); land and forests may be taking it in (sequestration) or holding it indefinitely (storage). To keep track of those changes there is the concept of “carbon pools”. Carbon pools are simply a way to note where sequestered carbon is stored. Tree biomass is one pool, that could be split into above ground (trunk and branches) and below ground (roots) portions. Soil carbon distributed through soil organic matter is another pool. The litter layer of leaves, sticks, and down trees on a forest floor is another type of pool. If a GHG inventory is analogous to an annual budget, carbon pools are the bank accounts.

In an ideal accounting of sequestration and other land use emissions, specific measurements of soil carbon, tree stand ages and health, sampling of the litter layer would all contribute to the understanding of the rates of carbon sequestration and release across the pools. Future studies on the potential of specific actions related to sustainable forestry, generation of carbon credits or some form certification of managing land for maximizing sequestration will need likely require these kind of field measurements, however they were beyond the scope of this inventory.

For this inventory default rates of carbon storage and annual sequestration were obtained from the State of Massachusetts GHG inventory calculations, which were performed using the US EPA State Inventory Tool. This tool provided rates of above and below ground carbon stock and annual sequestration for forested land. These rates were selected not only for their consistency with the State of Massachusetts inventory, but also that they provided a single, consistent source of data for the two largest carbon pools.

Sequestration and standing carbon rates were applied to the area of tree cover to obtain results for the study. For this part of the analysis the source of data for land cover was switched from Cropscape to the

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2016 Land Use / Land Cover GIS data layer from MassGIS. This source was selected for this category since it provided higher resolution of tree cover but also due to the fact that it is more readily combinable with addition GIS layers regarding protected open space, Chapter 61 & 61-A properties and other conservation related data available from the State. Overall, the differences in total tree cover between Cropscape and MassGIS is 779 acres.

While MassGIS layers have distinction between deciduous and evergreen trees as well as forested wetlands, the standing carbon and sequestration rates from the EPA State Inventory Tool did not contain this level of detail and all forest types were assigned consistent rates. Results of the analysis are summarized below.

It should be noted that for land use GHG accounting were developed for analyses done by states and nations. At that scale, significant releases from the carbon pools are accounted for only when the land use is converted from one land use type to another, such as from forest to agriculture or forest to development. Periodic disturbances even from harvesting are not typically counted as release of GHGs as long as the land is still considered forest and is allowed to regrow. Sequestration rates such as those developed from the USDA Forest Service Forest Inventory Analysis are intended to be applied as a scale where specific disturbances may not be detectable, and the factors have incorporated some amount of disturbance into the factors used in this analysis. Entirely missing from this analysis are releases of GHGs from trees lost in calendar year 2018 or other recent years. This is partially a limitation of the Mass GIS data source as it only covers a single snapshot in time. As the Town of Harvard continues to leverage its land resources for carbon capture, keeping track of local changes to tree cover, such as through the Environmental Assessment Form may be a more reliable and accurate way to track changes from 2016 as the update schedule for that data source is unknown.

Due to the data limitations described above, this analysis provides little information on the potential of different management techniques that could improve rates of sequestration but only the impact of land conversion. Future studies with field surveys of existing carbon pools in Harvard forest land could better inform more specific activities within forests.

In total annual sequestration from above and below ground tree biomass in Harvard is estimated at 42,895 $MTCO_2$ per year, a substantial figure relative to the sources of GHGs in the community. In addition, the carbon stored is estimated at 4,057,930 $MTCO_2$.

Division of forest land in Harvard among different land preservation states is a helpful way to consider what portion of the carbon held in forests is at risk and where the greatest potential for additional protection and guaranteed long term savings will come from. The values below were derived from a combination of the 2016 Land Use Land Cover Layer with the MassGIS Preserved Open Space layer as well as the Town of Harvard Chapter 61 and 61-A GIS layer developed through the spring 2020 WPI study.

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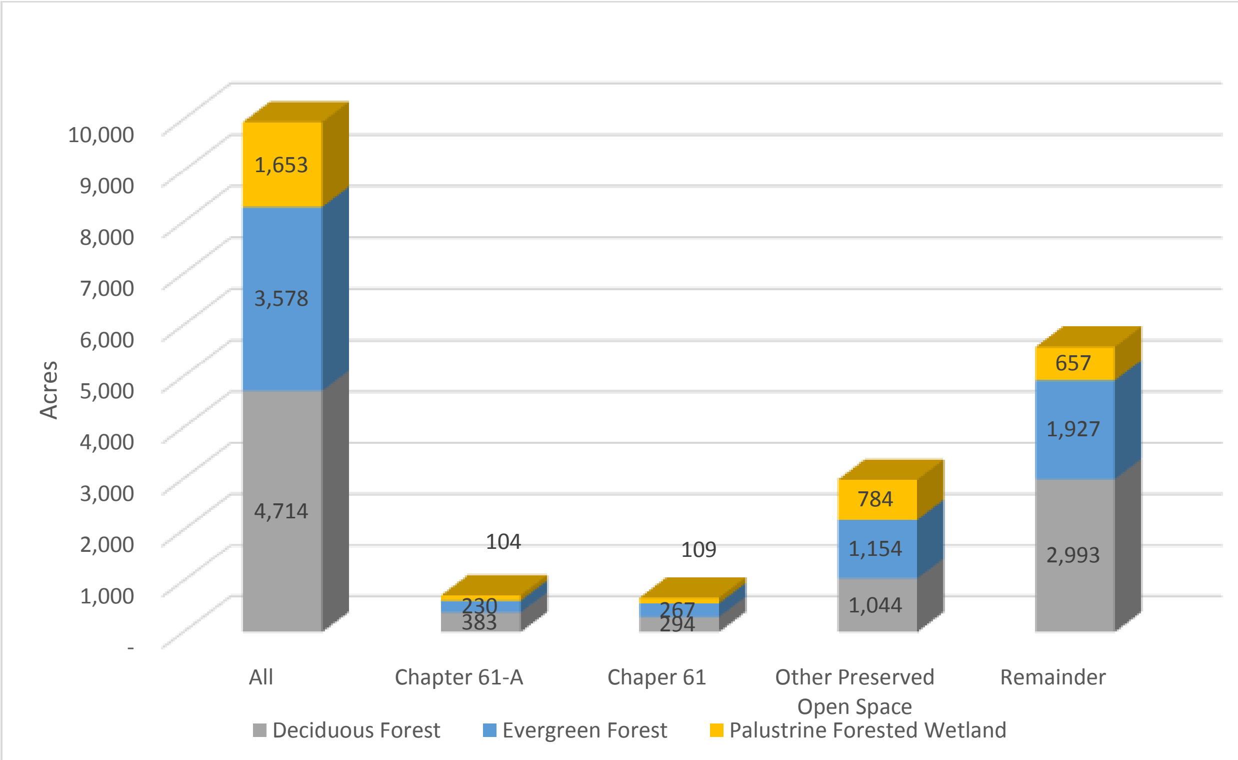
Figure 6 Tree Cover by Conservation Status



A few points about the distribution of forest cover is notable. Approximately 50% of all tree cover is part of protected open space or Chapter 61 property. An interesting result of the overall greater quantity of land in 61-A as oppose to 61 is that there nearly the same level of tree cover that is on a property that is primarily agriculture in use rather than forestry.

Sequestration in Agricultural Soils

It is known that a significant number of farms in Harvard use organic and regenerative practices on their fields. This includes additions of organic matter for fertilizer, reduced tillage and other actions that lead to improved soil carbon storage. However, details on the extent of these methods across all farms are not readily available. For the estimation of carbon in agricultural soils, acres by crop type from USDA Cropscape were combined with annual sequestration rates from Morgan, et al. 2010 in the Journal of Soil and Water Conservation. This document provided high and low values for different classes of agricultural production and in the absence of specific methods an average value was applied as appropriate for different production types in Harvard.

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Table 8 Soil Carbon Sequestration Estimates

		Mg C / ha / year	$MTCO_2e$ / ac / year	Average / Applied value	Cropscape Classes applied to	Acres in Class	Total $MTCO_2e$/year
Cropping Systems	Low	0.1	0.15	0.82	All Row Crops	1007	822
	High	1	1.48				
Rangeland	Low	.07	0.1	0.27	"Fallow" Idle	8.5	2.3
	High	.3	0.45				
Grazing lands - Pastures	Low	0.3	0.45	1.26	Grass / Pasture	43.31	54
	High	1.4	2.08				
Turfgrass	Low	0.32	0.47	0.98	Sod / Grass Seed	0.9	0.8
	High	1.00	1.48				
Cropping Systems	Low	0.1	0.15	1.48	Orchards	180	266
	High	1	1.48				
						Total	1,146

Appropriate default values for sequestration specific to orchard soils were not readily available. From the WPI study it is known that some orchards in Harvard leave woody litter and around trees and certainly soil disturbance in orchards is low both of which will contribute to higher sequestration rates. Thus, for orchards the high end of annual sequestration range was applied.

Supporting more soil carbon sequestration is a relatively unique action that Harvard and its producer community can wield to reduce atmospheric carbon. Perhaps one of the biggest limitations to this is the scale of the land area where it can be applied within Harvard.

Default published values for existing carbon stored within soils was not located in the course of this study and may be due to the fact that while sequestration rates are generalizable in response to different management practices, existing carbon in soils will be highly dependent on site specific conditions and management history which will be highly variable from place to place. Existing soil surveys from individual landowners likely hold a great deal of information about the levels of organic carbon across different farms in the community and future studies may be able to tap into that knowledge source from within the community.

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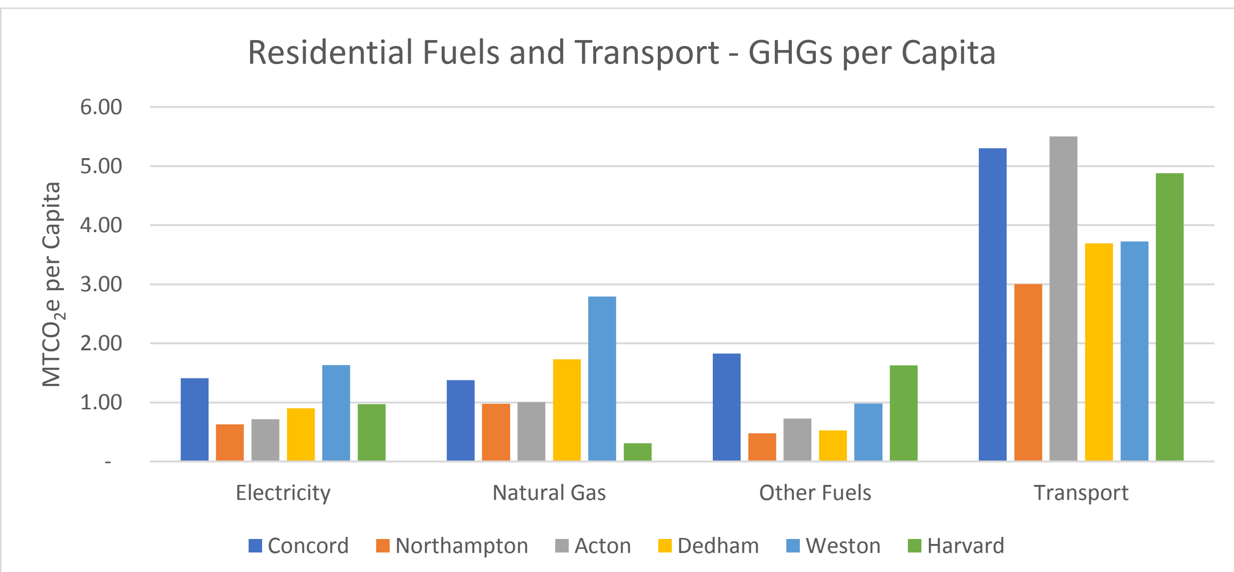
Conclusion

Harvard's contribution to climate change reflects the makeup of the community. The town has a relatively small footprint from municipal services, with little public lighting and limited water and wastewater services to the community. Schools and the library are among the largest consumers of energy due to their size.

Residential activities dominate the sources of GHGs from the community from residential energy use and transportation. Reducing energy and GHGs from these sources will require action on the part of residents to improve the efficiency of their homes and electrify their heating systems with heat pump technologies. Reducing transportation miles from carpooling, regional transit, or more efficient trip planning would have a substantial impact on total GHGs, as would transitioning to electric vehicles.

One way to judge overall performance is to look at a subset of sectors from other communities that can be consistently compared. Figure 7 summarizes per-capita GHGs from several other communities with inventories performed by KLA using comparable methods. By limiting the analysis to only residential energy use, we avoid making comparisons among very different commercial profiles of each community and by illustrating GHGs in per-capita terms, we can control for the population differences among the communities. Harvard tends to fall in the middle of the pack for several of these metrics and transportation emissions are lower per capita than Acton which is more comparable in terms of density and distance to Boston. One visible difference among these is the relatively small natural gas, but higher fuel oil and propane use which reflects the mix of fuels used more so than the efficiency of homes using them.

Figure 7 Residential-Related GHG Peer Comparison



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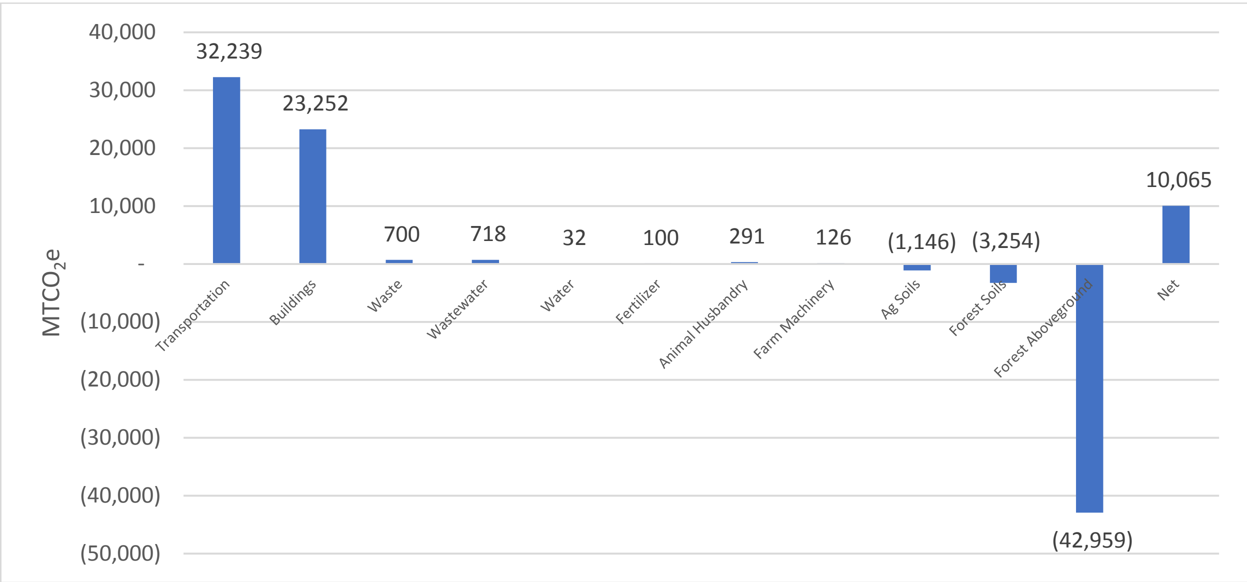
The contribution of agricultural activities to Harvard's GHG inventory is small relative to the energy used in homes or the miles driven by residents. As the predominant commercial activity for the town, this small contribution of GHGs from commercial activity highlights the how a community rooted in agriculture is more climate friendly than many services driven communities which create GHGs from energy intensive buildings and transportation demand.

Figure 8 Harvard 2018 GHGs



This 2018 inventory was performed for a calendar year prior to the town joining the Colonial Power CCA, which allows the town to claim carbon free electricity for participating customers. Future inventories that incorporate this new power supply arrangement can illustrate how it will offset nearly all of the 8,408 $MTCO_2e$ from electricity use within the town. Coupled with the annual sequestration benefit provided by the Town's tree cover, Harvard only needs to reduce GHGs by another 1,657 $MTCO_2e$ from waste, transportation, and heating fuel use to be able to claim net carbon neutrality.

While carbon neutrality would be a laudable achievement it also should not be a cap on the ambition of the community for further reductions that would allow Harvard to claim to be a regenerative community, that is consistently climate positive. To do that, continued reductions from the existing sources of GHGs, be they from building energy, transportation, and waste are needed, but it could provide a compelling narrative for Harvard's identity as an agricultural community with significant land preservation resources. Further, it should be recognized that while the Colonial Power CCA allows the claim of carbon free electricity, the town is still connected to the physical electric grid and the power consumption choices that residents make will continue to have carbon consequences and the need for local efficiency and distributed renewable energy resources remain.

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While sequestration is powerful force for reducing GHGs in Harvard, the values assigned to it here need be further refined before attempting to make a claim of carbon neutrality. At the very least, an assessment of the impact of tree loss on an annualized basis should be included to see the balance of GHGs from living biomass in the community. On a per acre basis, the release of GHGs from development would create a significant increase in emissions of 403 $MTCO_2$ that would need to be overcome but also would permanently reduce the rate at which tree cover in Harvard sequesters carbon by 4.26 $MTCO_2$ per year. In addition, the impact of periodic harvest for working forests should be accounted for in the sequestration and standing carbon rates applied to areas managed in that way.

There are opportunities for improved farm practices to have a positive impact on GHGs by putting more carbon into local productive soils and integrating forests with agricultural production. These benefits are real, but there are limits on the scale they can reach within the acres of land in production within the town. On the other hand, there are many options for Harvard to reduce its contributions to climate change from energy consumption. Space and water heating with fossil fuels is a significant source that can be addressed through efficiency and electrification of those building systems. Transportation emissions are the single highest source in the community, underscoring the need to find ways of connecting residents to alternative forms of commuting rather than single occupancy travel. As a tourist destination the Town can also consider ways of reducing the impact of people traveling to Harvard and how they get around from farm to farm while they are here.

A greenhouse gas inventory is a backward-looking tool to assess how a community like Harvard creates GHGs in its current form. Harvard's ability to reduce those emissions will be determined by both how it acts to address current sources, but also how the community grows in the future.

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