Methane Emissions from Disposal of Polyester in U.S. Landfills

A&WMA's 115th Annual Conference & Exhibition

June 27 – June 30, 2022

Paper # 1174501

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Abstract: Solid waste management (SWM) is an exigent and pressing problem for many cities. Globally landfills/open dumpsites are used to dispose of over 80% solid wastes, currently serving around 3.5-4 billion people. This number is expected to grow with increased urbanization and population growth (ISWA, 2015).

Methane generation, recovery, and emissions projections for biodegradable polyester fiber that will be used to create clothing products, which will eventually be disposed in municipal solid waste (MSW) landfills in the U.S. The scope of work described in this research project includes providing the methane estimates that discusses the data, assumptions, and calculation methods used to develop the estimates. Methane emissions estimates to help assess the potential impacts that producing new consumer products made with biodegradable polyester will have on greenhouse gas (GHG) emissions. As some U.S. states move towards requiring extended producer responsibility (EPR) for the packaging industry to address its waste management impacts, the analysis for the project commend firms for taking steps to pro-actively find a waste management solution for textiles, which may be the next target for Extended Producers Responsibility (EPR) legislation.

Objective 1 – Develop Estimates of Methane Generation from Disposed Polyester.

Objective 2 – Prepare Estimates of Methane Recovery Rates and Emissions Reduction from Utilization.

Objective 3 – Estimate Annual Net Methane Emissions for 100 Years.

The results are in the preliminary stage based on the assumptions for the methane generation potential and decay rates for the textiles. Indirect emissions reductions, avoided emissions from replacing the fossil fuel and utilizing the methane to generate electricity will be analyzed.

Thus, diverting waste going to the landfills helps in reducing the overall environmental impact by degradation of biodegradable polyester.

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Current scenario:

- The methane emissions estimates to help assess the potential impacts that producing new consumer products made with biodegradable polyester will have on greenhouse gas (GHG) emissions.
- Some U.S. states move towards requiring extended producer responsibility (EPR)
- Emissions estimation along with, collection system design, LFG utilization project due diligence and feasibility assessments play a vital role in biodegradation of polyester.

IPCC – the only methodology used to determine methane emissions from landfill.

Shortcomings and Limitations:

- US-based emissions can not be determined using the existing decay rate and methane generation potential values.
- Targets overall Municipal solid waste in the bulk waste only
- Does not help to understand the textile industry emissions

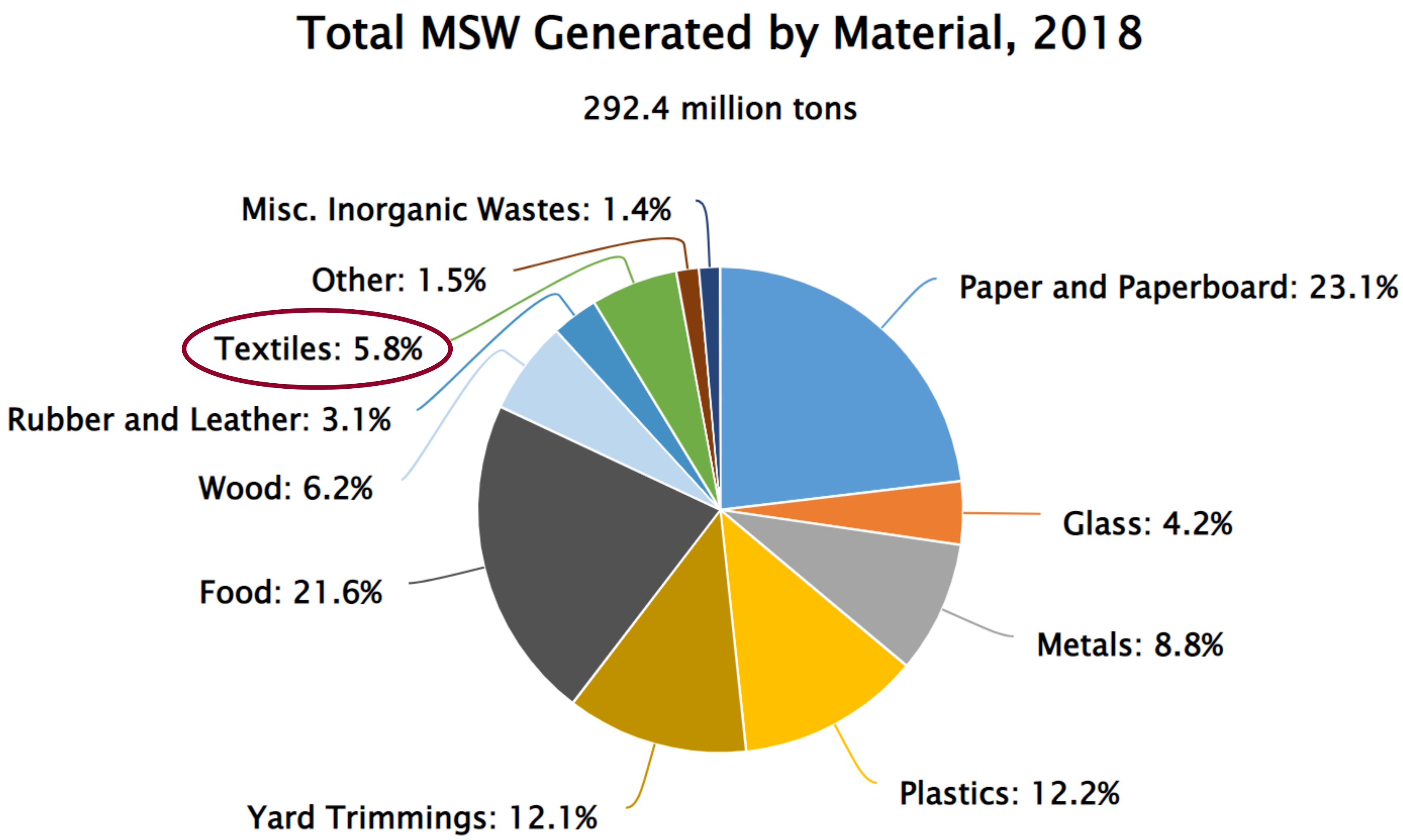
Goals & Objectives

Goal:

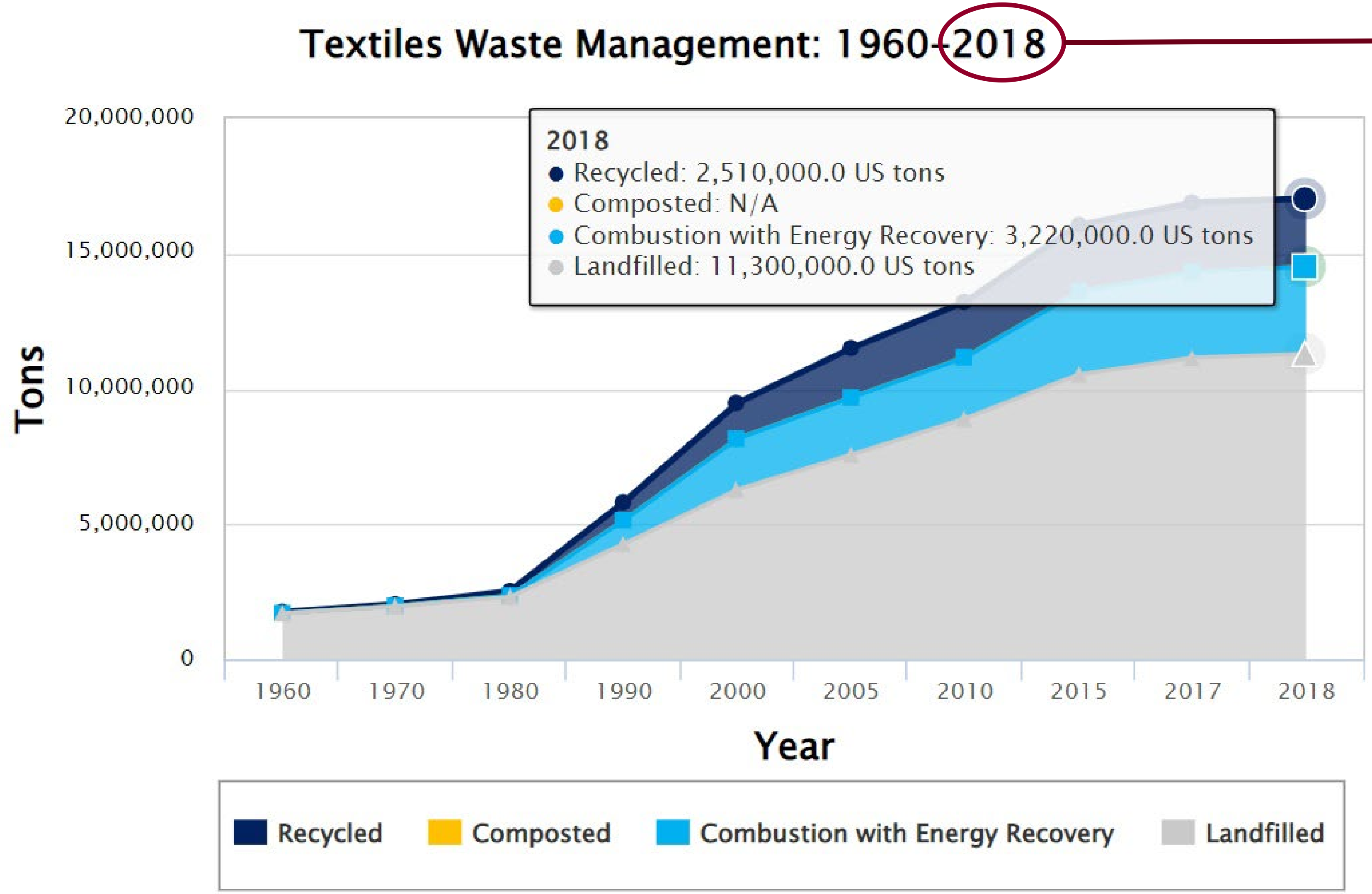
- To develop an estimation of Methane Emissions from Disposal of Polyester in U.S. Landfills

Objectives:

- Task 1 – Develop Estimates of Methane Generation from Disposed Polyester case study
- Task 2 – Prepare Estimates of Methane Recovery Rates and Emissions Reduction from Utilization (energy conversion technologies, Carbon credits, and revenue from it)
- Task 3 – Estimate Annual Net Methane Emissions for 50 years, and its environmental impact.
- Task 4 – Carbon credits, offsets and revenue generation from emission.



Ref: EPA Guide to the Facts and Figures Report about Materials, Waste and Recycling, 2018



Textile total production:
17 Million US tons

66% was landfilled

Case Study

Methods for Task.1:
Develop Estimates of Methane Generation from Disposed Polyester

Estimation methodology:

- 86 million pounds (43,000 tons) of polyester produced and used in the manufacture of clothing
- 87 percent disposed in landfill, (37,410 tons) per year.

Assumptions:

- Estimated disposal rate continues for 50 years with an annual growth rate.
- The estimated growth rate should reflect expected growth in product delivery to markets minus projected improvements in textiles recycling.
- An estimation of annual methane generation rates from disposed polyester covering a 50-year forecast period.

Methane utilization

A portion of methane collected from U.S. landfills is used

- To generate electricity in LFG-to-energy (LFGE) facilities,
- To direct methane at the industrial facilities as fuel, or
- To produce renewable natural gas (RNG).

Avoided Emissions:

- The beneficial use of landfill methane produces net emissions reduction by displacing fossil fuel use.
- The amount of emissions reduction accrued depends on the amounts of methane used in each of use category (electricity generation, direct use, or RNG) and the “carbon intensity” of the renewable fuels vs. fossil fuels being displaced.

Task 2 – Prepare Estimates of Methane Recovery Rates and Emissions Reduction from Utilization

- Estimates of annual methane recovery rates: Applying estimated collection efficiency (C.E.)
- The LFG C.E. based on the regulatory default value of 75 % at U.S. landfills with LFG collection systems.
- Varying site conditions (e.g. wet vs. dry climates) considered.

- Data extraction from the EPA's Landfill Methane Outreach program (LMOP) LFG database, and use information in other publications by the EPA and Environmental Research and Education Foundation to estimate the following:
  - Fraction of annual disposed to total MSW generated in the U.S. landfills.
  - Fraction of MSW landfills that capture LFG.
  - Weighted fraction of landfills in the U.S. that have LFG capture, based on annual disposal rates at active landfills.

Task 3 – Estimate Annual Net Methane Emissions for 50 Years

Annual net methane emissions from the disposal of polyester in U.S. landfills for a 50-year forecast period will be estimated by combining Tasks 1 and 2 in the following steps:

1. Annual methane generation and recovery rates will be calculated in ft^3/yr as described above in Task 1.

2. The annual amounts of methane collected, combusted in flares, utilized in different types of LFGE facilities to produce net emissions reduction estimated in Task 2 will be applied in the annual emissions calculation.

3. The annual amounts of methane produced from polyester that are uncollected will be reduced by an estimated methane oxidation rate to calculate methane emissions from landfills.

4. Estimated methane emissions (from Steps 1 and 3) will be converted to metric tons per year of methane and then to Carbon-dioxide equivalent (CO_2e) values using a conversion factor of 28. Finally, the emissions reductions from utilization (Step 2) will be-applied to calculate annual net emissions.

Background research

2018, 292.4 million tons Generated and Collected

146.1 million tons was disposed in landfills — 50 %

Recycling, composting, or anaerobic digestion facilities or food waste management programs — 38%

Combusted in waste-to-energy facilities (12%) — 12 %

The projected initial polyester disposal rate of 37,410 tons per year amounts to less than 0.014 percent of the total amount of MSW disposed in 2018.

Ref: U.S. EPA December 2020. Advancing Sustainable Materials Management: 2018 Fact Sheet.

2. Bryan Staley, Environmental Research and Education Foundation. "Recycling State of Practice: Policy, Tonnage & Beyond". Presentation at the Waste360 Recycling Summit, September 11, 2015.

Laboratory Data on Biodegradable Polyester Decay and Methane Production

To calculate annual methane generation rates from the decay of biodegradable polyester in U.S. landfills:

- Waste decay rate (model “k value”) of 0.101/yr.
- Methane production rate of 0.4 pounds of methane per pound of material disposed, based on laboratory measurements.

Model k is equal to the natural logarithm of 2 divided by the half-life (k = ln(2)/half life).

Steps to complete the assignment of appropriate k values for biodegradable polyester in dry, moderately wet, and wet climate landfills were as follows:

1. Assign average k values for MSW disposed in each climate category based on the population-weighted average of k values in each climate region calculated using default k values for each metropolitan region based on precipitation.

2. Convert the k values assigned to MSW to k values for biodegradable polyester assuming a ratio of 3.6 to 1. The resulting biodegradable polyester k values are as follows:
   a. 0.10 per year in dry climate landfills;
   b. 0.23 per year in moderately wet climate landfills; and
   c. 0.36 per year in wet climate landfills.

Average annual precipitation at 35 U.S. cities is based on 1991 – 2020 U.S. Climate Normals available at www.ncei.noaa.gov.

Ultimate Methane Generation Rate (Lo value)

- The methane production rate of 0.24 pounds of methane per pound of polyester measured in the laboratory is 1.5 times the methane yield of food waste (0.16) as a percentage of dry material disposed, according to WARM documentation, while 1.6 times the methane yield from IPCC value for food waste (0.15).

- This methane production rate implies an "ultimate methane generation" rate, or model "Lo" value, of 111 cubic meters per metric ton, which is the amount that will eventually be produced over time at a rate constrained by the decay rate (k value).

- The Lo value is calculated based on the degradable organic content (DOC) of the material and the amount of the DOC that degrades and produces LFG (DOCf), along with conversion factors. The estimated Lo value of 111 cubic meters per metric ton assumes that 17 percent of the material consists of DOC which decomposes and produces methane (DOC x DOCf = 0.17). The DOCf reported by the IPCC for food waste is 0.7 (IPCC, 2019). This DOCf is likely a maximum value achievable only under optimal conditions. If a DOCf of 0.7 for polyester is assumed, a DOC of 0.24 is required to result in an Lo of 111 cubic meters per metric ton.

- Lo=MCF*DOC*DOCf*F*16/12
- CH_4 density = 0.714 kg/m^3

Ref: Intergovernmental Panel on Climate Change, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3 – Solid Waste Disposal.

Annual Methane Generation Rates

Year	Total Methane Generation (tons/year)	Fraction of Methane from Dry Climates (%)	Fraction of Methane from Moderately Wet Climates (%)	Fraction of Methane from Wet Climates (%)
10	15,386	17%	21%	62%
25	20,188	22%	21%	57%
50	26,318	23%	21%	56%
100	43,330	23%	21%	56%

Collection Rates for Methane Generated from Polyester

The LFG collection efficiencies applied vary by climate category and were estimated based on the following considerations:

- The U.S. EPA assigns a regulatory default value of 75 percent to reflect the estimated average or "typical" collection efficiency achieved at U.S. landfills with LFG collection systems.

- The fraction of total waste disposed in active landfills MSW landfills in the U.S. that have LFG capture is 90 percent, according to the U.S. EPA's Landfill Methane Outreach Program (LMOP) Landfill and Project Database ("LMOP Database").

- High waste decay rates experienced in wet climates result in higher methane generation rates in the first years after waste is placed in a landfill before LFG collection occurs.

The LMOP Database is an Excel file available at https://www.epa.gov/lmop/landfill-technical-data.

Oxidation and Emissions of Uncollected Methane

- The default value reported by both the U.S. EPA and IPCC: 10%.
- A literature review of field investigations of oxidation rates based on measurements of methane emissions (SWICS, 2009)[9] different soil cover types:

  Range: 22 % - 55 %

  Average: 35%.

The SWICS study summarizing research on oxidation indicates the following:

- The average oxidation rate at U.S. landfills is likely to be significantly higher than 10 %.
- Oxidation rates are strongly influenced by:

  - cover type
  - thickness and by the
  - flow rate of methane to the cover soils.

- Landfills with high collection efficiencies and very low rates of methane flow to the cover soils have the potential to achieve high oxidation rates approaching 100 %.

40 CFR Part 98 Subpart HH – Municipal Solid Waste Landfills. Available at https://www.epa.gov/ghgreporting/subpart-hh-municipal-solid-waste-landfills.

Emissions Reduction from Methane Utilization and Destruction

- The amount of emissions reduction accrued depends on the amounts of methane used in each of utilization category
  - ✓Electricity generation,
  - ✓Direct use, or
  - ✓RNG
- The "carbon intensity" of the renewable fuels vs. fossil fuels being displaced.

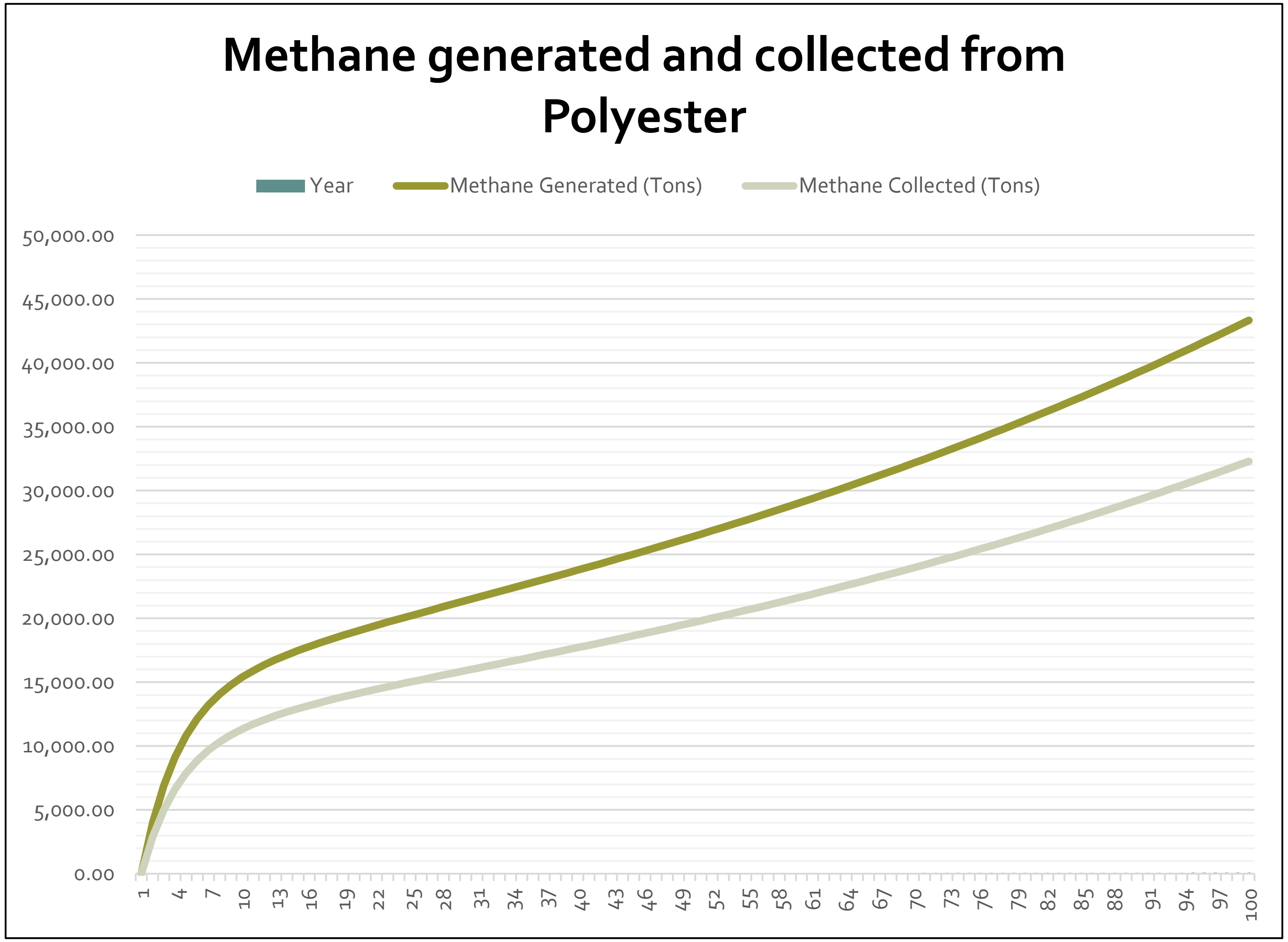
The LMOP Database includes information on annual flow rates of LFG recovered from U.S. landfills combusted in flares and used to fuel different types of methane utilization projects. Using this information. The following percentages for the fate of methane recovered were assigned from U.S. landfills in Year 1 of the emissions forecast:

- 49.8 percent is combusted to generate electricity.
- 14.2 percent is used to produce RNG.
- 4.5 percent is used directly in industrial facilities.
- 31.4 percent is combusted in flares.

- Methane Destruction Efficiency : > 98% in Flares*

*The methane destruction efficiency for flares was estimated to be 99.96 percent based on a SWICS paper summarizing research on methane destruction efficiencies (SWICS, 2007). Solid Waste Industry for Climate Solution (SWICS), 2007. Current MSW Industry Position and State of the Practice on Methane Destruction Efficiency in Flares, Turbines, and Engines. Prepared by SCS Engineers in July 2007.

Estimated annual methane emissions



STUDY RESULTS AND CONCLUSIONS

Year	Total Methane Emissions from Biodegradable Polyester ($CO2_e$ tons/year)	Fraction of 2020 Methane Emissions from MSW Landfills* (%)
10	84,540	0.06%
25	107,564	0.11%
50	139,308	0.15%
100	229,253	0.24%

Methane Emissions from Biodegradable Polyester
*Approximately 94,800,000 tons $CO2_e$

STUDY RESULTS AND CONCLUSIONS CONTI…

Year	Annual Methane Generation	Annual Methane Generation	CO_2 equivalents of Methane (Carbon credits)	Revenue from carbon credit	Equivalent electricity produced	Revenue form electricity
	m^3/yr	scfm	(tCO2e)	($)	(kW)/yr	($)
2021	2.70E+06	1.45E+02	3.61E+04	4.33E+05	8.21E+06	8.21E+05
2030	1.62E+07	8.70E+02	2.17E+05	2.61E+06	4.94E+07	4.94E+06
2040	2.06E+07	1.08E+03	2.76E+05	3.31E+06	6.28E+07	6.28E+06
2050	2.55E+07	1.22E+03	3.41E+05	4.09E+06	7.76E+07	7.76E+06
2060	2.93E+07	1.36E+03	3.93E+05	4.71E+06	8.94E+07	8.94E+06
2070	3.03E+07	2.03E+03	4.05E+05	4.86E+06	9.23E+07	9.23E+06

STUDY RESULTS AND CONCLUSIONS CONTI…

Year	**Avoided emissions benefit**	
	Net avoided Coal emissions	**Net avoided NG emissions**
	(tCO_2)	**(tCO_2)**
2021	3.97E+04	3.55E+04
2030	2.38E+05	2.12E+05
2040	3.04E+05	2.71E+05
2050	3.75E+05	3.35E+05
2060	4.32E+05	3.86E+05
2070	4.46E+05	3.98E+05

Avoided consumption and emissions

	Coal				Natural Gas			
Year	Avoided Coal consumption	Avoided Coal emissions	Avoided SO_2 emissions	Avoided NO emissions	Avoided Natural Gas (NG) consumption	Avoided NG emissions	Avoided SO_2 emissions	Avoided NO emissions
	Kg of Coal for Kwhr/yr generation	Kg CO2 for kWh/y generation	g SO2for kWh/y generation	g NO for kWh/y generation	Mcf of NG for Kwhr/yr generation	Kg CO2 for kWh/y generation	g SO2for kWh/y generation	g NO for kWh/y generation
2021	6.11E+06	7663076	5.87E+07	3.54E+07	6.45E+04	3.43E+06	2.99E+06	2.99E+06
2030	3.66E+07	4.59E+07	3.51E+08	2.12E+08	3.86E+05	2.05E+07	1.79E+07	1.79E+07
2040	4.68E+07	5.87E+07	4.49E+08	2.71E+08	4.94E+05	2.62E+07	2.29E+07	2.29E+07
2050	5.77E+07	7.24E+07	5.54E+08	3.35E+08	6.10E+05	3.24E+07	2.82E+07	2.82E+07
2060	6.65E+07	8.34E+07	6.39E+08	3.86E+08	7.02E+05	3.73E+07	3.25E+07	3.25E+07
2070	6.87E+07	8.61E+07	6.59E+08	3.98E+08	7.25E+05	3.85E+07	3.35E+07	3.35E+07

Conclusion

- It was observed that considering the high biodegradation of organic polyester will give high Lo value.

- The high Lo value for biodegradable polyester implies that very little carbon will be stored in the landfill.

- Having DOC as 1 (assuming fully organic polyester material) the Lo value obtained was on higher side than the usual range but lower than 0.4 fraction of the methane (CH_4) density considered for biodegradable polyester.

- To select the Lo value based on DOC as 1 would be more feasible for estimating the CH_4 generation in the landfill from a specific polyester material as close estimates will be achieved to obtain the maximum CH_4 production from the total biodegradable polyester.

- Estimating decay rates based on the annual rainfall play a specific role to determine the biodegradation of the organic polyester component.

- Thus, diverting waste going to the landfills helps in reducing the overall environmental impact by degradation of biodegradable polyester.

Questions??

<u>Contact information:</u>

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Steps to complete the assignment of appropriate k values for biodegradable polyester in dry, moderately wet, and wet climate landfills were as follows:

1. Assign annual MSW disposal into fractions going to U.S. landfills in dry (less than 20 inches per year precipitation), moderately wet (20 to 39 inches per year precipitation), and wet climates (at least 40 inches per year precipitation) based on average annual precipitation reported for the 35 metropolitan regions with 2020 census population estimates of at least 2 million persons, with adjustments to consider the transfer of waste from cities in wet climates to landfills in dry climates (e.g., Portland Oregon). An estimated 26.4 percent of MSW is disposed in landfills in dry climates, 21.3 percent in landfills in moderately wet climates, and 52.3 percent in landfills in wet climates.

2. Assign average k values for MSW disposed in each climate category based on the population-weighted average of k values in each climate region calculated using default k values for each metropolitan region based on precipitation.

3. Convert the k values assigned to MSW to k values for biodegradable polyester assuming a ratio of 3.6 to 1. The resulting biodegradable polyester k values are as follows:
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Ultimate Methane Generation Rate (Lo value)

- The methane production rate of 0.4 pounds of methane per pound of biodegradable polyester measured in the laboratory is 2.5 times the methane yield of food waste as a percentage of dry material disposed, according to WARM documentation. This methane production rate implies an "ultimate methane generation" rate, or model "Lo" value, of 610 cubic meters per metric ton, which is the amount that will eventually be produced over time at a rate constrained by the decay rate (k value).

- The Lo value is calculated based on the degradable organic content (DOC) of the material and the amount of the DOC that degrades and produces LFG (DOCf), along with conversion factors. The estimated Lo value of 610 cubic meters per metric ton assumes that 60 percent of the material consists of DOC which decomposes and produces methane (DOC x DOCf = 0.6). The DOCf reported by the IPCC for food waste is 0.7 (IPCC, 2019). This DOCf is likely a maximum value achievable only under optimal conditions. If a DOCf of 0.7 for polyester is assumed, a DOC of 0.86 is required to result in an Lo of 610 cubic meters per metric ton.

- Since our emissions calculations are applying the estimated annual tons of biodegradable polyester manufactured from organic materials, this high percentage of degradable organic carbon appears reasonable.

Intergovernmental Panel on Climate Change, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3 – Solid Waste Disposal.