ASSESSMENT OF SUSTAINABLE MATERIALS MANAGEMENT APPLICATION IN MARYLAND

December 2018

Prepared for:
American Institute for Packaging and the Environment, AMERIPEN

Prepared by:
Dr. Timothy G. Townsend, Principal Investigator
Malak Anshassi, Graduate Research Assistant

University of Florida
Sustainable Materials Management Research Lab
Department of Environmental Engineering Sciences
Engineering School of Sustainable Infrastructure and Environment

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The United States (US) Environmental Protection Agency (EPA) promotes state and federal governments and business to follow sustainability models to reduce their adverse environmental impacts. More recently, the EPA has adopted the sustainable materials management (SMM) model which focuses on minimizing resource consumption and adverse environment impacts throughout a material's lifecycle, this includes the following life stages: extraction, processing, manufacturing, usage, and end-of-life management. Adoption of this model has sparked interest by the American Institute for Packing and the Environment (AMERIPEN). Based off previous research from the University of Florida related to an approach to apply the SMM model in Florida, AMERIPEN requested that the University of Florida extend their research to also evaluate methods to apply the SMM model to other state governments, specifically California, Maryland, and Minnesota. Application of the SMM model is dependent on municipal solid waste (MSW) mass flow data reported by each state. The objectives of this research were to collect all available state-reported MSW data, evaluate if the data were sufficient to apply the SMM model, and develop and illustrate application of SMM approaches in each of these states. This report provides a detailed data and SMM approach specific to only Maryland.

Five SMM application approaches were developed and applied to Maryland for calendar year (CY) 2005 and 2015. The first four approaches used SMM to strategically plan and prioritize materials, technology, or policies, they included the following approaches: 1) Best Target Materials Recycling; 2) Best Disposal Management; 3) Prioritizing Policy and Technology; and 4) Prioritizing Stakeholders. The last approach used SMM to measure the performance or set goals for a solid waste system and was referred to as the Effective Recycling Rates approach. A description of each approach and their key finding is summarized in Table ES1.

Each approach required an environmental footprint which relied on the annual mass data of individual materials generated, recycled, combusted, and landfilled and lifecycle impact data provided for by the US EPA Waste Reduction (WARM) lifecycle assessment (LCA) model. We collected information on calendar year CY 2005 and 2015. Maryland only reported the individual mass of materials recycled. To estimate individual materials generated, combusted and landfilled mass other Maryland Department of the Environment (MDE) published reports related to MSW were retrieved and assumptions were applied to those data. Using MDE provided data and our assumption we estimated sufficient data for CY 2015 to successfully illustrate the application of the five approaches, however, we hypothetically illustrated application of the fifth approach.

Table ES1. Description of the five SMM approaches applied to MD and their key finding.

Approach	Description	Key Finding
Best Target Materials Recycling	Determines which materials to prioritize recycling by ranking their environmental impact	Policy makers should prioritize recycling of paper and metal products because they had the largest impact on decreasing the environmental footprint.
Best Disposal Management	Evaluates whether to strategically dispose of a material via combustion or landfilling	From a GHG emissions perspective most materials should be landfilled because they release less emissions than when combusted. But from an energy perspective most material should be combusted instead of landfilled.
Prioritizing Policy and Technology Approach	Identifies which solid waste policy or technology contributes the most environmental avoidances	Policies related to recycling metals, paper, and plastic products result in a large impact on decreasing the environmental footprint.
Prioritizing Stakeholders	Identifies stakeholders that reduce adverse environmental impact	Stakeholders following SMM have a large potential in reducing the environmental footprint, especially residential stakeholders.
Effective Recycling Rates	Relies on a target baseline year and year-of-interest's environmental footprint. The year-of-interest footprint is converted to an "effective" recycling rate, where effective refers to converting the year-of-interest's environmental footprint to a percentage using the baseline year's target environmental footprint and mass-based recycling rate.	Policy makers can measure their recycling progress using the SMM-based metric, which when compared to the mass-based recycling rate was greater in achieving the hypothetical SMM targets.

1 BACKGROUND

Many local governments and business are shifting from solid waste management to sustainable materials management (SMM) of municipal solid waste (MSW). SMM as defined by the United States (US) Environmental Protection Agency (EPA) refers to "a systemic approach to using and reusing materials more productively over their entire lifecycles". The major difference between solid waste management and SMM is the focus on using life cycle thinking to identify the best management practice for a material based on its social, environmental, and economic impacts.

Traditionally, a solid waste management's progress toward sustainability is measured using a mass-based recycling rate, where the total recycled mass is divided by the total generated mass. Many local governments establish mass-based recycling rate goals to track their solid waste management program's sustainability progress over time. However, this method does not consider the individual social, environmental, or economic impact of an individual material. It also does not provide insight on how to best manage that material according to its impact. When implementing SMM a solid waste decision-maker can use lifecycle results, such as the environmental impact of recycling versus landfilling newspaper, to make more conscious decisions.

Based on these motivators, in a previous study we outlined a methodology that created an alternative metric to the traditional mass-based recycling rate using lifecycle thinking and then evaluated the application of SMM in Florida using those alternative SMM-based metrics. As requested by the American Institute for Packing and the Environment (AMERIPEN), we conducted an analysis to identify the viability of applying SMM in California (CA), Maryland (MD), and Minnesota (MN). The objective of this study was to collect all data needed to implement SMM and then demonstrate its application in MD to understand the viability of the model and opportunities to leverage SMM thinking into policy. In this report, we described the previous approach, identified all the compiled available MSW data required for SMM application, identified any knowledge or data gaps, and applied SMM approaches to MD.

2 SUSTAINABLE MATERIALS MANAGEMENT IN FLORIDA

In the previous study, we used Florida's solid waste management data as a case study to evaluate the application of lifecycle-based metrics and SMM. The approach used the MSW data provided in the Florida Department of Environmental Protection (FDEP) annual reports along with the US EPA Waste Reduction (WARM) lifecycle assessment (LCA) model, which uses lifecycle impact (LCI) indicators for greenhouse gas (GHG) emissions and energy use, to quantify the environmental impact (or footprint) of Florida's solid waste management. The approach relied on three components: 1) individual material mass disposition data per person (e.g., tons of newspaper per person recycled, combusted, landfilled) for a baseline year, 2) and for a year-of-interest; 3) and LCI indicators.

The general approach followed that the individual materials' mass disposition data per person were multiplied by LCI conversion factors extracted from WARM to estimate an associated GHG emission and energy use footprint. The WARM (version 14, spreadsheet) provided LCI conversion factors for 54 types of waste and their six management approaches: source reduction, recycling, landfilling, combustion, composting, and anaerobic digestion (ICF International, 2016a). The WARM LCI factors were used in their absolute form and converted a mass of material managed to the GHG emissions and energy use. These two impact categories are typically widely accepted in LCA because the data used to create the conversion factors is abundant and collected from various regions internationally. In WARM, GHG emissions are measured in units of metric tons of carbon dioxide equivalence (tCO2eq.) and energy use is measure in units of million British thermal units (mmBTU) which we converted to megajoules (MJ). Results from WARM can be defined as waste management-based GHG emissions or energy use footprint (or when referring to both called an environmental footprint). For each impact category the results are specific to a material and its management, which means that there is a potential for the GHG emissions or energy use footprint to be contradictory of each other. WARM, and other LCA models alike, give decision makers the ability to choose the impact category most important to them and use it to guide their decision making.

A flow chart is presented in Figure 2-1 that outlined the general Florida-specific methodology. The FDEP annual report provided data on generated and recycled disposition on an individual material basis. However, the data related to disposal (landfilled and combustion) was provided on a mixed MSW basis. Assumptions derived from the mixed MSW data were used to estimate the mass of the individual materials combusted and landfilled, including the ash landfilled and recycled. The individual material mass disposition data were multiplied by their respective WARM LCI factors (represented by the dashed line), then summed to generate an estimated GHG emission and energy use footprint per person (represented by the light-gray shaded box). The environmental footprint was estimated for both the baseline year (2008) and the year-of-interest (2020, which was projected from 2015 data).

To evaluate the application of SMM in Florida, we created five hypothetical SMM scenarios in 2020 (based on 2015 FDEP data) and compared them to two baselines (using 2008 FDEP data) that hypothetically reached a 75% recycling rate. The baselines waste management were altered to correspond to a 75% recycling rate because that was the year that a statewide 75% recycling rate goal was enacted. To measure the progress of the scenario toward the baseline the total GHG emissions and energy use of the five scenarios were compared to the baseline GHG emissions and energy use. Doing this, illustrated what it takes to achieve the baseline's mass-based recycling rate target, and its associated GHG emissions and energy use footprint. This established a 75% mass-based recycling rate target and a GHG emission and energy use footprint target for each baseline. However, instead of a straight comparison of tCO2eq. or MJ, the 2020 footprint was converted to an alternative metric, an LCI-normalized recycling rate. The term normalized referred to adjusting values measured on different scales to a common scale. Where, the adjusted values were the GHG emissions and energy use and they were adjusted to a percentage, the unit used by a recycling rate. Equation 1 described how we adjusted the GHG emissions (in units of tCO2eq.) and the energy use (in units of MJ) to a percentage (%). Figure 2-1 showed the mass data collected (recycled, landfilled, combusted, landfilled & recycled ash) and used as inputs to calculate a baseline year and year-of-interest's environmental impact (in GHG emissions and energy use) and how Equation 1 was used to estimate LCI-normalized recycling rates.

$$R_{\text{LCI,Year of Interest}} = \frac{\text{LCI}_{\text{Year of Interest}}}{\text{LCI}_{\text{Baseline Year}}} \text{ (Recycling Rate Target)} \qquad \text{Eq. 1}$$

Where,

$R_{\text{LCI, Year of Interest}}$ refers to the LCI-normalized year-of-interest recycling rate corresponding to the total GHG emissions or energy use.

$\text{LCI}_{\text{Year of Interest}}$ refers to the total GHG emissions or energy use in the year-of-interest.

$\text{LCI}_{\text{Baseline Year}}$ refers to the baseline total GHG emissions or energy use. Multiplying by the target mass-based recycling rate normalizes the results so that the GHG emissions and energy use units are in a percent like the mass-based recycling rate.

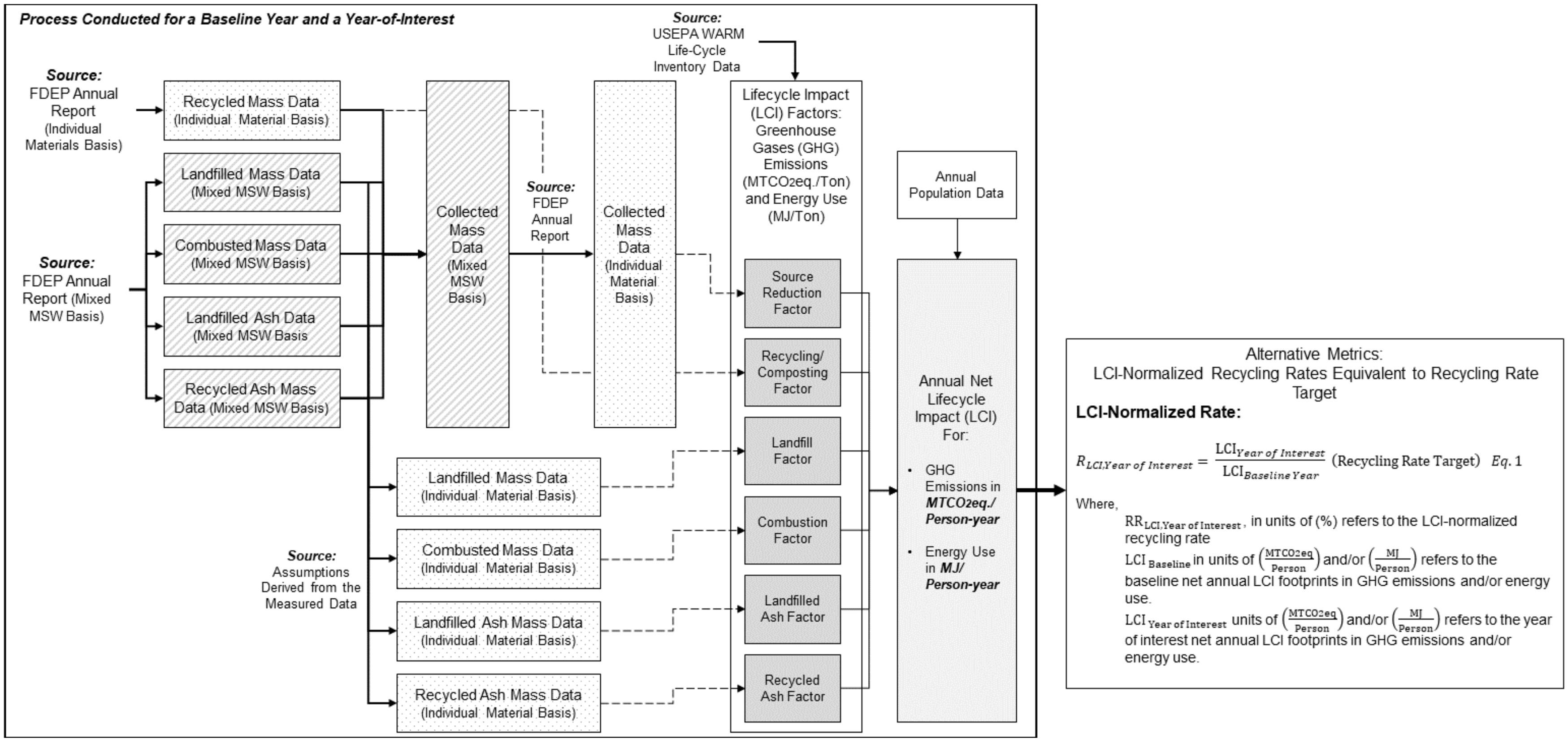

Figure 2-1. Florida-specific methodology to estimate mass data (recycled, landfilled, combusted, landfilled & recycled ash) used as inputs to calculate a baseline year and year-of-interest's net lifecycle impact (LCI) (in GHG emissions and energy use) which was converted to an LCI-normalized recycling rate equivalent to a recycling rate target

3 DATA AVAILABLE FOR MARYLAND

As previously discussed, the main objective of this study was to evaluate the application of the SMM methodology in other states, specifically MD. To execute the application of the SMM methodology in MD, data was compiled for 2005 and 2015 from the Maryland Department of the Environment (MDE) published annual reports that detailed waste management data managed by MD permitted solid waste acceptance facilities. We assumed that a ten-year time difference was appropriate to measure and track any trends to the waste stream in waste generated more of in 2015 relative to 2005 (referred to as source generated waste) and waste generated less of in 2015 relative to 2005 (referred to as source reduced waste).

For CY 2005, the MDE published two separate reports: 1) Annual Report Solid Waste Management in MD CY 2005; and 2) 2006 MD Waste Diversion Activities Report. While for CY 2015, the MDE published only the 2016 MD Solid Waste Management and Diversion Report. These reports along with MDE provided spreadsheets that detail more in depth (than the reports) the materials recycled and their masses, were used to compile direct data on the total mass generated, managed, recycled, combusted, landfilled, recycled and landfilled ash, the individual materials recycled mass, and the composition of the recycled and landfilled ash. The total mass generated and landfilled were modified to remove any imported waste managed by the state, and to account for any waste exported out-of-state for landfill disposal. Also, it should be noted that MD accounts for two waste streams: 1) the waste generated, which includes all waste generated by MD and; 2) the waste managed, which includes only waste that is accepted and managed at MD permitted solid waste acceptance facilities. In 2016, the MDE contracted with MSW Consultants to perform a statewide composition study (MSW Consultants, 2017). This document's findings were used to estimate indirect data on the individual materials composition and mass landfilled and combusted, not provided directly by the MDE reports or spreadsheets. Whereas, population data needed by the methodology was retrieved from the US Census Bureau website.

Another component required by the methodology was the mass-based recycling rate for the baseline year (2005) and the year-of-interest (2015). Table 3-1 provides detailed information related to the mass-based recycling rate, the mass-based recycling rate targets, and how recycling rates are calculated by the MDE. There were three recycling rates calculated using the MDE provided data, these included: 1) the EPA recycling rate, which is calculated by the EPA after MDE submits their data; 2) the MDE recycling rate (without inclusion of additional credits), which includes only Maryland Recycling Act (MRA) materials; and 3) the MDE waste diversion rate (includes additional credits), such as the MDE recycling rate, resource recovery facility credit, and source reduction credit. The primary difference between the EPA recycling rate and the MDE recycling rate(s) was that the EPA rate did not include the reuse of materials or recycled industrial waste materials in the recycling rate. The MRA materials included compostables, glass, metals, paper, plastic, and miscellaneous (commingled containers, compost/mulch other organics, compost/mulch yard waste, glass, metals, other materials, paper, and plastic). The quantities of these materials disposed of are gathered from MRA Tonnage Reporting Surveys, submitted by MD counties (including Baltimore City) and from Solid Waste Tonnage Reports submitted by permitted facilities. Table 3-2 provides the type of data available for MD in 2005 and 2015, and Table 3-3 shows the results of the mass estimates for 2005 and 2015.The MDE recycling rate was calculated using Equation 2, whereas, the MDE waste diversion rate was calculated using Equation 3.

$$\text{MDE Recycling Rate} = \frac{(\text{MRA recycling tonnage})}{(\text{MRA recycling tonnage}+\text{MRA waste disposed of})} \text{ x } 100 \qquad \text{Eq. 2}$$

$$\text{MDE Recycling Rate} = \frac{(\text{MRA recycling tonnage})}{(\text{MRA recycling tonnage} + \text{MRA waste disposed of})} \text{ x } 100 + \text{Resource recovery facility credit} + \text{Source reduction credit} \qquad \text{Eq. 3}$$

Where the resource recovery facility credit specifies that a 5% recycling credit is awarded if a county “achieves a reduction of at least 5% in the volume of its waste through the utilization of one or more resource recovery facilities in operation as of January 1, 1988.”. And the source reduction credit is awarded based on the number of source reduction activities accomplished by a county.

Table 3-1. Recycling information related to recycling rate or waste diversion targets and the recycling rates as calculated by the study and by MD. The Maryland Recycling Act (MRA) recycling tonnage refers to only compostables, glass, metals, paper, plastic, and miscellaneous.

	Baseline Year (2005)	Year-of-Interest (2015)	Recycling Rate Target Calculation
Recycling Rate or Waste Diversion Target	40% Waste Diversion Goal for 2005 & 35% MRA recycling rate plus up to 5% source reduction activities credit	60% Waste Diversion Goal for 2020 & Mandatory County Recycling Rate of 20 or 35% (based on population)	-
EPA Recycling Rate	34.90%	38.20%	MDE submits data to EPA and EPA provides EPA Recycling Rate. Does not include reuse of materials or industrial wastes
MDE Recycling Rate (Without Inclusion of Additional Credits)	39.20%	41.20%	RR = (MRA Recycling Tonnage) / (MRA Recycling Tonnage + MRA Waste Disposed)
MDE Waste Diversion Rate (Includes Additional Credit)	42.60%	47.20%	RR = MRA Recycling Rate + SR Credit + Resource Recovery Facility Credit

Table 3-2. Input parameters needed to implement a MD-specific SMM approach. The check mark symbols imply that the MDE provided published reports (Kendl P. Philbrick and Horacio Tablada, 2006; Kendl P. Philbrick and Jonas A. Jacobson, 2006; Resource Management Program & Land and Materials Administration, 2016) or data sets that satisfy the associated data requirement for the baseline year and year of interest.

Data Type	Baseline Year (2005)			Year-of-Interest (2015)		
	Data Availability	**Associated Mass (Tons)**	**Source**	**Data Availability**	**Associated Mass (Tons)**	**Source**
Population Data*	✓	5,592,000	US Census Bureau	✓	6,001,000	US Census Bureau
MSW Composition Study	n/a	-		✓, published in 2017	-	Table 3-1, 2016 Maryland Statewide Waste Characterization Study
Total Mixed MSW Data						
Generated	✓	12,304,422	Summation of Total Mixed MSW Data Recycled, Combusted, and Landfilled	✓	12,200,631[b]	Table 2 and 13, Maryland Solid Waste Management and Diversion Report 2016
Managed	✓	8,502,827	Table 4, Annual Report Solid Waste Management in Maryland CY 2005	✓	8,065,760	Table 2, Maryland Solid Waste Management and Diversion Report 2016
Recycled	✓	5,869,453	Table 1, Maryland Waste Diversion Activities Report 2006	✓	6,604,833	Table 2, Maryland Solid Waste Management and Diversion Report 2016
Combusted	✓	1,358,876	Table 4, Annual Report Solid Waste Management in Maryland CY 2005	✓	1,484,477	Table 15, Maryland Solid Waste Management and Diversion Report 2016
Landfilled	✓	5,076,093[a]	Table 2,3 and 4, Annual Report Solid Waste Management in Maryland CY 2005	✓	4,111,321[c]	Table 2,13 and 15, Maryland Solid Waste Management and Diversion Report 2016
Recycled Ash	✓	242,682	Table 4, Annual Report Solid Waste Management in Maryland CY 2005	✓	197,396	Table 2, Maryland Solid Waste Management and Diversion Report 2016
Ash and By-pass	n/a	-		✓	174,554	Table 2, Maryland Solid Waste Management and Diversion Report 2016
Back-End Scrap Metal	n/a	-		✓	22,842	Table 2, Maryland Solid Waste Management and Diversion Report 2016
Landfilled Ash	✓	185,557	Table 4, Annual Report Solid Waste Management in Maryland CY 2005	✓	442,904	Table 2, Maryland Solid Waste Management and Diversion Report 2016
MSW-ash, back-end scrap metal, & by-pass	n/a	-		✓	275,870	Table 2, Maryland Solid Waste Management and Diversion Report 2016
Non-MSW ash & By-pass	n/a	-		✓	167,034	Table 2, Maryland Solid Waste Management and Diversion Report 2016
Individual Material Data						
Generated	n/a	n/a		n/a	n/a	
Managed	n/a	n/a		n/a	n/a	
Recycled	✓	See Table A2	Table 1, Maryland Waste Diversion Activities Report 2006 & State Provided Data Sheets	✓	See Table A2	Table 20, Maryland Solid Waste Management and Diversion Report 2016 & State Provided Data Sheet
Landfilled	n/a	n/a		n/a	n/a	
Combusted	n/a	n/a		n/a	n/a	
Recycled Ash	n/a	n/a		n/a	n/a	
Landfilled Ash	n/a	n/a		n/a	n/a	

*Units in persons.

a- Calculated by removing imported waste disposed of and including exported waste disposed of.
3,056,269 tons (Landfilling, Table 4) +(2,700,585 tons (Transported Out-of-State, Table 4) – 148,915 tons (Recycling Transported Out-of-State, Table 3)) – 531,846 tons (Imported, Table 2) = **5,076,093 tons**.

b- Calculated by removing imported waste disposed of.
12,471,636 tons (Landfilling, Table 4) – 271,005 tons (Imported, Table 13) = **12,200,631 tons**.

c- Calculated by removing the incinerated waste from the total tons disposed of and the removing the imported waste disposed.
5,866,803 tons (Total waste disposed, Table 2) – 1,484,477 (Incinerated in MD, Table 15) = 4,382,326 tons (Landfilled)
4,382,326 tons (Landfilled) – 271,005 tons (Imported, Table 13) = **4,111,321 tons.**

Table 3-3. 2005 and 2015 individual material mass estimates and associated recycling rates for MD.

Item No.	Material	2005 Generated (Tons/ Person)	2005 Recycled & Composted (Tons/ Person)	2005 Combusted (Tons/ Person)	2005 Landfilled (Tons/ Person)	2015 Generated (Tons/ Person)	2015 Recycled & Composted (Tons/ Person)	2015 Combusted (Tons/ Person)	2015 Landfilled (Tons/ Person)	2005 Recycling Rate	2015 Recycling Rate[a]
1	Newspaper	-	0.034	-	-	0.034	0.019	0.004	0.011	-	56%
2	Glass	-	0.016	-	-	0.043	0.021	0.006	0.016	-	50%
3	Aluminum Cans	-	0.005	-	-	0.005	0.001	0.001	0.003	-	23%
4	Steel Cans	-	0.164	-	-	0.013	0.001	0.003	0.008	-	11%
5	Corrugated Paper	-	0.010	-	-	0.145	0.065	0.021	0.059	-	45%
6	Plastic Bottles	-	0.004	-	-	0.024	0.002	0.006	0.016	-	6%
7	Yard Trash	-	0.276	-	-	0.205	0.149	0.015	0.041	-	73%
8	Mixed Plastics	-	0.071	-	-	0.119	0.011	0.029	0.079	-	9%
9	Food Waste	-	-	-	-	0.202	0.035	0.044	0.123	-	17%
10	Mixed Paper	-	0.068	-	-	0.210	0.066	0.038	0.106	-	31%
11	Mixed Metals	-	0.004	-	-	0.209	0.186	0.006	0.016	-	89%
12	Textiles	-	0.022	-	-	0.009	0.003	0.024	0.068	-	29%
13	Tires	-	0.236	-	-	0.045	0.006	0.000	0.001	-	13%
14	Electronics	-	-	-	-	0.023	0.002	0.001	0.003	-	10%
15	C&D Debris	-	0.009	-	-	0.380	0.276	0.027	0.076	-	73%
16	Miscellaneous	-	0.130	-	-	0.369	0.258	0.021	0.058	-	70%
	Total	**-**	**1.050**	**-**	**-**	**2.033**	**1.101[b]**	**0.247**	**0.685**	-	**54.1%**
	Total (without C&D or Misc.)	**-**				**1.284**					

Note: The recycled masses were provided by the Maryland Department of the Environment (MDE) reports and spreadsheets. The combusted and landfilled masses were estimated by applying a MDE statewide disposal waste composition study. Because no waste composition data exists for 2005 no combusted or landfilled estimates were made for that year. Generated masses were calculated as the sum of recycled, combusted, and landfilled. The material categories in the report were re-organized to these 16 material categories but MDE does not report estimates of food waste and electronics recycled in 2005 (see Appendix).

a: Recycling rate was calculated as the recycled & composted mass divided by generated mass.
b: The recycled & composted mass includes all 16 materials

4 EVALUATION OF DATA NEEDS

After compiling all the available data related to MD’s solid waste management, we identified that there were still knowledge gaps. Directly the mass of individual materials generated, landfilled, and combusted for both years were not reported. However, using our methodology we indirectly estimated the mass of individual materials landfilled and combusted by applying the findings of the waste composition studies to the total mass disposed of (landfilled and combusted). Then using those estimates and the reported mass of individual materials recycled we indirectly estimated the mass of individual materials generated as the sum of the individual materials recycled, landfilled, and combusted.

This process to estimate the individual material’s mass balance was possible for MD’s 2015 data because the 2015 report provided the total landfilled and combusted, and individual materials mass recycled, and the 2017 waste composition study provided the composition of the disposal stream. Although, the 2005 report provided the total landfilled and combusted masses, and the individual materials recycled masses, no composition study existed for 2005 or around that year, resulting in no way of estimating the 2005 individual material’s landfilled, combusted, and generated masses for 2005. Furthermore, the 2015 report directly reported the mass composition of recycled and landfilled ash; however, no mass composition estimates exist for 2005.

Additional data need concerns were associated with the tracking and reporting of material types. In this analysis we estimated disposition masses for the materials reported by MDE in the annual reports and for the materials evaluated by the waste composition studies. Because the type of recycled materials tracked and reported differed in 2005 and 2015, we re-organized the suite of recycled material categories so that they are comparable. Similarly, we re-organized the suite of materials evaluated in the 2016 waste composition study for simplification. The purpose of this re-organization was to identify a standardized suite of material categories so that an individual category was associated with a recycled, landfilled, and combusted mass to estimate an individual material’s generated mass. It should be noted that some material types were accounted in the recycling disposition but were not accounted in the landfill or combustion dispositions- because they were not evaluated by the composition study or the recycled material was not required to be tracked- and vice versa. All materials re-organization are shown in the Appendix.

5 SUSTAINABLE MATERIALS MANAGEMENT IN MARYLAND

A local government may apply SMM using various approaches, this section will focus on five approaches. The first four approaches use SMM to strategically plan and prioritize materials, technology, or policies, they include the following approaches: 1) Best Target Materials Recycling; 2) Best Disposal Management; 3) Prioritizing Policy and Technology; and 4) Prioritizing Stakeholders. The last approach uses SMM to measure the performance or set goals for a solid waste system and will be referred to as the Effective Recycling Rates approach. A description of each approach and their data needs was provided in Table 5-1.

Table 5-1. Description of the five SMM approaches applied to MD.

Approach	Description	Data Needs
Best Target Materials Recycling	Determines which materials to prioritize recycling by ranking their environmental impact	Environmental footprint for a single year-of-interest
Best Disposal Management	Evaluates whether to strategically dispose of a material via combustion or landfilling	Environmental footprint for a single year-of-interest
Prioritizing Policy and Technology Approach	Identifies which solid waste policy or technology contributes the most environmental avoidances	Environmental footprint for a single year-of-interest
Prioritizing Stakeholders	Identifies stakeholders that reduce adverse environmental impact	Environmental footprint for a single year-of-interest
Effective Recycling Rates	Relies on a historic target baseline year and year-of-interest's environmental footprint. The year-of-interest footprint is converted to an "effective" recycling rate, where effective refers to converting the year-of-interest's environmental footprint to a percentage using the baseline year's target environmental footprint and mass-based recycling rate.	Environmental footprint for a historic year and a year-of-interest and

The application of the study's SMM methodology required individual materials mass generation and disposition and their WARM LCI factors to estimate an environmental footprint for a baseline year and year of interest. The materials and their associated WARM GHG emissions and energy use factors are shown in Table 5-2. Using the data in Table 3-3, we estimated a net environmental footprint of -1.261 $tCO_2eq.$/person and -17,802 MJ/person associated with MD's 2015 waste management system but the data was insufficient to estimate a footprint associated with the 2005 baseline. The total footprint was calculated by summing the footprints associated with recycling, landfilling, and combusting MSW. Each of these footprints are provided on a per person and a total basis in Table 5-3 for 2015. The negative values indicated that the state's management of waste resulted in an avoidance of GHG emissions and energy due to the large recycling offsetting virgin materials. The environmental footprints are used in the SMM approaches and discussed in the next sections.

Table 5-2: WARM emission and energy factors for MSW materials, based on EPA WARM v14 and for energy use the units are converted from WARM default units of mmBTU/short ton to MJ/short ton.

MSW material	Source Reduction (tCO_2eq./short ton)	Recycled (tCO_2eq./short ton)	Combusted (tCO_2eq./short ton)	Landfilled (tCO_2eq./short ton)	Source Reduction (MJ/short ton)	Recycled (MJ/short ton)	Combusted (MJ/short ton)	Landfilled (MJ/short ton)
Newspaper	-4.77	-2.75	-0.581	-0.823	-38,472	-17,398	-7,948	55
Glass	-0.526	-0.277	0.028	0.020	-7,285	-2,247	526	283
Aluminum Cans	-4.91	-9.11	0.035	0.020	-94,629	-161,170	630	283
Steel Cans[a]	-3.06	-1.81	-1.57	0.020	-31,526	-21069	-18,079	283
Corrugated Paper	-5.60	-3.12	-0.509	0.235	-23,549	-15,900	-7,009	-259
Plastic Bottles[b]	-1.84	-0.993	1.22	0.020	-58,802	-43,294	-15,550	283
Yard Trash[c,d]	n/a	-0.146	-0.175	-0.268	n/a	612	-2,616	125
Mixed Plastic	-1.92	-1.02	1.22	0.020	-57,415	-40,978	-14,384	283
Food Waste[c]	-3.66	-0.176	-0.141	0.543	-15,361	612	-2,171	-25
Mixed Paper	-6.75	-3.53	-0.512	0.127	-31,064	-21,576	-7,036	-218
Mixed Metals[a]	-3.70	-4.34	-1.02	0.020	-53,393	-69,623	-11,596	283
Textiles	-3.82	-2.36	1.08	0.020	-96,078	-22,652	-7,585	283
Tires	-4.28	-0.376	0.506	0.020	-75,659	-3,756	-30,090	283
Electronics	-50.5	-2.50	-0.188	0.020	-1,009,416	-30,759	-6,618	283
C&D Debris[e]	-	-	-	-	-	-	-	-
Miscellaneous[e]	-	-	-	-	-	-	-	-

Note: This assumes WARM defaults, including typical US national average landfill gas collection and recovery for energy and default distance from collection site to landfill/recycling facility of 20 miles.

a. *For steel cans and mixed metals in WARM steel is assumed to be recovered after combustion, but we assumed the associated GHG emissions or energy use avoidance originally included by WARM in the combustion factors were not included in the analysis.*

b. *Emission/energy factors do not exist for plastic bottles in WARM; an average of the WARM categories for HDPE and PET was used as a proxy.*

c. *Recycling emission/energy factors do not exist for organic materials in WARM; composted emission/energy factors were used as a proxy.*

d. *Source reduction emission/energy factors do not exist for yard trash in WARM.*

e. *C&D Debris and miscellaneous materials' GHG emissions and energy use footprints were not assessed in the study.*

Table 5-3. Environmental footprint for recycling, combustion, and landfill for MD in 2015.

Disposition	GHG Emissions (tCO_2eq.)	Energy Use (10,000 MJ)	GHG Emissions (tCO_2eq./Person)	Energy Use (MJ/Person)
Recycling	-8,206,364	-9,927,260	-1.367	-16,543
Combustion	167,910	-770,360	0.028	-1,284
Landfill	468,967	14,506	0.078	24
Total Footprint	-7,569,486	-10,683,114	-1.261	-17,802

Note: Tables 5-4 and 5-5 details each materials GHG emissions and energy use per person for 2015.

Table 5-4. GHG emissions footprint for each material's disposition (i.e., recycling & compositing, combustion, and landfill) for MD in 2005 and 2015.

		2005				2015					
Item No.	Material	Recycling & Composting Emissions ($tCO_2eq.$/ Person)	Combustion Emissions ($tCO_2eq.$/ Person)	Landfill Emissions ($tCO_2eq.$/ Person)	Total Emissions ($tCO_2eq.$/ Person)	Recycling & Composting Emissions ($tCO_2eq.$/ Person)	Combustion Emissions ($tCO_2eq.$/ Person)	Landfill Emissions ($tCO_2eq.$/ Person)	Source Reduction (SR) Emissions ($tCO_2eq.$/ Person)	Total Emissions with SR ($tCO_2eq.$/ Person)	Total Emissions without SR ($tCO_2eq.$/ Person)
1	Newspaper	-	-	-	-	-0.0512	-0.0023	-0.0090	-	-	-0.0625
2	Glass	-	-	-	-	-0.0059	0.0002	0.0003	-	-	-0.0054
3	Aluminum Cans	-	-	-	-	-0.0104	0.0001	0.0001	-	-	-0.0103
4	Steel Cans	-	-	-	-	-0.0025	0.0001	0.0002	-	-	-0.0023
5	Corrugated Paper	-	-	-	-	-0.2024	-0.0108	0.0138	-	-	-0.1994
6	Plastic Bottles	-	-	-	-	-0.0015	0.0072	0.0003	-	-	0.0061
7	Yard Trash	-	-	-	-	-0.0218	-0.0026	-0.0110	-	-	-0.0354
8	Mixed Plastics	-	-	-	-	-0.0108	0.0349	0.0016	-	-	0.0258
9	Food Waste	-	-	-	-	-0.0062	-0.0062	0.0666	-	-	0.0542
10	Mixed Paper	-	-	-	-	-0.2317	-0.0196	0.0134	-	-	-0.2379
11	Mixed Metals	-	-	-	-	-0.8088	0.0001	0.0003	-	-	-0.8083
12	Textiles	-	-	-	-	-0.0063	0.0264	0.0014	-	-	0.0214
13	Tires	-	-	-	-	-0.0022	0.0003	<0.0001	-	-	-0.0019
14	Electronics	-	-	-	-	-0.0057	0.0003	0.0001	-	-	-0.0053
15	C&D Debris[a]	-	-	-	-	-	-	-	-	-	-
16	Miscellaneous[a]	-	-	-	-	-	-	-	-	-	-
	Total	-	-	-	-	**-1.365**	**0.0280**	**0.0781**	-	-	**-1.261**

Note: Each disposition's GHG emissions were calculated by first multiplying each materials' recycling & composted masses found in Table 3-3 (in tons/person) by their respective recycled WARM GHG emissions factors found in Table 5-2. The total for each disposition (e.g., recycling & composting emissions, etc.) are also shown in Tables 5-3.

a. C&D Debris and miscellaneous materials' GHG emissions and energy use footprints were not assessed in the study.

Table 5-5. Energy use footprint for each material's disposition (i.e., recycling & compositing, combustion, landfill, and source reduction) for MD in 2005 and 2015.

		2005				2015					
Item No.	Material	Recycling & Composting Energy Use (MJ/Person)	Combustion Energy Use (MJ/Person)	Landfill Emissions Energy Use (MJ/Person)	Total Energy Use (MJ/ Person)	Recycling & Composting Energy Use (MJ/ Person)	Combustion Energy Use (MJ/Person)	Landfill Energy Use (MJ/ Person)	Source Reduction (SR) Energy Use (MJ/ Person)	Total Energy Use with SR (MJ/Person)	Total Energy Use without SR (MJ/Person)
1	Newspaper	-	-	-	-	-324.3	-31.46	0.6011	-	-	-355.1
2	Glass	-	-	-	-	-47.48	2.995	4.460	-	-	-40.03
3	Aluminum Cans	-	-	-	-	-184.5	0.623	0.7757	-	-	-183.1
4	Steel Cans	-	-	-	-	-29.17	1.472	2.327	-	-	-25.37
5	Corrugated Paper	-	-	-	-	-1,032	-149.1	-15.26	-	-	-1,196
6	Plastic Bottles	-	-	-	-	-65.21	-92.32	4.654	-	-	-152.9
7	Yard Trash	-	-	-	-	91.92	-38.83	5.141	-	-	58.24
8	Mixed Plastics	-	-	-	-	-432.2	-412.7	22.49	-	-	-822.5
9	Food Waste	-	-	-	-	21.616	-96.12	-3.038	-	-	-77.54
10	Mixed Paper	-	-	-	-	-1,416	-269.8	-23.19	-	-	-1,709
11	Mixed Metals	-	-	-	-	-12,972	3.257	4.654	-	-	-12,964
12	Textiles	-	-	-	-	-60.89	-185.8	19.20	-	-	-227.5
13	Tires	-	-	-	-	-22.20	-14.36	0.3878	-	-	-36.17
14	Electronics	-	-	-	-	-70.08	-1.605	0.9696	-	-	-70.71
15	C&D Debris	-	-	-	-	-	-	-	-	-	-
16	Miscellaneous	-	-	-	-	-	-	-	-	-	-
	Total	-	-	-	-	**-16,543**	**-1,284**	**24.17**	-	-	**-17,802**

Note: Each disposition's GHG emissions were calculated by first multiplying each materials' recycling & composted masses found in Table 3-3 (in tons/person) by their respective recycled WARM GHG emissions factors found in Table 5-2. The total for each disposition (e.g., recycling & composting emissions, etc.) are also shown in Tables 5-3.

a. *C&D Debris and miscellaneous materials' GHG emissions and energy use footprints were not assessed in the study.*

5.1 Best Target Materials Recycling Approach

5.1.1 Methodology

The purpose of this approach was to demonstrate how solid waste policy makers can use the SMM model to prioritize which materials to recycle to increase progress towards sustainability by increasing their recycling rate and decreasing their environmental footprint. Materials were ranked by their impact to decrease or increase the GHG emissions and energy use footprint; the following steps were used to rank materials using 2015 mass data (Table 3-3):

→ **Step 1:** For an individual material, its recycled mass was multiplied by 1.05, to represent a hypothetical 5% increase in the recycled mass.

> *Note: We increased the recycled mass to account for potentially available recycled mass; materials with a low recycling rate will generate a larger increased mass than those with high rates. The 5% value was not specific to any policy or regulation.*

→ **Step 2:** For an individual material, the increased recycled mass was removed from its landfilled and combusted masses proportionally. We calculated the decreased landfill mass by multiplying the additional increased recycled mass by a ratio calculated as the initial 2015 landfilled mass divided by the sum of its initial 2015 landfilled. Then, we calculated the decreased combusted mass by multiplying the additional increased recycled mass by a ratio calculated as the initial 2015 combusted mass divided by the sum of its initial 2015 landfilled and combusted masses.

→ **Step 3:** For an individual material, we estimated its environmental footprint using the increased recycled mass, decreased landfilled mass, and decreased combusted masses from Steps 1 and 2 multiplied by their respective WARM GHG emission and energy use factors.

→ **Step 4:** Steps 1 thru 3 were repeated for each and all individual materials.

→ **Step 5:** Materials were ranked from most negative GHG emissions and energy use footprints to least negative value.

5.1.2 Application in Maryland

Table 5-6 presents the results of the approach, where higher ranked materials signify that increasing their recycled mass resulted in a larger impact in decreasing the footprint, and lower ranked materials resulted in a smaller impact to decreasing the footprint or their recycling resulted in increasing the footprint.

The materials that resulted in the most additional GHG emissions and energy avoidance were mixed metals, mixed paper, and corrugated paper. WARM assumes that recycled materials replace the use of virgin materials and this offsets emissions/energy associated with extracting, processing, and manufacturing (ICF International, 2016b). In WARM the materials with the greatest GHG emissions and energy avoidances when recycled are metals and paper products because they offset virgin material's extraction and processing.

The materials ranked the lowest from a GHG emissions perspective was yard trash, and for energy, tires, food waste, and yard trash ranked lowest. Recycled yard trash and food waste are ranked lowest because they are composted, a process energy intensive that requires heavy machinery (ICF International, 2016c). Whereas, recycling tires does offset energy, but the increased recycled mass originating from the combusted mass results in a loss of avoidance because combustion generates more avoidance than recycling (ICF International, 2016d). MD solid waste policy makers can prioritize their efforts to focus on which materials to recycle based off the environmental impacts.

Table 5-6. Results of the Best Target Materials Recycling approach applied to MD's waste management in 2015.

	Material		Material
Material Organized by Their Impact to Reduce the 2015 GHG Emissions Footprint (Larger to Smaller)	Mixed Metals	Material Organized by Their Impact to Reduce the 2015 Energy Use Footprint (Larger to Smaller)	Mixed Metals
	Mixed Paper		Mixed Paper
	Corrugated Paper		Corrugated Paper
	Newspaper		Mixed Plastics
	Food Waste		Newspaper
	Mixed Plastics		Aluminum Cans
	Aluminum Cans		Electronics
	Textiles		Plastic Bottles
	Glass		Textiles
	Electronics		Glass
	Tires		Steel Cans
	Plastic Bottles		**Tires**
	Steel Cans		**Food Waste**
	Yard Trash		**Yard Trash**

Note: Bolded materials are associated with an emission of GHG or an energy usage. And the approach was not applied to C&D debris and Miscellaneous materials.

5.2 Best Disposal Management Approach

5.2.1 Methodology

The current approach to manage materials for disposal is to collect comingled MSW and mass burn or landfill, in this approach we use the SMM model to demonstrate how solid waste policy makers may evaluate which disposal method is most appropriate by comparing the environmental footprint resulting when landfilling or combusting a material. The following steps were used to identify which disposal method resulted in the most GHG emissions and energy use avoidance using 2015 mass data (Table 3-3):

→ **Step 1:** For an individual material, its landfilled mass was multiplied by 1.05, to represent a 5% increase in the landfilled mass.

Note: The 5% value was not specific to any policy or regulation.

→ **Step 2:** For a material, the increased landfilled mass was removed from its combusted masses; the recycled mass was unaltered.

→ **Step 3:** For a material, we estimated an environmental footprint associated with the increased landfilled mass and the decreased combusted mass from Steps 1 and 2 multiplied by their respective WARM GHG emission and energy use factors.

→ **Step 4:** Steps 1 thru 3 were repeated for each individual material. These results will be used in Step 9.

Note: Steps 1 thru 3 correspond to increasing the landfill mass and Steps 5 thru 7 correspond to increasing the combusted mass. We increased the landfilled and combusted masses each by the same mass increase (5%) to ensure we are evaluating the impacts of landfilling or combusting the same mass.

→ **Step 5:** For a material, its combusted mass was multiplied by 1.05, to represent a 5% increase in the combusted mass.

Note: The 5% value was not specific to any policy or regulation.

→ **Step 6:** For a material, the increased combusted mass was removed from its landfilled masses; the recycled mass was unaltered.

→ **Step 7:** For a material, we estimated an environmental footprint associated with the decreased landfilled mass and the increased combusted mass from Steps 5 and 6 multiplied by their respective WARM GHG emission and energy use factors

→ **Step 8:** Steps 5 thru 6 were repeated for each individual material.

→ **Step 9:** For a material, its GHG emissions footprint from Step 3 and Step 7 were compared, if Step 3 had a greater negative value then it was labeled with "landfill" signifying landfilling that material generated a smaller GHG emissions footprint than combusting it, but if Step 7 had a greater negative value it was labeled with "combusted".

→ **Step 10:** For a material, Step 9 was repeated but based on its energy use footprint from Step 3 and Step 7.

→ **Step 11:** Steps 9 and 10 were repeated for all materials using the results from Steps 4 and 8.

5.2.2 Application in Maryland

Table 5-7 showed how we identified if a greater avoidance resulted from landfilling or combusting that material by labeling a material as "landfill" or "combustion". Combusting mixed paper and mixed metals were preferred over landfilling to reduce the GHG emissions footprint. Combusting paper products generates less emissions than landfilling because landfilling these materials generates methane (CH_4) and CO_2, and although WARM does not count the CO_2 because the materials are naturally expectant to release CO_2 when they decompose, the CH_4 is accounted for and has 25 times the global warming potential (GWP) of CO_2 (ICF International, 2016a, 2016d). The combustion and landfilling emission factor for mixed metals were both 0.02 $MTCO_2$eq./ton, so the disposal method with the least mass resulted in the least emissions, and this was combustion (ICF International, 2016d).

From an energy perspective most, materials generated more energy avoidance when combusted than landfilled because those materials have energy content that when combusted offset the use of fossil fuels used to generate electricity (ICF International, 2016b). However, the materials that should be landfilled instead was mixed metals because although they offset energy, the energy content recovered during combustion is not large enough offset the energy of operating and combusting the materials in a waste-to-energy facility.

Table 5-7. Illustration of the Best Disposal Management approach for MD's waste management in 2015, where for each material either landfilling or combusting the material resulted in a smaller footprint. If landfilling the material resulted in more emissions/energy use than combustion then "landfill" is displayed, and if combustion resulted in more emissions/energy use than landfill then "combustion" is displayed.

Material	GHG Emissions Perspective	Energy Use Perspective
Mixed Plastics	Landfill	Combustion
Mixed Paper	Combustion	Combustion
Mixed Metals	Combustion	Landfill
Textiles	Landfill	Combustion
Tires	Landfill	Combustion

5.3 Prioritizing Policy and Technology Approach

5.3.1 Methodology

Across the nation solid waste policy makers are faced with strategically investing in policies and technologies to best manage their waste stream. The prioritizing policy and technology approach compares the environmental impact of various policy and technology scenarios to a current environmental footprint to determine which policy or technology reduces the environmental footprint the most. In this approach we demonstrated how MD policy makers may evaluate various policies or technologies using three hypothetical scenarios as an example. The three scenarios included the following: 1) composting yard trash and food waste, which assumes MD passes a mandatory statute to collect, construct, and operate an organics composting facility; 2) commercial recycling, which assumes MD institutes a statute for mandatory commercial recycling of glass, aluminum cans, steel cans, corrugated paper, plastic bottles, and mixed paper ;and 3) combusting yard trash and tires, where MD invests in a renewable energy facility that combusts yard trash and tires for electricity generation. The following steps were used to identify which scenario resulted in the most GHG emissions and energy use avoidance using 2015 mass data (Table 3-3):

→ **Step 1:** For the composting yard trash and food waste scenario the mass of yard trash and food waste landfilled were multiplied by 0.15, individually.

> *Note: the 0.15 value represented a 15% reduction of yard trash and food waste landfilled mass. This value was not specific to any policy or regulation.*

→ **Step 2:** The mass corresponding to the 15% landfilled mass from Step 1 was assumed composted and we estimated the scenario's environmental footprint by multiplying the individual masses by the respective WARM GHG emission and energy use factors for composting yard trash and food waste. The composting yard trash and food waste scenario's GHG emissions and energy use footprint will be used in Step 7.

→ **Step 3:** For the commercial recycling scenario the mass of glass, aluminum cans, steel cans, corrugated paper, plastic bottles, and mixed paper landfilled were multiplied by 0.15, individually.

Note: the 0.15 value represented a 15% reduction of glass, aluminum cans, steel cans, corrugated paper, plastic bottles, and mixed paper landfilled mass. This value was not specific to any policy or regulation.

→ **Step 4:** The masses corresponding to the 15% landfilled masses from Step 3 were assumed recycled and we estimated the scenario's environmental footprint by multiplying the individual masses by the respective WARM GHG emission and energy use factors for recycling glass, aluminum cans, steel cans, corrugated paper, plastic bottles, and mixed paper. The composting commercial recycling scenario's GHG emissions and energy use footprint will be used in Step 7.

→ **Step 5:** For the combusting yard trash and tires scenario the masses of yard trash and tires landfilled were multiplied by 0.15.

Note: the 0.15 value represented a 15% reduction of yard trash and tires landfilled masses. This value was not specific to any policy or regulation.

→ **Step 6:** The mass corresponding to the 15% landfilled mass from Step 5 was assumed combusted and we estimated its environmental footprint by multiplying the mass by its respective WARM GHG emission and energy use factors for combusting yard trash ad tires. The combusting yard trash and tires scenario's GHG emissions and energy use footprint will be used in Step 7.

→ **Step 7:** The GHG emissions and energy use footprints from Steps 2, 4, and 6 were compared; the scenario with the greatest negative values for both footprints should be prioritized.

5.3.2 Application in Maryland

For each scenario the environmental footprint was estimated and compared to the original 2015 footprint shown and the net difference was plotted in Figure 5-1. Of the three scenarios, the commercial recycling scenario generated the most GHG emissions and energy avoidance, thus this scenario would have the largest impact in decreasing the 2015 environmental footprint. This scenario emphases recycling over composting or combusting. In WARM recycling generates a greater avoidance than combusting or combusting because of the offsets associated with using recycled materials in place of virgin materials. The scenario with the lowest GHG emissions avoidance was the combusting yard trash and tires scenario because combusted yard trash emits nitrous oxide (N_2O), which has a GWP of 298, and combusted tires releases CO_2 (ICF International, 2016d, 2016b). The scenario with the lowest energy use avoidance was the composting yard trash and food waste scenario because of the energy input needed to operate a compositing facility.

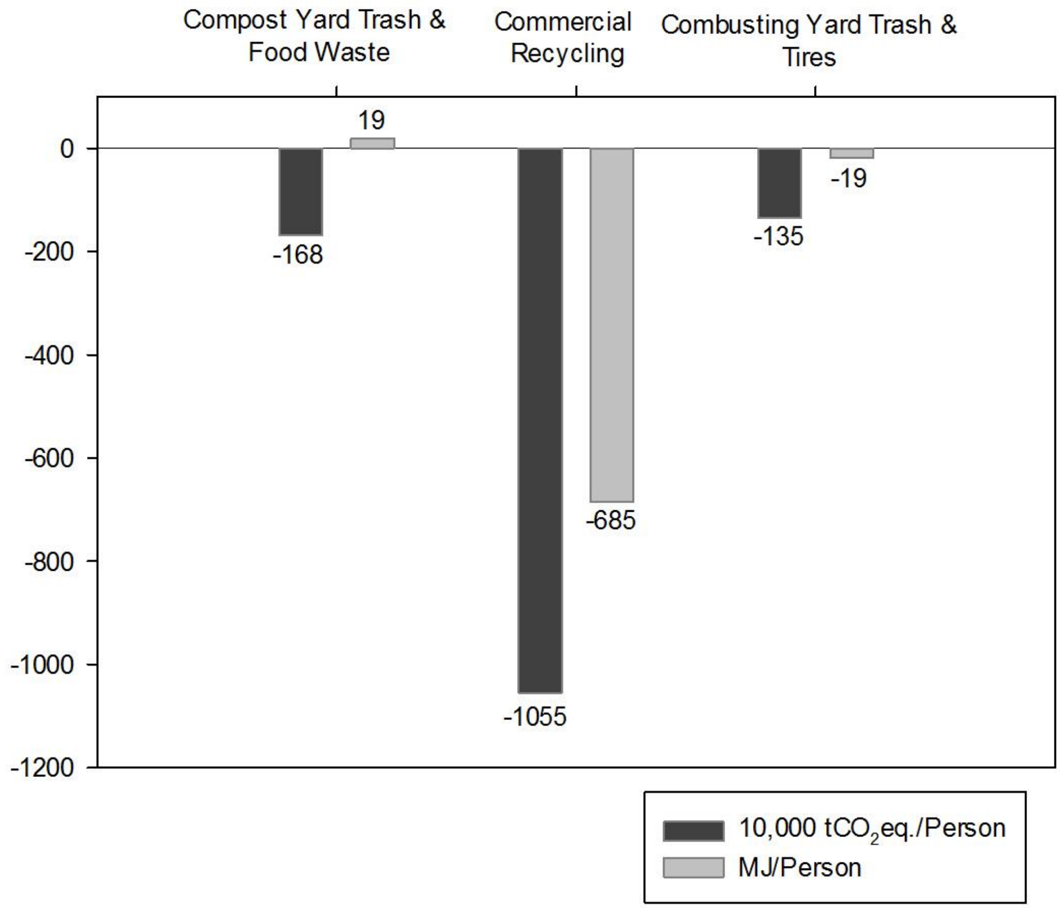

Figure 5-1. Example results of applying the Prioritizing Policy and Technology approach illustrated using three scenarios: 1) composting yard trash and food waste; 2) commercial recycling; and 3) combusting yard trash and tires. Each scenario's environmental footprint was compared to the original 2015 footprint and the net difference is shown.

5.4 Prioritizing Stakeholders Approach

5.4.1 Methodology

The prioritizing stakeholders approach recognizes that certain parties generating MSW have the potential to decrease the environmental footprint. This approach attempts to reduce the environmental footprint by identifying stakeholders associated with the material's GHG emissions/energy use and directing policy makers to institute polices to promote stakeholders reduce their footprints by following SMM. Application of this approach is similar to the prioritizing policy and technology approach, where we illustrate application using examples and compare the environmental impact to determine which stakeholders reduces the environmental footprint the most. The three scenarios evaluated in this approach included: 1) restaurant food waste composting, which assumes restaurant's send their food waste to be composted instead of landfilled; 2) multi-family recycling, which assumes multi-family residents (e.g., apartment complexes) increase their recycling of newspaper, glass, aluminum cans, steel cans, corrugated paper, plastic bottles, and mixed paper; and 3) commercial retailers recycling, which assumes retailers that sell electronics collect and recycle all their electronics. The following steps were used to identify which scenario resulted in the most GHG emissions and energy use avoidance using 2015 mass data (Table 3-3):

→ **Step 1:** For the restaurant food waste composting scenario the mass of food waste landfilled was multiplied by 0.10.

> *Note: the 0.10 value represented a 10% reduction of food waste landfilled mass. This value was not specific to any policy or regulation.*

→ **Step 2:** The mass corresponding to the 10% landfilled mass from Step 1 was assumed composted and we estimated the scenario's environmental footprint by multiplying the mass by the respective WARM GHG emission and energy use factors for composting food waste. The composting food waste scenario's GHG emissions and energy use footprint will be used in Step 7.

→ **Step 3:** For the multifamily recycling scenario the mass of newspaper, glass, aluminum cans, steel cans, corrugated paper, plastic bottles, and mixed paper landfilled were multiplied by 0.10, individually.

> *Note: the 0.10 value represented a 10% reduction of food waste landfilled mass. This value was not specific to any policy or regulation.*

→ **Step 4:** The masses corresponding to the 10% landfilled masses from Step 3 were assumed recycled and we estimated the scenario's environmental footprint by multiplying the individual masses by the respective WARM GHG emission and energy use factors for recycling newspaper, glass, aluminum cans, steel cans, corrugated paper, plastic bottles, and mixed paper. The multifamily recycling scenario's GHG emissions and energy use footprint will be used in Step 7.

→ **Step 5:** For the commercial retailer recycling scenario the mass of electronics landfilled was multiplied by 0.10.

> *Note: the 0.10 value represented a 10% reduction of electronics landfilled mass. This value was not specific to any policy or regulation.*

→ **Step 6:** The mass corresponding to the 10% landfilled mass from Step 5 was assumed source reduced and we estimated its environmental footprint by multiplying the mass by its respective WARM GHG emission and energy use factors for recycling electronics. The commercial retailers recycling scenario's GHG emissions and energy use footprint will be used in Step 7.

→ **Step 7:** The GHG emissions and energy use footprints from Steps 2, 4, and 6 were compared; the scenario with the greatest negative values for both footprints should be prioritized.

5.4.2 Application in Maryland

For each scenario the environmental footprint was estimated and compared to the original 2015 footprint shown and the net difference was plotted in Figure 5-2. The multi-family recycling scenario generated the largest avoidance because the recycled materials include aluminum cans, which have the largest emission (-9.10 tCO_2eq./person) and energy avoidances (-161,175 MJ/person) compared to the other materials (ICF International, 2016d). The commercial retailers recycling focuses on electronics and although these materials make up a small portion of MD's total generated waste (Table 3-4) their environmental impact is large, especially their energy avoidance when recycled (-30,759 MJ/person) (ICF International, 2016e). MD policy makers can expand the list of scenarios to identify potential stakeholders that when they manage their waste stream using SMM could decrease the overall environmental footprint.

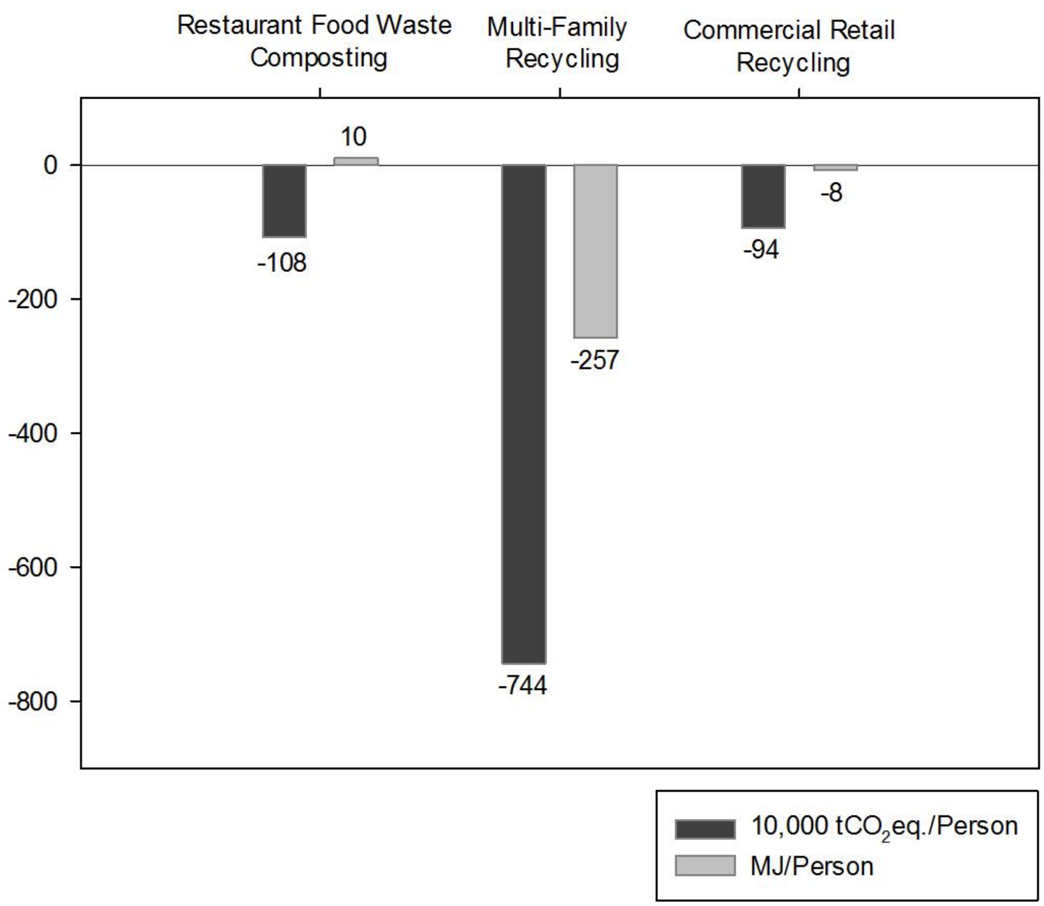

Figure 5-2. Example results of applying the Prioritizing Stakeholders approach illustrated using three scenarios: 1) restaurant food waste composting; 2) multi-family recycling; and 3) commercial retailers recycling. Each scenario's environmental footprint was compared to the original 2015 footprint and the net difference is shown.

5.5 Effective Recycling Rates

5.5.1 Methodology

This approach follows the previous approach applied to Florida and described in Section 2. The data required for this approach was estimated in Table 3-3, application of this approach using a historic target (i.e., 2005) will not be evaluated for MD because results may be inconclusive since the approach relies on the 2005 and 2015 mass estimates which were estimated using unverified assumptions for individual materials' recycled masses. The quality of tracked and reported individual materials' recycling data for both time frames has a large potential to increase or decrease the 2005 or 2015 environmental footprint, and thus results of this approach. However, we will hypothetically evaluate how MD could apply this approach using a hypothetical 2015 target baseline and compare it with the estimated 2015 data. Figure 5-3 depicts the SMM approach, which details the method to estimate the environmental footprint and calculate the alternative metric, additional detailed steps are provided below.

A. To calculate the hypothetical 2015 target baseline using 2015 mass data (Table 3-4):

→ **Step A1:** The hypothetical 2015 target baseline was calculated by increasing the mass of specific materials until they reached a maximum threshold recycling rate. The materials and their associated recycling rates included: yard trash to 85%, aluminum and steel cans to 75%, newspaper and corrugated paper to 65%, food waste to 60%, glass to 55%, and plastic bottles to 25%.

Note: We altered those eight materials' recycled, combusted, and landfilled masses but all other materials' recycled, combusted, and landfilled masses were not altered. The maximum threshold recycling rate values were selected based on the threshold rates reported from the MDE's in the "Waste Reduction and Resource Recovery Plan Goals and Metrics Recommendations September 2018 Draft" document.

→ **Step A2:** For the yard trash, aluminum and steel cans, newspaper and corrugated paper, food waste, and glass, the increased recycled mass was removed proportionally from each material's landfilled and combusted masses. We calculated the decreased landfill mass by multiplying the additional increased recycled mass by a ratio calculated as the initial 2015 landfilled mass divided by the sum of its initial 2015 landfilled and combusted masses. Then, we calculated the decreased combusted mass by multiplying the additional increased recycled mass by a ratio calculated as the initial 2015 combusted mass divided by the sum of its initial 2015 landfilled and combusted masses.

→ **Step A3:** For the yard trash, aluminum and steel cans, newspaper and corrugated paper, food waste, and glass, we calculated their 'new' landfilled masses by subtracting their individual decreased landfilled mass calculated in Step A2 from their individual initial 2015 landfilled mass. Also, we calculated their 'new' combusted masses by subtracting their individual decreased combusted mass calculated in Step A2 from their individual initial 2015 combusted mass.

→ **Step A4:** We calculated the hypothetical 2015 target baseline's recycling rate by summing the total recycled mass (which includes the increased mass from Step A1 and the initial recycled masses of the other materials) divided by the total generated mass.

→ **Step A5:** We estimated the hypothetical 2015 target baseline's total environmental footprint by multiplying each material's recycled (which included the increased mass from Step A1), landfilled (which accounted for the decreased mass from Step A2), and combusted (which accounted for the decreased mass from Step A2) masses multiplied by their respective WARM GHG emission and energy use factors.

B. To calculate the hypothetical 2015 target baseline's alternative metrics conversion factors:

→ **Step B1:** Like Florida's approach, we can use the baseline's recycling rate, GHG emissions and energy footprints to create equivalent LCI-normalized recycling rates. The effective recycling approach calculates the same results as the Florida approach and Eq. 4-6 show the general methodology.

→ **Step B1.1:** We assumed for a baseline (i.e., the hypothetical 2015 target baseline):

$$\mathrm{RR_{Mass,Baseline}} = \mathrm{LCI_{Baseline\ Year}} \qquad \text{Eq. 4}$$

Where,

$\mathrm{RR_{Mass,Baseline}}$ in units of (%) refers to the baseline's mass-based recycling rate.

$\mathrm{LCI_{\ Baseline}}$ in units of $\left(\frac{\mathrm{tCO_2eq.}}{\mathrm{Person}}\right)$ and/or $\left(\frac{\mathrm{MJ}}{\mathrm{Person}}\right)$ refers to the baseline's annual GHG emissions and/or energy use footprints.

Note: For the hypothetical 2015 target baseline, $RR_{Mass,Baseline}$ refers to the recycling rate from Step A4 and $LCI_{\ Baseline}$ refers to the GHG emissions and energy use footprints from Step A5.

→ **Step B1.2:** Then, we assumed using Eq. 4 that we could create a conversion factor where a 1% mass-based recycling rate was equivalent to a certain GHG emissions or energy use footprint. We calculate this by solving for $\mathrm{LCI_{\ n}}$:

$$\frac{\mathrm{RR_{Mass,Baseline}}}{\mathrm{LCI_{\ Baseline}}} = \frac{1\%}{\mathrm{LCI_{\ n}}} \qquad \text{Eq. 5}$$

$$1\% = \mathrm{LCI_{\ n}} \qquad \text{Eq. 6}$$

Where,

$\mathrm{LCI_{\ n}}$ is in units of $\left(\frac{\mathrm{tCO_2eq.}}{\mathrm{Person}}\right)$ and/or $\left(\frac{\mathrm{MJ}}{\mathrm{Person}}\right)$ and is equivalent to the $\left(\frac{\mathrm{tCO_2eq.}}{\mathrm{Person}}\right)$ and/or $\left(\frac{\mathrm{MJ}}{\mathrm{Person}}\right)$ associated with a 1% mass-based recycling rate.

C. To calculate the initial 2015 solid waste management progress toward the 2015 target baseline's alternative metrics:

→ **Step C1:** Apply the conversion factor to the year-of-interest's footprint to calculate it's LCI-normalized recycling rate(s) (referred to as $\mathrm{R_{LCI,Year\ of\ Interest}}$):

$$\mathrm{R_{LCI,Year\ of\ Interest}} = \mathrm{LCI_{\ Year\ of\ Interest}} \left(\frac{1\%}{\mathrm{LCI_{\ n}}}\right) \qquad \text{Eq. 7}$$

Where,

$\mathrm{RR_{LCI,Year\ of\ Interest}}$, in units of (%) refers to the year-of-interest's LCI-normalized recycling rate.

$\text{LCI}_{\text{Year of Interest}}$ units of $\left(\frac{\text{tCO}_2\text{eq.}}{\text{Person}}\right)$ and/or $\left(\frac{\text{MJ}}{\text{Person}}\right)$ refers to the year-of-interest annual GHG emissions and/or energy use footprints.

Note: If the year-of-interest and the baseline year were not both the same (e.g., baseline is 2005 and year-of-interest is 2015) then the $RR_{LCI,Year\ of\ Interest}$ should include the impacts of waste generated per person more of in 2015 than in 2005 (source generated waste) and waste generated per person less of in 2015 than in 2005 (source reduced waste). We would do this for each material by subtracting their 2015 generation rate from their 2005 rate. Then to calculate the environmental impact we would multiply that difference in mass by the material's WARM source reduction GHG emissions and energy factors and by -1.

5.5.2 Application in Maryland

For the hypothetical 2015 target baseline its associated recycling rate and environmental footprints are presented in Table 5-8. We used this information and the Equations 4-7 to estimate conversion factors shown in Table 5-9. Figure 5-4 presents how the hypothetical 2015 target baseline compared to the estimated 2015 data. The bar labeled mass refers to the 2015 mass-based recycling rate, GHG refers to the 2015 GHG-normalized recycling rate, energy use refers to the 2015 energy-normalized recycling rate. The solid line represents the baseline's mass-based recycling rate, GHG emissions footprint, and the energy footprint.

In MD the LCI-normalized recycling rate were greater than the mass-based recycling rate, suggesting that MD decision makers focused efforts on materials with a larger environmental impact than a mass impact. The difference between the mass-based recycling rate and the LCI-normalized recycling rates is that the mass-based rate only accounts for the weight of a material, while the LCI-normalized rate accounts for the weight of a material and its individual environmental impact. Also, the mass-based rate only incorporates the mass impact of each material from the year-of-interest and not the baseline year. The LCI-normalized rate incorporates the mass and environmental impacts associated with each material from the year-of-interest and the baseline year.

As stated before, MD lacks the individual materials' recycled masses which is needed to properly apply the Effective Recycling Rates Approach. In the future MD should focus on tracking the annual mass of individual material's recycled, but also their generated, landfilled, and combusted masses

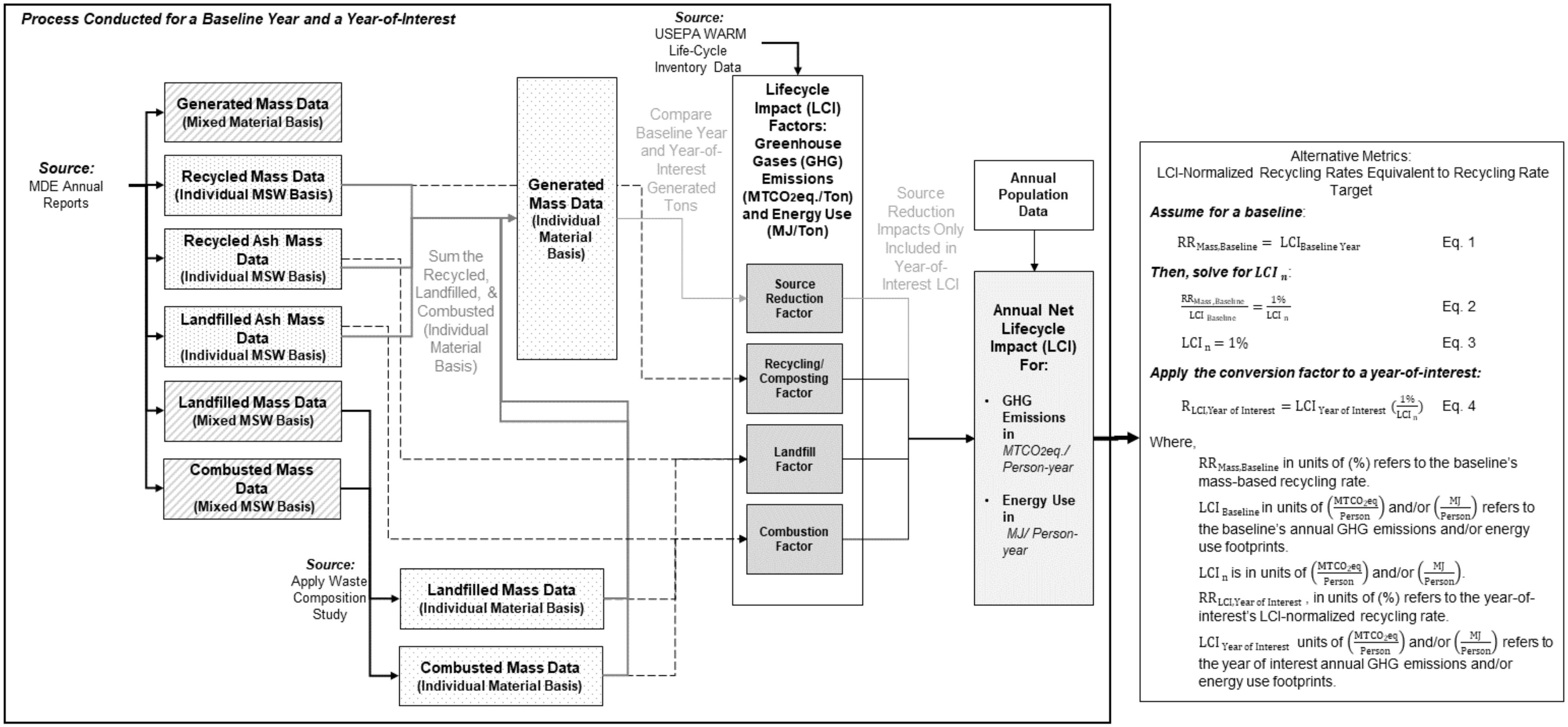

Figure 5-3. MD-specific methodology to estimate mass data (recycled, landfilled, combusted, landfilled & recycled ash) used as inputs to calculate a baseline year and year of interest's net lifecycle (LCI) impact (in GHG emissions and energy use) which is then converted to an LCI-normalized recycling rate equivalent to a recycling rate target.

Table 5-8. Recycling rate and environmental footprint for the 2015 hypothetical baseline.

State	Recycling Rate	GHG Emissions ($tCO_2eq.$/Person)	Energy Use (MJ/Person)
MD	56.2%	-1.273	-17,937

Table 5-9. Conversion factors for MD used in the Effective Recycling Rates approach. The 1% recycling rate refers to the recycling rate and the environmental footprints associated with the 2015 target, shown in Table 5-8 and calculated using Equations 4-7.

Region	Recycling Rate		GHG Emissions ($tCO_2eq.$/ Person/ 1% Recycling Rate)	Energy Use (MJ/ Person/ 1% Recycling Rate)
MD	1%	=	-0.0268	-320.4

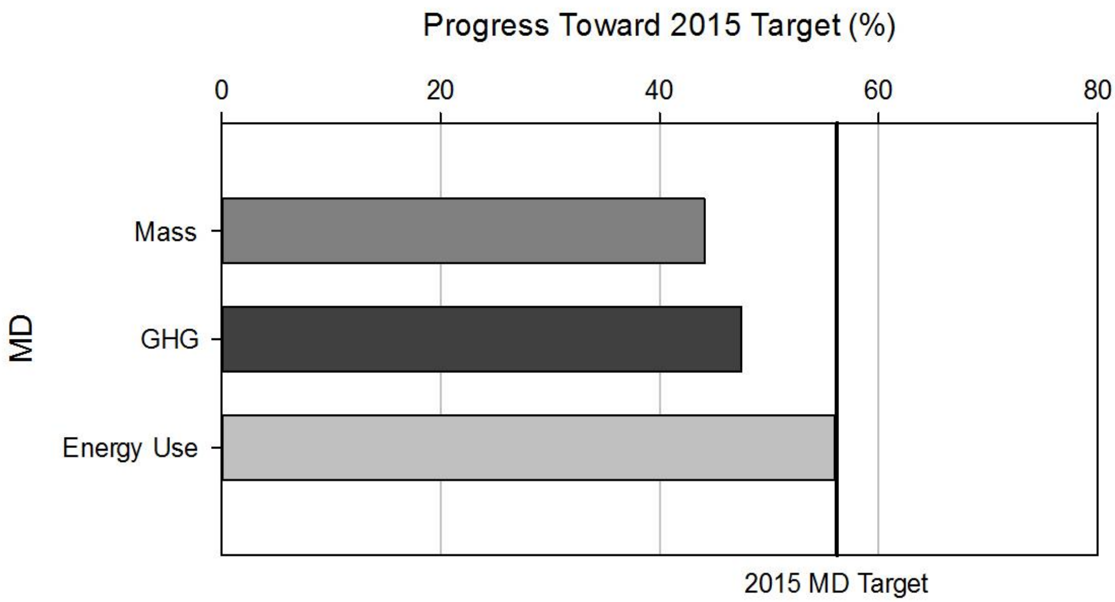

Figure 5-4. The Effective Recycling Rates approach applied to MD. A 2015 hypothetical baseline was created and the 2015 recycling rate, and environmental footprints were compared to see the progress of the 2015 performance to the 2015 target. The bar labeled mass refers to the 2015 mass-based recycling rate, GHG refers to the 2015 GHG-normalized recycling rate, energy use refers to the 2015 energy-normalized recycling rate. The solid line represents the baseline's mass-based recycling rate, GHG emissions footprint, and the energy footprint.

CONCLUSION AND RECOMMENDATIONS

This report provided details on the methodologies taken to collect mass data for MD for 2005 and 2015, to evaluate remaining areas where mass data is lacking and needed for SMM-based approaches, and to demonstrate application of the SMM-based approaches in MD.

We followed various assumptions and calculations to estimate the required individual materials generated, recycled, combusted, and landfilled masses needed to evaluate as inputs for calculating the GHG emissions and energy use footprints used in the SMM-based approaches. Although we were able to estimate the above listed mass dispositions for individual materials in both 2005 and 2015, MD should still focus their efforts on better tracking and reporting systems so that the environmental footprints are calculated using actual reported numbers instead of estimated values. We calculated MD's recycling rate as 54.1% in 2015. This value does include recycled miscellaneous or C&D debris. From the mass-based recycling rate, we see that MD has made progress in recycling large components of their waste stream, but we cannot identify from the recycling rate whether MD prioritized materials with a large potential to decrease their environmental footprint.

The SMM model can be applied in various ways and we focused on five different application approaches and demonstrated their application in MD using 2015 data. The approaches were categorized by how the SMM model can be used; the two methods the SMM model can be used were to prioritize and strategically plan and to measure performance outcomes. We formulated and demonstrated four approaches that used the SMM model to prioritize and strategically plan, that included: 1) Best Target Materials Recycling, 2) Best Disposal Management, 3) Prioritizing Policy and Technology Approach, and 4) Prioritizing Stakeholders. Of these four approaches MD policy makers can use existing infrastructure and use the SMM model to follow the Best Target Materials Recycling and Best Disposal Management approaches. From these two approaches, policy makers can use the SMM model to prioritize the recycling of paper and metal products to minimize their GHG emissions and energy use footprints. They can also strategically plan to combust most mixed plastics, paper, and metals to minimize their environmental footprints. The Prioritizing Policy and Technology and Prioritizing Stakeholders approaches use the SMM model to identify from a set of potential management scenarios the best scenario based on its potential impact to reduce MD's environmental footprint. MD policy makers can follow the methodology presented here to further evaluate other potential scenarios while using the SMM model's principles.

The last approach called the Effective Recycling Rates approach uses the SMM model to measure their system's environmental progress. Policy makers can measure their recycling progress using the SMM-based metric, which when compared to the traditional mass-based recycling rate was greater and it achieved the hypothetical SMM target's mass-based and SMM-based values. This approach showed that MD policy makers can incorporate the SMM model's principles into metrics that can reach policy targets (e.g., recycling rate goals) while quantifying the environmental impacts. In fact, MD recently begun to work toward SMM by passing an Executive Order that instructs MD to adopt SMM policy, and MDE has recently provided recommendations to fulfill the goals and metrics of the Executive Order.

REFERENCES

ICF International, 2016a. Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM): Background Chapters.

ICF International, 2016b. Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM): Management Practices Chapters.

ICF International, 2016c. Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM): Organic Materials Chapters.

ICF International, 2016d. Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM): Containers, Packaging, and Non-Durable Good Materials Chapters.

ICF International, 2016e. Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM): Durable Goods Materials Chapters.

Kendl P. Philbrick, Horacio Tablada, 2006. Maryland Waste Diversion Activities Report 2006. Maryland Department of the Environment.

Kendl P. Philbrick, Jonas A. Jacobson, 2006. Annual Report Solid Waste Management In Maryland Calendar Year 2005. Maryland Department of the Environment.

MSW Consultants, 2017. 2016 Maryland Statewide Waste Characterization Study.

Resource Management Program & Land and Materials Administration, 2016. Maryland Solid Waste Management and Diversion Report 2016. Maryland Department of the Environment.

APPENDIX

Table A1. Waste composition data extracted from the 2016 Maryland Waste Composition Study (MSW Consultants, 2017).

Item No.	Material	Total Percentage of Waste Stream	Item No.	Material	Total Percentage of Waste Stream
1	**Paper**	**25.6%**	34	**Organics**	**24.0%**
2	Newspaper	1.6%	35	Food Waste	17.9%
3	Corr. Cardbd/Kraft Pap. (Uncoated)	8.6%	36	Grass	1.2%
4	Magazines	0.7%	37	Leaves	0.3%
5	Paperboard	2.4%	38	Brush/Prunnings/Trimmings	1.2%
6	(High Grade) Office Paper	0.5%	39	Other/Non-Compostable	3.3%
7	Books	0.3%	40	**C&D Debris**	**15.3%**
8	Other Recyclable Paper	3.2%	41	Wood - Clean Lumber	2.0%
9	Compostable Paper	7.5%	42	Wood - Painted/Treated	3.8%
10	Non-Recyclable Paper	0.9%	43	Wood - Pallets	1.8%
11	**Plastic**	**14.0%**	44	Non-C&D Wood	0.3%
12	PET (#1) Bottles/Jars	1.4%	45	Drywall/ Gypsum Board	0.7%
13	PET (#1) Other	0.2%	46	Concrete/Brick/Rock/ Other C&D	2.5%
14	HDPE (#2) Bottles- Natural	0.3%	47	Carpet, Carpet Padding, & Rugs	4.2%
15	HDPE (#2) Color Bottle/All Non-Bot.	0.5%	48	**Household Hazardous Waste**	**0.4%**
16	#3 thru #7 Bottles	0.1%	49	Medical Waste & Sharps	0.2%
17	Plastic Packaging #3 - #7	1.2%	50	Batteries - Lead Acid	0.0%
18	Durable Plastic Products #3 - #7	1.2%	51	Batteries - Other Rechargeable	0.0%
19	Expanded Polystyrene "Styrofoam"	0.8%	52	Batteries - All Other	0.0%
20	Clean Film & Clean Shopping Bags	0.7%	53	Other Hazardous Waste/ HHW	0.2%
21	Contaminated Film/Other Film	4.7%	54	**Electronics**	**0.5%**
22	Remainder/Composite Plastic	2.9%	55	Computers/ Related Elec. Prods.	0.5%
23	**Metal**	**3.9%**	56	**Other Wastes**	**13.9%**
24	Aluminum Cans & Containers	0.4%	57	Textiles & Leather Products	5.7%
25	Other Aluminum	0.4%	58	Diapers & Sanitary Products	2.7%
26	Other Non-Ferrous	0.5%	59	Bulky Items	2.0%
27	Tin/Steel Containers	1.2%	60	Tires	0.2%
28	Other Ferrous	1.5%	61	Other/Not Classified	1.1%
29	**Glass**	**2.3%**	62	Fines & Dirt	2.2%
30	Clear Glass Containers	1.1%			
31	Brown Glass Containers	0.6%			
32	Green Glass Containers	0.3%			
33	Non-Container/Other Glass	0.3%			

Table A2. Recycling composition and mass associated extracted from the Maryland Waste Diversion Activities Report 2006 and the 2015 Maryland Solid Waste Management and Diversion Activities Annual Reports.

Item No.	Baseline Year (2005)		Year-of-Interest (2015)	
	Material	Recycled Mass (Tons)	Material	Recycled Mass (Tons)
	Commingled Containers	**41,903**	**Commingled Containers**	**56,863**
1	Commingled Containers	41,901	Commingled Containers	56,863
2	Christmas Trees	2		
	Compost/Mulch Other Organics	**354,417**	**Compost/Mulch Other Organics**	**250,703**
3	Bakery Waste	2,138	Bakery Waste	4,255
4	Chicken Litter	17,600	Chicken Litter	6,540
5	Food Waste	78,471	Food Waste	66,716
6	Manure	21,329	Manure	17,850
7	Other Organics	1,437	Other Organics	45,061
8	Pallets	18,109	Pallets	279
9	Sawdust	11,711	Sawdust	8,141
10	Straw/Manure	20,179	Straw/Manure	50
11	Wood Materials	161,939	Wood Materials	81,825
12	Wood Shavings	19,690	Wood Shavings	8,691
13	Animal Bedding	520	Bark	2,001
14	Christmas Trees	461	Corn Ensilage	3,031
15	Hatchery Waste	832	Grain/Yeast	6,261
	Compost/Mulch Yard Waste	**589,942**	**Compost/Mulch Yard Waste**	**640,541**
16	Brush and Branches	177,767	Brush and Branches	274,701
17	Grass	9,188	Grass	34,983
18	Leaves	29,246	Leaves	80,835
19	Mixed Yard Waste	291,858	Mixed Yard Waste	248,284
20	Bark	2,600	Other Organics	1,348
21	Grass/Leaves	79,283	Christmas Trees	391
	Glass	**57,889**	**Glass**	**127,074**
22	Brown Glass	3,970	Brown Glass	684
23	Clear Glass	1,125	Clear Glass	1,330
24	Fluorescent Bulbs	15	Fluorescent Bulbs	180
25	Green Glass	3,277	Green Glass	1,201
26	Mixed Glass	24,669	Mixed Glass	88,618
27	Other Glass[1]	24,834	Other Glass[1]	35,061

1- For some categories the reports provided masses greater than the spreadsheet, to account for this discrepancy the missing mass of 24,834 tons and 35,060 tons for 2005 and 2015, respectively, were added in manually to the “other glass” category.

Table A2 (continued).

Item No.	Baseline Year (2005)		Year-of-Interest (2015)	
	Material	Recycled Mass (Tons)	Material	Recycled Mass (Tons)
	Metals	**535,195**	**Metals**	**426,341**
28	Aluminum Cans	3,552	Aluminum Cans	6,870
29	Back-end Scrap	20,867	Back-end Scrap	22,841
30	Front-end Scrap	359,429	Front-end Scrap	80,811
31	Lead Acid Batteries	8,738	Lead Acid Batteries	10,629
32	Litho Plates	106	Litho Plates	256
33	Mixed Cans	6,197	Mixed Cans	12,282
34	Oil Filters	180	Oil Filters	1,849
35	Other Metals[2]	10,084	Other Metals[2]	8,443
36	Printer's Waste	2,116	Printer's Waste	108
37	Tin/Steel Cans	5,523	Tin/Steel Cans	8,310
38	White Goods	118,404	White Goods	272,506
39	Silver Sludge/Photo Proc	1	Batteries	1,438
	Non-MRA	**2,923,879**	**Non-MRA**	**3,797,245**
40	Animal Protein/Fat (liquid)	62	Animal Protein/Fat (liquid)	10,840
41	Antifreeze	1,714	Antifreeze	1,740
42	Asphalt	363,434	Asphalt	686,021
43	C&D Debris	275,593	C&D Debris	429,042
44	Coal Ash	145,039	Coal Ash	511,480
45	Concrete	651,393	Concrete	478,139
46	Land clearing Debris	187,741	Land clearing Debris	90,849
47	Other Materials[3]	78,327	Other Materials[3]	501,797
48	PCB Ballasts	107	PCB Ballasts	6
49	Scrap Automobiles	343,105	Scrap Automobiles	129,458
50	Scrap Metal	615,795	Scrap Metal	577,583
51	Sewage Sludge	87,840	Sewage Sludge	134,007
52	Shingle Tabs	3,035	Shingle Tabs	1,106
53	Soils	121,615	Soils	216,126
54	Solvents	15	Solvents	312
55	Telephone/Utility Poles	31	Telephone/Utility Poles (wood)	250
56	Waste Oil	43,774	Waste Oil	27,881
57	Miscellaneous Recyclables	5,190	Textiles/Cloth	309
58	Other Metals	69	Vegetable Oil	300
59			Ballasts	1

2- For some categories the reports provided masses greater than the spreadsheet, to account for this discrepancy the missing mass of 7,917 tons and 8,333 tons for 2005 and 2015, respectively, were added in manually to the “other metals” category.

3- For some categories the reports provided masses greater than the spreadsheet, to account for this discrepancy the missing mass of 77,804 tons and 464,285 tons for 2005 and 2015, respectively, were added in manually to the “other materials” category.

Table A2 (continued).

Item No.	Baseline Year (2005)		Year-of-Interest (2015)	
	Material	Recycled Mass (Tons)	Material	Recycled Mass (Tons)
	Other Materials	**518,933**	**Other Materials**	**395,615**
61	Animal Protein/Fat (solid)	96	Animal Protein/Fat (solid)	62,044
62	Bark	1,484	Bark	1,162
63	Electronics	4,287	Electronics	13,672
64	Food Waste	324	Food Waste	38,295
65	Household Hazardous Waste	44	Household Hazardous Waste	170
66	Lime Mud/Grits	3,246	Lime Mud/Grits	1,812
67	Miscellaneous Recyclables	15	Misc. Recyclables (MRA)	3,270
68	Municipal Incinerator Ash	257,474	Municipal Incinerator Ash	147,786
69	Paint	4	Paint	702
70	Pallets	78,785	Pallets	41,772
71	Shingle Tabs	27,297	Shingle Tabs	19,485
72	Textiles/Cloth	18,072	Textiles/Cloth	15,943
73	Tires (Recycled)	30,866	Tires (Recycled)	34,933
74	Tires (Retread)	1,987	Tires (Retread)	277
75	Tires-to-Cement Kilns	1,317	Tires-to-Cement Kilns	254
76	Animal Protein/Fat	57,797	Chicken Litter	3,759
77	Bakery Waste	4,256	Grain/Yeast	8,790
78	Carpet Padding	597	Mattresses	186
79	Film Plastic	5	Other Organics	21
80	Laser Toner Cartridges	17	Other Plastic	13
81	Poultry Processing By-product	30,801	Sawdust	553
82	Vegetable Waste	163	Toner Cartridges	714
	Paper	**840,644**	**Paper**	**894,974**
83	Magazines	1,141	Magazines	4,770
84	Mixed Paper	356,658	Mixed Paper	333,496
85	Newspaper	71,924	Newspaper	111,883
86	Office/Computer Paper	80,522	Office/Computer Paper	49,851
87	Old Corrugated Cardboard	313,354	Old Corrugated Cardboard	389,238
88	Other Paper[4]	16,895	Other Paper	3,905
89	Printer's Waste	138	Printer's Waste	5
90	Telephone Directories	12	Telephone Directories	1,750
91			Shrink Wrap	75
	Plastic	**26,858**	**Plastic**	**72,342**
91	Film Plastic	109	Film Plastic	3,890
92	Mixed Plastic	9,161	Mixed Plastic	36,731
93	Other Plastic[5]	12,282	Other Plastic[5]	17,988
94	Plastic Code #1	46	Plastic Code #1	6,404
95	Plastic Code #2	168	Plastic Code #2	2,634
96	Plastic Code #4	6	Plastic Code #4	2,347
97	Plastic Code #5	210	Plastic Code #5	1,229
98	Plastic Code #7	714	Plastic Code #7	44
99	Shrink Wrap	27	Shrink Wrap	668
100	Plastic Codes #1 & #2	4,135	Carpet	169
101			Plastic Code #6	18
102			Plastic Code #3	221
	TOTAL	**5,847,758**	**TOTAL**	**6,604,835**

4- For some categories the reports provided masses greater than the spreadsheet, to account for this discrepancy the extra mass of 341 tons for 2005 was removed manually from the “other paper” category.

5- For some categories the reports provided masses greater than the spreadsheet, to account for this discrepancy the missing mass of 9,488 tons and 13,469 tons for 2005 and 2015, respectively, were added in manually to the “other plastic” category.

Table A3. Re-organized landfilled/combusted materials for 2015. The materials column shows the re-organized materials category and the assumptions columns (which references materials f2rom Table A1) shows which materials are included in the re-organized material categories.

Material	Assumptions for 2015 Disposed Materials
Newspaper	2
Glass	29
Aluminum Cans	24
Steel Cans	27
Corrugated Paper	3
Plastic Bottles	12 thru 16
Yard Trash	36 thru 38
Mixed Plastics	17 thru 22
Food Waste	35
Mixed Paper	4 thru 10
Mixed Metals	25 + 26 + 28
Textiles	57
Tires	60
Electronics	54
C&D Debris	40
Miscellaneous	39 + 48 + 58 thru 62

Table A4. Re-organized recycled materials for 2005 and 2015. The materials column shows the re-organized materials category and the assumptions columns (which references materials from Table A2) shows which materials are included in the re-organized material categories.

Material	Assumptions for 2005 Recycled Materials	Assumptions for 2015 Recycled Materials
Newspaper	85	85
Glass	22 thru 27	22 thru 27
Aluminum Cans	28	28
Steel Cans	37	37
Corrugated Paper	87	87
Plastic Bottles	94 + 95 + 100	94 +95
Yard Trash	8 + 14 + 16 thru 21 + 47 + 55+ 62 + 70	8 + 13 + 16 thru 21 + 47 + 55 +62 +70
Mixed Plastics	79 + 91 thru 93 + 96 thru 99	80 + 91 thru 93 + 96 thru 99 + 101 + 102
Food Waste	40 + 64 + 61 + 76 + 77 + 81 + 82	40 + 64 + 61 + 76 + 77
Mixed Paper	83 + 84 + 86 + 88 thru 90	83 + 84 + 86 + 88 thru 91
Mixed Metals	29 thru 36 + 38 + 39 + 49 + 50 +58	29 thru 36 + 38 + 39 + 49 +50
Textiles	72 + 78	57 + 100
Tires	73 thru 75	73 thru 75
Electronics	63	63
C&D Debris	42 + 43 + 45 + 52 + 53 +71	42 + 43 + 45 + 52 + 53 + 71
Miscellaneous	41 + 44 + 47 + 48 + 51 + 54 + 56 + 57 + 65 thru 69 + 80	41 + 44 + 47 + 48 + 51 + 54+ 56 + 58 + 59 + 65 thru 69 + 78 + 79 + 81 + 82