Technical Appendix: Mid-Hudson Municipal Landfill Emissions Mitigation Project

GHG Reduction Estimate Method: The EPA's Landfill Gas Emissions Model (LandGEM) is used to estimate emission rates for total landfill gas, methane, carbon dioxide, nonmethane organic compounds, and individual air pollutants from municipal solid waste (MSW) landfills. LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills.[1] This tool can use site-specific data to estimate emissions, or it can use default parameters if no site-specific data are available.

Air emissions from landfills come from landfill gas generated by the decomposition of waste in the landfill. Landfill gas is assumed by this model to be roughly half methane and half carbon dioxide with additional, relatively low, concentrations of other air pollutants.[2]

HVRC utilized the LandGEM tool to calculate methane emissions rates (metric tons) and total waste in place (tons) for the years the landfill was in operation. This data was inputted into ICLEI's ClearPath Tool to calculate total emissions in metric tons of carbon dioxide equivalent (MTCO2e) for each landfill.

ClearPath is an online application for the calculation, tracking and management of greenhouse gas emissions at the government operations and community scales. ClearPath was designed, built, and is maintained by ICLEI, a non-profit organization supporting a national consortium of local governments. [3] ClearPath allows users to create GHG inventories consistent with the Local Government Operations Protocol, the US Community Protocol, and major governmental reporting requirements.

The California Air Resources Board's (CARB) Landfill Emissions Tool was run to confirm this methodology.[4] The CARB Landfill Emissions Tool is recommended in the EPA's Local Government GHG Inventory Tool to calculate emissions from landfills that do not have active landfill gas collection systems.[5] This tool is also based on a first-order decay model and requires annual waste deposited in landfill (derived from population and waste disposal estimates) and the opening and closing year of the landfill. NY State-specific solid waste discard composition data was used to find the fractions of waste types which contain anaerobically degradable carbon (ANDOC). The new % ANDOC value was entered into the "Landfill Model Inputs" tab to replace the default numbers. The CARB Tool produces methane and carbon dioxide emissions in MTCO2e, however does not model future emissions. Results from the CARB Tool were within 1% of the results from ClearPath. The emissions were slightly higher than the estimate produced by LandGEM and Clearpath. Therefore, the conservative method of using both LandGEM and ClearPath was used to calculate emissions.

[1] EPA, 2024. Landfill Gas Emissions Model (LandGEM)
[2] Ibid.
[3] ICLEI, 2024. ClearPath.
[4] California Air Resources Board. Landfill Emissions Tool.
[5] EPA, 2024. Local Government GHG Inventory Tool.

Table 1: Global Warming Potential Values

Greenhouse Gas	Global Warming Potential
Carbon Dioxide	1
Methane	28
Nitrous Oxide	265

The Global Warming Potential values used are from the 2013 IPCC AR5 Fifth Assessment Report.[6]

Models/Tools Used: EPA's LandGEM is a macro-enabled Microsoft Excel file (.xlsm) that utilizes visual basic for applications (VBA) processes to function. It has been tested on systems running Microsoft Office 2007 and more recent versions. The current version, LandGEM, Version 3.03, was released in 2020. This version fixed a minor error in the weighting and calculation of carbon dioxide masses in landfill gas. Methane and other pollutants volumes/masses were not affected.[7]

Measure Implementation Assumptions: The literature shows that biofilters can remove methane from closed landfills at a rate of up to 90%.[8] Methane uptake rates can be affected by moisture content, temperature, and soil properties. [9] Studies have shown that high oxidation capacity is associated with coarse, porous and soil rich in organic matter and has increased with more moisture. [10] The most effective media are wood chips, bark mulch and compost.[11]

Methane monitoring will be done monthly for the first two years after the biofilters have been installed. After two years, methane monitoring will be done quarterly. There are no operation costs. Biofilter media may need to be added at the five-year point, or sooner dependent on external factors.

GHG Reduction Estimate Assumptions: LandGEM calculations are based on yearly waste acceptance rates. This data was not readily available; therefore, yearly waste acceptance rates were estimated using 5.15 pounds of waste per person per day for landfills that only accepted municipal solid waste (MSW).[12] For landfills that accepted a combination of MSW, commercial and/or industrial waste, the estimate was decreased to 4.6 pounds of waste per person per day. This number was determined by reducing 5.15 by 10% to account for commercial and industrial waste that produces less methane emissions. [13] Population estimates for each municipality were based on historical US Census data as reported in 10-year intervals for the years each landfill was open.

Yearly Waste Acceptance rate = 5.15 lb./person x Est. Population x 365 days/yr. x 1Mg/2204.63 lb.

[6] IPCC Fifth Assessment Report (AR5). Global Warming Potential Values.
[7] EPA, 2024. Landfill Gas Emissions Model (LandGEM).
[8] Duan et al., 2021; Gebert & Grongroft, 2005; Haubrichs & Widmann, 2006; Huber-Humer et al., 2008; Pecorini et al., 2020.
[9] Ibid.
[10] Haubrichs & Widmann, 2006; Pecorini et al., 2020.
[11] Huber-Humer et al., 2008.
[12] NYSDEC, 2010. Beyond Waste: A Sustainable Materials Management Strategy for New York State.
[13] EPA, 2024. Basic Information about Landfill Gas.

Table 2. Inputs for LandGEM, Baseline Year 2019

Landfill	Lbs./person /day	lbs./person /year	Population[14]	Tons of waste/Year	Total Waste in Place (Tons)	Methane (metric tons)	Total Landfill Emissions (MTCO2e)
Amenia Town Landfill	5.15	1,879.75	7,433	6,340	234,589	68	2,242
Town of Bethel Landfill	4.6	1,679	2,450	1,866	76,501	25	700
Beacon City Landfill	4.6	1,679	13,110	9,984	369,421	73	2,044
Cornwall Town Landfill	5.15	1,879.75	6,857	5,847	239,709	68	1,904
Dutchess County Landfill	4.6	1,679	95,904	73,039	365,194	167	4,676
Town of Gardiner Landfill	4.6	1,679	2,675	2,037	83,527	53	1,484
Town of Hurley Landfill	5.15	1,879.75	6,189	5,277	237,465	136	3,808
Mamaroneck Taylor's Lane	4.6	1,679	16,345	12,448	261,408	76	2,128
New Paltz Landfill	5.15	1,879.75	5,176[15]	4,413	136,811	132	3,696
North East Town Landfill	5.15	1,879.75	2,842	2,423	65,427	44	1,232
Philipstown Landfill	5.15	1,879.75	8,705	7,422	230,090	222	6,216
Rhinebeck Town Landfill	5.15	1,879.75	6,223	5,306	158,596	112	3,136
Wallkill Town Landfill	4.6	1,679	18,338	13,966	418,977	338	9,464
Woodstock Town Landfill	5.15	1,879.75	6,276	5,351	165,886	138	3,864

[14] US Census. Historical Population Data.

[15] Population totals for the Town of New Paltz only, not including Village of New Paltz population.

Table 3. Historic Landfill Data

Landfill	Size (acres)	Waste Type accepted	Year Opened	Year Closed
Amenia Town Landfill	10	MSW, C&D; Hazardous waste detected	1940	1976
Town of Bethel Landfill	15	MSW, C&D, industrial	1940	1980
Beacon City Landfill	10	MSW, C&D, industrial	1930	1968
Cornwall Town Landfill	5	MSW	1937	1977
Dutchess County Landfill	30	MSW, industrial	1968	1972
Town of Gardiner Landfill	8	MSW, C&D, industrial	1953	1993
Town of Hurley Landfill	13	MSW	1960	1994
Mamaroneck Taylor's Lane	7.85	MSW, industrial; Hazardous waste detected	16,345	12,448
New Paltz Landfill	13	MSW	1968	1998
North East Town Landfill	15	MSW, industrial; Hazardous waste detected	1963	1989
Philipstown Landfill	13.4	MSW	1968	1998
Rhinebeck Town Landfill	10	MSW	1961	1991
Wallkill Town Landfill	68	MSW, C&D; Hazardous waste detected	1965	1994
Woodstock Town Landfill	18.5	MSW	1965	1994

MSW – Municipal Solid Waste; C&D – Construction & Demolition

The tables and figure below are examples of results from one landfill. The accompanying spreadsheet has this information for all landfills.

Table 4. LandGEM Estimated Waste Acceptance Rates

Tons of waste per year was calculated from population pounds of waste generated per person per day. This is input into LandGEM during the years each landfill was in operation.

Year	input units *(short tons/year)*	Calculated Units *(Mg/year)*
1950	12,448	11,316
1951	12,448	11,316
1952	12,448	11,316
1953	12,448	11,316
1954	12,448	11,316
1955	12,448	11,316
1956	12,448	11,316
1957	12,448	11,316
1958	12,448	11,316
1959	12,448	11,316
1960	12,448	11,316
1961	12,448	11,316
1962	12,448	11,316
1963	12,448	11,316
1964	12,448	11,316
1965	12,448	11,316
1966	12,448	11,316
1967	12,448	11,316
1968	12,448	11,316
1969	12,448	11,316
1970	12,448	11,316

Table 5. ClearPath Solid Waste Inputs and Outputs

Total waste in place and methane results from LandGEM is input into ClearPath to calculate total waste emissions in MTCO2e.

Inputs

	Value	Units
CH4	76	Metric Tons
Waste in Place	261408	Tons

Outputs

Name	Value
Waste in Place (Tons)	261408
CO2e (MT)	2128
Scope	Scope 1

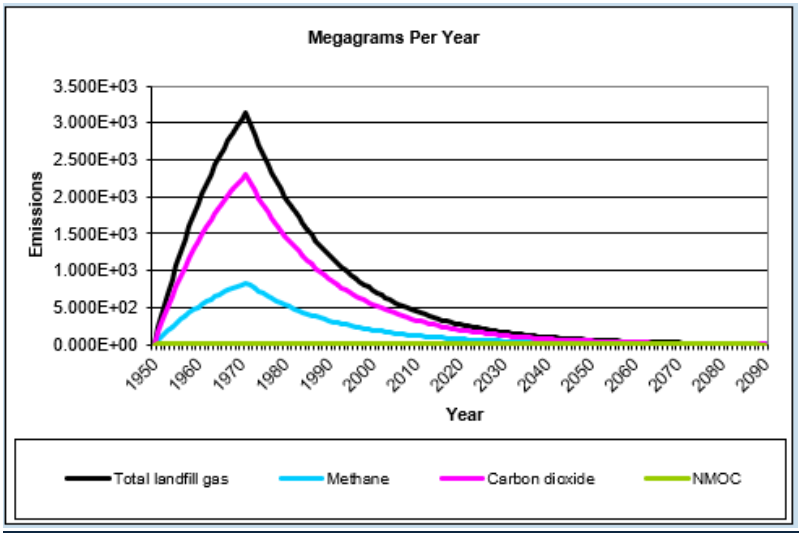
Table 6. LandGEM Inventory Results Report

LandGEM generates an inventory results report for each landfill.

Gas / Pollutant	Emission Rate				
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(ft^3/year)*	*(short tons/year)*
Total landfill gas	2.841E+02	2.275E+05	1.528E+01	8.033E+06	3.125E+02
Methane	7.588E+01	1.137E+05	7.642E+00	4.017E+06	8.347E+01
Carbon dioxide	2.082E+02	1.137E+05	7.642E+00	4.017E+06	2.290E+02
NMOC	4.892E-01	1.365E+02	9.170E-03	4.820E+03	5.381E-01
1,1,1-Trichloroethane (methyl chloroform) - HAP	6.059E-04	1.092E-01	7.336E-06	3.856E+00	6.664E-04
1,1,2,2-Tetrachloroethane - HAP/VOC	1.747E-03	2.502E-01	1.681E-05	8.836E+00	1.922E-03
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	2.247E-03	5.459E-01	3.668E-05	1.928E+01	2.472E-03
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	1.834E-04	4.549E-02	3.057E-06	1.607E+00	2.018E-04
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	3.839E-04	9.326E-02	6.266E-06	3.294E+00	4.223E-04
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	1.924E-04	4.094E-02	2.751E-06	1.446E+00	2.117E-04
2-Propanol (isopropyl alcohol) - VOC	2.844E-02	1.137E+01	7.642E-04	4.017E+02	3.128E-02
Acetone	3.846E-03	1.592E+00	1.070E-04	5.623E+01	4.231E-03
Acrylonitrile - HAP/VOC	3.163E-03	1.433E+00	9.629E-05	5.061E+01	3.479E-03
Benzene - No or Unknown Co-disposal - HAP/VOC	1.404E-03	4.322E-01	2.904E-05	1.526E+01	1.545E-03
Benzene - Co-disposal - HAP/VOC	8.129E-03	2.502E+00	1.681E-04	8.836E+01	8.942E-03
Bromodichloromethane - VOC	4.805E-03	7.051E-01	4.738E-05	2.490E+01	5.285E-03
Butane - VOC	2.749E-03	1.137E+00	7.642E-05	4.017E+01	3.024E-03
Carbon disulfide - HAP/VOC	4.178E-04	1.319E-01	8.864E-06	4.659E+00	4.595E-04
Carbon monoxide	3.710E-02	3.185E+01	2.140E-03	1.125E+03	4.081E-02
Carbon tetrachloride - HAP/VOC	5.822E-06	9.099E-04	6.113E-08	3.213E-02	6.404E-06

Figure 1. Projected Landfill Emissions Per Year

This is one example of the figures generated by LandGEM showing exponential decay of total landfill gas, methane, carbon dioxide and nonmethane organic compounds (NMOC).



Reference Case Scenario (GHG Emissions or Activity Level): The reference scenario used to quantify GHG emissions reductions for biofilters is the modeled estimated methane emissions from the EPA's LandGEM tool. This reference scenario will be updated upon award of the grant with actual monitored methane emissions data for each vent at each landfill. This will ensure the biofilters are placed where the methane is being emitted, to reduce emissions most efficiently.

Table 7. Projected Landfill Emissions without Reduction Measure, Mamaroneck Taylor's Lane Site

Year	CH4	MTCO2e
2025	56	1,568
2026	53	1,484
2027	51	1,428
2028	48	1,344
2029	46	1,288
2030	44	1,232
2025-2030	**299**	**8,344**
2031	42	1,176
2032	40	1,120
2033	38	1,064
2034	36	1,008
2035	34	952
2036	32	896
2037	31	868
2038	29	812
2039	28	784
2040	27	756

2041	25	700
2042	24	672
2043	23	644
2044	22	616
2045	21	588
2046	20	560
2047	19	532
2048	18	504
2049	17	476
2050	16	448
2025-2050	**838**	**23,520**

Measure-Specific Activity Data: The data used to estimate GHG emission reductions for biofilters on closed landfills include modeled emissions from the EPA's LandGEM tool based on several assumptions as well as historical data. The actual emissions from each methane vent at each landfill will be monitored monthly to ensure we have accurate data before starting the project. This data will be used to decide on the number of biofilters installed. The cost estimates for biofilter design and construction are based on one small landfill that is similar to most of the others.

GHG Emissions Reduced: GHG emission reduction estimates for each landfill are in the attached spreadsheet and cumulative emissions are included in the Workplan narrative. An example of emission reductions for one landfill is seen in the table below.

Table 8: Projected Landfill Emissions after Implementation of Biofilters, Mamaroneck Taylor's Lane Site

This projection accounts for a 90% methane removal rate as a result of biofilter installation.

Year	CH4	MTCO2e
2025	6	157
2026	5	148
2027	5	143
2028	5	134
2029	5	129
2030	4	123
2025-2030	**30**	**834**
2031	4	118
2032	4	112
2033	4	106
2034	4	101
2035	3	95
2036	3	90
2037	3	87
2038	3	81
2039	3	78
2040	3	76
2041	3	70

2042	2	67
2043	2	64
2044	2	62
2045	2	59
2046	2	56
2047	2	53
2048	2	50
2049	2	48
2050	2	45
2025-2050	**84**	**2,352**